SEVENTH FRAMEWORK PROGRAMME
THEME 3
Information and Communication Technologies

Grant agreement for: Small or medium-scale focused research project

Annex I - "Description of Work"

Project acronym: OPPORTUNITY
Project full title: Activity and Context Recognition with Opportunistic Sensor Configurations
Grant agreement no.: 225938

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PART A

A1. Budget breakdown and project summary

A.1.1 Overall budget breakdown for the project

Participant number in this project [9]	Participant short name	Estimated eligible costs (whole duration of the project)					Total receipts	Requested EC contribution
		RTD / Innovation (A)	Demonstration (B)	Management (C)	Other (D)	Total A+B+C+D		
1	ETH Zurich	498,320.00	0.00	75,120.00	0.00	573,440.00	0.00	448,860.00
2	UNI PASSAU	501,712.00	0.00	11,752.00	0.00	513,464.00	0.00	388,036.00
3	JKU	446,560.00	0.00	9,832.00	0.00	456,392.00	0.00	344,752.00
5	EPFL	423,360.00	0.00	9,600.00	0.00	432,960.00	0.00	327,120.00
TOTAL		1,869,952.00	0.00	106,304.00	0.00	1,976,256.00	0.00	1,508,768.00

A.1.2 Project summary

OPPORTUNITY picks up on the very essential methodological underpinnings of any Ambient Intelligence (AmI) scenario: recognizing (and understanding) context and activity.

Methodologies are missing to design context-aware systems: (1) working over long periods of time despite changes in sensing infrastructure (sensor failures, degradation); (2) providing the freedom to users to change wearable device placement; (3) that can be deployed without user-specific training. This limits the real-world deployment of AmI systems.

We develop opportunistic systems that recognize complex activities/contexts despite the absence of static assumptions about sensor availability and characteristics. They are based on goal-oriented sensor assemblies spontaneously arising and self-organizing to achieve a common activity/context recognition goal. They are embodied and situated, relying on self-supervised learning to achieve autonomous operation. They makes best use of the available resources, and keep working despite-or improves thanks to-changes in the sensing environment. Changes include e.g. placement, modality, sensor parameters and can occur at runtime.

Four groups contribute to this goal. They develop: (1) intermediate features that reduce the impact of sensor parameter variability and isolate the recognition chain from sensor specificities; (2) classifier and classifier fusion methods suited for opportunistic systems, capable of incorporating new knowledge online, monitoring their own performance, and dynamically selecting most appropriate information sources; (3) unsupervised dynamic adaptation and autonomous evolution principles to cope with short term changes and long term trends in sensor infrastructure, (4) goal-oriented cooperative sensor ensembles to opportunistically collect data about the user and his environment in a scalable way.

The methods are demonstrated in complex opportunistic activity recognition scenarios, and on robust opportunistic EEG-based BCI systems.

A.1.3 List of beneficiaries

Beneficiary Number *	**Beneficiary name**	**Beneficiary short name**	**Country**	**Date enter project****	**Date exit project****
1(coordinator)	ETHZ Zürich, Institut für Elektronik, Wearable Computing Laboratory	ETHZ	Switzerland	Month 1 (start of project)	Month 36 (end of project)
2	University of Passau, Embedded Systems Laboratory	UP	Germany	Month 1 (start of project)	Month 36 (end of project)
3	Johannes Kepler Universität Linz, Dept. of Pervasive Computing	JKU	Austria	Month 1 (start of project)	Month 36 (end of project)
4	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland	Month 1 (start of project)	Month 36 (end of project)

* Please use the same beneficiary numbering as that used in the Grant Agreement Preparation Forms

** Normally insert “month 1 (start of project)” and “month n (end of project)”

PART B

B1. Concept and objectives, progress beyond state-of-the-art, S/T methodology and work plan

B.1.1 Concept and project objective(s)

B.1.1.1 Main objective

*We envision **opportunistic activity recognition systems.** They are **goal-oriented sensor assemblies** that **spontaneously arise** and **self-organize** to achieve a **common goal**, here **activity and context recognition.***

*The objective of OPPORTUNITY is to develop **generic principles, algorithms and system architectures** to reliably **recognize complex activities** and contexts despite the **absence of static assumptions about sensor availability and characteristics** in opportunistic systems.*

The objective of this project is to develop **mobile systems** to **recognize human activity** and **user context** with **dynamically varying sensor setups,** using **goal oriented, cooperative sensing**. We refer to such systems as **opportunistic**, since they take advantage of sensing modalities that just happen to be available, rather than forcing the user to deploy specific, application dependent sensor systems.

This project is grounded in wearable computing and pervasive/ubiquitous computing, collectively named hereafter **Ambient Intelligence (AmI)**. The vision of AmI is that of pervasive but transparent technology, always on, always present, that provides the appropriate information, assistance and support to users at appropriate moments, proactively and in a natural way. The key mechanism to achieve this is to recognize the user's activities and the user's context from body-worn and ambient sensor-enabled devices, in order to infer automatically when, how, and by which modality to support the user.

OPPORTUNITY aims to develop **a novel paradigm for context and activity recognition that will remove the up-to-now static constraints placed on sensor availability, placement and characteristics.** This is in contrast to most state of the art approaches that assume fixed, narrowly defined sensor configurations dedicated to often equally narrowly defined recognition tasks. Thus, currently, for each application, the user needs to place specific sensors at certain well-defined locations in the environment and on his body. For a widespread use of context awareness and activity recognition this approach is not realistic. As the user moves around, he is at times in highly instrumented environments, where a lot of information is available. At other times he stays in places with little or no sensor infrastructure. Concerning on-body sensing, the best one can realistically expect is that at any given point in time the user carries a more or less random collection of sensor enabled devices. Such devices include mobile phones (today often equipped with GPS, and a variety of sensors), watches (today also available with a wide range of sensors), headsets, or intelligent garments (shoe worn motion sensors are already commercially available). As the user leaves devices behind, picks up new ones and changes his outfit, the sensor configuration changes dynamically. In addition the on-body location of the sensors may also change. For example, a mobile phone can be placed in the trousers pocket, in a hip holder, in the backpack or in the users hand. Finally, large scale sensor systems deployed in real life environments over long time periods are bound to experience failures, again leading to dynamically varying sensor setups.

In summary, considering realistic settings, **no static assumptions can be made about the availability, placement, and characteristics of sensors** (sensors and other information sources become dynamically available/unavailable at unpredictable points in time).

OPPORTUNITY addresses this challenge by developing generic principles, algorithms and system architecture to reliably recognize complex activities and contexts despite the absence of static assumptions about sensor configurations.

B.1.1.2 Core ideas behind the approach

The following key means towards the above objective will be pursued by OPPORTUNITY

1. **Sensors with Self-* properties in particular self-characterization and self-description** to keep track and advertise dynamically evolving sensing capabilities and limitations. Thus, when a given sensor signal degrades (e.g. due to position change or obstruction) this should be autonomously recognized, noted and advertised. The same is true for new sensing capabilities coming into the system.

2. **Algorithms and control paradigms for goal oriented, spontaneous, cooperative sensing** that allows sensor ensembles to dynamically, autonomously form and cooperate to efficiently extract a maximum of useful information in any given situation.

3. **Signal conditioning and sensor fusion** that will reduce the impact of sensor parameter variations on the classification and classifier fusion stages.

4. **An abstract feature layer** that will isolate the classification and classifier fusion stages from changes in sensor configuration.

5. **Modular, adaptive machine learning methods** that will ensure graceful degradation in case of sensor information degrading (instead of total failure or dramatic performance drop found in state of the art systems), and give the system the ability to dynamically exploit additional and/or improved information sources (which state of the art systems can not do).

6. **Novel methods for fusion of dynamically changing classifiers** to allow spontaneous, high level cooperation between different activity recognition systems.

7. **Unsupervised dynamic adaptation method**, by which the system components (cooperative sensing, signal processing, feature extraction, classification and classifier fusion) are autonomously, dynamically configured and combined in a way most appropriate for the situation at hand.

8. **Unsupervised mid to long term evolution,** that will allow the system to spot re-occurring configurations, follow gradual developments of the environmental sensing infrastructure (sensors gradually degrading over time, sensor setups being extended and improved as time passes), and in general cope with dynamic and open-ended environments.

An obvious challenge for OPPORTUNITY is to make sure that the methods developed by the project are not restricted to a small set of examples studied in the project but are applicable to a broad range of activity recognition domains (and beyond) and types of dynamic adaptation. At the same time, as a small STREP with limited resources, OPPORTUNITY must be careful to stay focused on specific well defined problems. To this end, the work in the project is based on a hierarchical decomposition of activity recognition into basic, composable components. These include among others (see section B.1.3) location, modes of locomotion, hand activities, interaction with devices and object, and interaction with other humans. By demonstrating that our methods are applicable to those components, and work well with combinations thereof, we will underscore the general validity of the OPPORTUNITY paradigm.

Thus, the methods developed in the project will be systematically evaluated in experiments starting from individual activity components, through simple combinations of such components, towards two exemplary case studies motivated by complex real-life applications. The experiment will compare the performance of conventional static recognition systems that are specifically designed for a given sensor configuration with the performance of OPPORTUNITY methods and their adaptation principles, in conditions of changing sensor configurations. The case studies will come from the domains of **Ambient Assisted Living/Health-related Lifestyle Management** and **Intelligent Energy Management in Homes and Offices**. These domains are important to the overall goals and vision of FP7. They include a wide variety of activities (e.g. activities of daily living, physical exercise, social interactions, manipulative gestures) that are relevant in other domains also.

We highlight the general applicability and scientific value of the OPPORTUNITY methods to the challenging problem of developing robust and fault tolerant **opportunistic Brain-Computer Interfaces** on the basis of EEG signals (cognitive context recognition).

B.1.1.3 Quantified specific objectives

Objective #1: Self-* capabilities of sensors and sensor ensembles.

Self description: We will investigate metadata formats for sensor self-descriptions, i.e. investigate markup languages suitable for metadata description of sensor typology and interoperability, develop (XML) parsing technologies for very small and tiny execution platforms (i.e. small form factors, low memory footprint, etc.), develop metadata similarity analysis and semantic interoperability of sensor systems, and develop a sensor ontology particularly addressing scenarios of opportunistic sensing.

<u>Success Criteria.</u> The ability to provide adequate description of all relevant sensor parameters and variations for different sensor types in the OPPORTUNITY case studies (see objective 7) within a small microcontroller based node (8/16 bit, 4 MHz, <64kByte memory)

Dynamic sensor self-characterisation: We develop methods that allow sensors to automatically characterize themselves. In particular we want sensor to be able to automatically detect when their performance degrades. The detection ability should work for degradation caused by internal factors (e.g. drift) as well as environment related degradation (occlusion, displacement). The specific measures that we intend to develop are

- Degradation detection based on sudden events followed by long term change in the statistical properties of the signal. Thus for example we might detect a sudden drop in the intensity of the sound detected through a mobile phone microphone followed by all the statistical properties except the intensity being unchanged. This would indicate that the phone was placed in a pocket damping the sound intensity.
- Using information about user activity and context to re-calibrate the sensors. In previous work we have demonstrated how the knowledge that the user is walking can be used to determine the on body placement of an acceleration sensor. We intend to develop similar methods for other sensors and variation types.

<u>Success Criteria:</u> Demonstration in the OPPORTUNITY cases studies (see objective 7) that we can detect degradation with a precision and recall both in the range of 90% and an accuracy (in terms of degree of degradation) of about plus/minus 20%. Examples of specific types of degradation that we will focus on are position changes of on body motion sensors, intensity variations in on body sound sensors caused by different enclosures (e.g. e mobile phone being put onto a bag) and signal strength variations in RF positioning systems.

Self Managed interaction and configuration. We will develop methods and algorithms to allow for a self-managed interaction among sensors in spontaneous sensor ensemble configurations. We will:

- Address scalability and protocols for large sensing ensembles, i.e. investigate algorithms and protocols for redundant and fail safe sensing within cooperative ensembles involving many sensors, develop models for fault tolerant and fail safe sensing systems involving multiple, multimodal sensor nodes, and develop utility models for sensor ensembles relating the resource effort (number of sensors, energy and powering, deployment strategy) to the quality of sensing.

- Develop inconsistency and uncertainty protocols for sensing ensembles, i.e. develop models to cope with faulty, stale, unavailable sensor nodes involved in cooperative sensing missions, and develop utility based reliability and dependability mechanisms able to guarantee cooperative sensing and at least a certain levels of quality of service

Success Criteria. Demonstration within the OPPORTUNITY case studies of complex interactions and configurations in sensor ensembles of 100 and more sensors. Demonstrate quantitatively the benefit in terms of recognition rate.

Objective #2: Creating and Coordinating ad-hoc goal-oriented sensor ensembles.

Goal oriented behavior: Individual sensing activities in spontaneous sensor ensembles need to be aligned according to the information demands coming from the application. To this end, OPPORTUNITY will:

- Develop goal representations and strategies for goal processing, i.e. identify knowledge and goal representation techniques and metadata formats, together with mechanisms for storing and retrieving, implement a goal generation, goal processing, goal distribution and resource configuration engine able to steer cooperative sensing in dynamic ensembles, and implement a goal extraction and sensor data capture kernel able to physically collect data according to the goal/utility.
- Develop solutions for cooperative sensing mission management by first studying methods to extract goals from application request and encode them in the respective goal representation, then develop protocols for the identification, execution and harmonious adjustment of individual sensing efforts towards the accomplishment of a sensing mission goal, and finally develop a framework for the formation of sensing missions involving sensors able to contribute to the ensemble sensing goals, respecting utility, resource effort and quality of service.

Ensemble coordination architectures: A coordination architecture steering the individual sensing efforts towards a sensing goal will be developed (and exhibited in application scenarios). OPPORTUNITY will:

- Design and develop a sensor ensemble management system supporting the dynamic participation (join, leave, re-join) of individual sensor nodes, while sustaining the ensemble sensing mission.
- Develop protocols for the identification, execution and harmonious adjustment of individual sensing efforts towards the accomplishment of an ad-hoc ensemble sensing goal.
- Develop protocols and mechanisms for distributed sensor querying based on the sensor markup developed before. These query mechanisms, for scalability reasons, will go beyond traditional flooding type protocols.
- Designing an overall spontaneous interaction coordination architecture, and integrate the protocols for distributed querying with the scalability, inconsistency, and uncertainty protocols into a consistent protocol architecture and software framework.
- Develop and implement the components towards an infrastructure-free cooperative sensing system.

Success Criteria. The success criterion will be the availability of a spontaneous goal-oriented sensing coordination architecture implemented in a software framework that allows to generate sensing missions (goals) from an application at run-time, that plans sensor resources need to accomplish the sensing mission, that uses this plan to acquire and solicit sensors and to configure them as an ensemble, and to coordinate the sensing mission during the whole lifetime of the application, subject to dynamic changes in the sensor population, availability, capability and semantic interoperability.

In quantitative terms we will demonstrate the functionality with up to 50 sensor nodes showing quantitative information content of spontaneous assemblies (e.g. through mutual information or test classifications) not more than 20% under the performance of hand optimized systems.

Objective #3: Variations tolerant Signal Processing and Feature Extraction

Variability tolerant signal conditioning. The signal processing methods used by an opportunistic system should not only lead to optimal class separation under one specific set of parameters, but be as insensitive as possible to parameter variations. Thus, even considerable variations in the sensor parameters should lead to only small changes in the probability density distributions of the involved classes and the optimal separation surfaces. To this end we will investigate the following:

- Typical variations to be expected in different classes of activity recognition problem and ways to modify the usual features used in this problems to be less sensitive to such variations.
- Features based on combinations of different sensors in which one sensor can compensate degradation caused to the other by typical changes in environmental parameters. In previous work we have for example shown how signals from and accelerometer and a gyroscope can be combined in such a way that the resulting feature is insensitive to shifts of the sensor within a body part [Kunze08].

<u>Success Criteria.</u> To demonstrate on specific examples that large (double percentage digits) variations in sensor parameters can be neutralized in the sense that they only cause small (<5%) degradation in recognition performance. Initially we will build on our work on body-worn sensor displacement, followed by sound sensor intensity changes, and indoor localization accuracy variations.

Abstract, sensor independent features. Different physical quantities can provide the same abstract information about an activity. Thus, for example, on-body inertial sensors, clothing-integrated textile elongation sensors, and visual tracking, all give information about body parts trajectories. If the classifiers are trained on such trajectories rather than on raw sensor signals, then the classification system will be able to easily tolerate sensor modality changes. With respect to such abstract features we intend to:

- Define abstract feature sets for the most common activity recognition problems
- Show how such features can be computed from different sensor configuration. In particular demonstrate how dynamic changes in the sensor configuration can be handled. We will apply and adapt different variability tolerant signal conditioning methods to the computation of the abstract features (see previous sub-objective)
- Show how differences in the levels of detail, reliability and accuracy that different types of sensors will provide for a certain abstract feature can be handled. Consistent methods are needed to specify how such differences propagate to the features and how the following stages of the recognition chain can be made aware of such changes.

<u>Success Criteria.</u> Demonstration of several (at least 8) types of abstract features and the fact that they can be computed using different sensor combinations. The recognition accuracy of the system using the abstract features should not vary by more then a few percent when different sensing modalities are used. Initially we will work with abstract features related to body motion, location, and interaction with devices.

Objective #4: Machine learning algorithms optimized for opportunistic networks

Opportunistic classifiers: we will use machine learning techniques to develop improved classification algorithms for activity recognition. In order to be suitable for dynamically changing sensor networks OPPORTUNITY algorithms should exhibit the following properties:

- Graceful performance degradation with respect to changes in the quality of the input signal
- Provide a measure of the reliability of their decisions, taking into account the (estimated or reported) uncertainty of available inputs
- Allow for fast training, and online adaptation incorporating supervisory information provided either by the user or by an external system (c.f. WP3 on dynamic adaptation and autonomous evolution)
- Achieve signal segmentation and classification respecting application-specific constraints of pervasive and wearable computing (e.g. real-time operation, computational cost)

Success Criteria. The success criterion is the comparison of the opportunistic classifiers to state of the art dedicated classifiers on a set of realistic problems. We aim at a recognition rate comparable to the dedicated classifiers (not more than 10% to 20% below). We will do a systematic performance evaluation of the developed classifiers with respect to sensitivity to signal noise, training requirements, and their suitability for online implementations

Opportunistic Classifier Fusion: Develop and adapt classifier fusion methods able to cope with changes in the availability, type, and characteristics of their input classifiers/sensors. To this end we will:

- Make a comparative assessment of classifier fusion methods with emphasis on the specific characteristics of opportunistic sensor setups, such as scalability and robustness.
- Develop methods for dynamic selection and fusion of sensing modalities with respect to application-defined requirements.
- Develop fault-recovery mechanisms based on the addition or removal of input channels based on the reliability of available sensors.

Success Criteria. Again, a comparison of our system against dedicated recognition systems will be made, aiming for not more than 10% to 20% performance difference. Moreover, opportunistic decisions based on classifier fusion are expected to outperform dedicated systems in case of sensor failure or sensor network reorganization. Opportunistic fusion will be evaluated in terms of the performance degradation and fault-recovery in cases of sensor noise and sensor failure, as well as its ability to perform dynamic input selection based on the reliability of available sensors.

Objective #5: Unsupervised dynamic adaptation

System modelling of context recognition systems: we will develop, based on information theoretical models and empirical approaches:

- Models linking system configuration to multiparametric performance metrics focusing on the specific properties of opportunistic systems
- Methods to quantify the benefit resulting from including specific additional sensors and features based on the information provided in the sensor meta description, as well as runtime evaluation of channel's information content.

Dynamic adaptation of context recognition systems: we develop dynamic adaptation methods to cope with rapid changes in sensor configurations (e.g. change in desired performance, or re-occuring changes in number of Self-* sensor). To this end we:

- Develop heuristics, based on system models, for the optimal dynamic adaptation of an opportunistic system in a given situation. The adaptivity dimensions are defined by the system performance models and include as a minimum the linkage between sensor number and performance goal.

Success Criteria. The success criteria will be the ability of our models to predict performance gains of our system when using various sensor combinations. We aim the model to be accurate within 10%.

Objective #6: Autonomous evolution

Runtime supervision. We will develop methods to monitor the performance of the activity recognition system with respect to long term changes in sensor configurations. These methods will:

- Provide a confidence assessment of classifier outputs w.r.t. to possible signal degradation (due to e.g. sensor degradation, slow change in placement/orientation, or long term changes in user action-limb trajectories) in order to trigger a system retraining

- Provide an indication of correlation between sensors (at the signal, feature, and class output level) in order to support self-supervised learning
- Investigate the use of error-related EEG correlates (brain signal patterns occurring when a system deviates from expected behavior) as an endogenous, automatically detected, measure of system performance.

Autonomous evolution. We will develop methods for long-term gradual adaptation of the system to a new sensor configuration. These methods are:

- Self-supervised learning techniques to train classifiers of sensor devices (not yet capable of Self-*) entering the system.
- Self-supervised learning techniques to re-train classifiers of sensors when long term sensor degradation is observed.
- Performance metrics characterizing online adaptation. This includes traditional machine learning performance metrics (precision/recall, ROC curves) and novel metrics suited for autonomous evolution that will indicate adaptation speed, system robustness and stability, evolution of activity class signal templates and attractors.

Interactive minimally supervised adaptation: In some cases it may be more valuable to rely on interactive user feedback to supervise system adaptation. These method will:

- Evaluate the gain obtained by one time interactive supervision w.r.t. self-supervised learning, on the basis of confidence values and information content in the system parameters and sensors.
- Decide when user input shall be queried to minimize user disturbance while maximizing information gain.
- Rely on error-related EEG correlates and include them as a self-supervisory feedback to support autonomous evolution.

Success Criteria. The success of this objective will be assessed experimentally by quantifying the improvement brought about by the autonomous evolution. Performance will be compared to a trained baseline system not capable of dynamic adaptation while sensor variations are introduced. Variations include: sensor addition, sensor removal, long term slow (w.r.t. activity occurrence dynamics) changes in sensor orientation and placement (with body-worn acceleration sensors in a first step), slow (w.r.t. activity occurrence dynamics) addition of progressively higher signal noise. Performance will be characterized along the metrics introduced above. We aim at achieving sustained performance within the range of adaptation capabilities of the systems. The range of these capabilities will be characterized with respect to the tradeoffs intrinsic to autonomous evolution (e.g. faster adaptation speed vs stability, template evolution v.s. attractor strength). A success criteria is to characterize the level at which achieve autonomous evolution can proceed without user interaction and with which tradeoffs, as well as characterizing the benefits of interactive user feedback and EEG-based feedback.

Objective #7: Empirical validation

A three-stage empirical validation procedure is followed, starting from simple synthetic activities up to complex recognition scenarios typical of real-world applications. This minimizes risks by ensuring that basic goals are fulfilled, while not limiting the scope of the project.

- Stage 1: the methods will be demonstrated in simple activities with limited number of sensors (1-3 sensors). Adaptivity will be demonstrated while recognizing at least 3 modes of locomotion, 10 postures, 10 typical hand gestures and presence/location. Variations will include rotation of body-worn sensors, change in on-body placement, addition of noise, and addition/removal of sensors.

- Stage 2: the methods will be demonstrated in composite activities that include a larger number of sensors and more variability, including object manipulation, device use and social interactions and cooperation between humans (coordinated physical activities).
- Stage 3: the methods are demonstrated in complex scenarios involving real-world gestures and a large number of sensors (the activities stem from the field of indoor activity monitoring, and health and wellness oriented lifestyle monitoring). The sensor set will encompass between 10 and 20 sensors of the most common types such as body mounted motion sensors, microphones, location information, information of device activity, and object usage and motion (exact setup will be determined in the project). For each scenario we will consider at least 10 different sensor configuration.
- Opportunistic BCI validation: the last case study comes from the field of mental activity recognition using Brain-Computer Interfaces. In this scenario non invasive electroencephalography (EEG) signals will be used to identify the user's mental states such as error-detection, anticipation of imaginary movements. Building up on previous research endeavours at EPFL, sensor configurations of 32 and 64 (homogeneous) electrodes will be used to capture the brain electrical activity. Performance changes in both existing and OPPORTUNITY approaches will be assessed with respect to changes in the number of available reliable sensors, as well as changes in the incoming EEG signal.

Success Criteria. The ultimate success criterion will be the empirical comparison of our system to state of the art traditional (non opportunistic) activity recognition systems.

To this end we will train our system on a large, fixed set of typical sensors. We will then dynamically change the sensor configuration. Using classical recognition methods, a new system needs to be designed and trained for each of such configurations. In contrast, our system will be expected to automatically adapt to the new configuration. For each configuration we will then compare the performance of our opportunistic system to the performance of a state of the art system specifically designed and trained for this configuration. On average we aim to achieve about 80% of the recognition rate of the dedicated system when sensor configuration is not changed. However we expect the opportunistic system to outperform the dedicated system when the configuration of the sensors is changed.

Objective #8: Scientific dissemination

Scientific dissemination is a key objective of OPPORTUNITY. It includes the highest level of scientific publication, but also includes other means of bringing the methods developed by OPPORTUNITY into the community, such as tutorial and demos at key conferences, and making software packages publicly available under GPL licence.

Success Criteria. By month 36, at least **12 journal papers** will be published dedicated only to the methods developed within the project. We foresee at least 2 journal paper per partner focusing on its specific domain within the project, and 2 additional papers summarizing the overall project contributions. We will **publish a book** about opportunistic activity and context recognition systems, to disseminate the knowledge acquired during the project with the highest scientific standards. In addition we will have at least two publications per partner per year in the top conferences in the respective field (top defined as acceptance rates below 30%). Finally over the project course 3 software packages to be released under GPL, one interdisciplinary retreat and one technical workshop.

The metrics to measure the effect of our community building efforts include:

- Number of people who have signed up to the newslette
- Number of attendees at the technical workshop and retreat
- Follow-up of the technical workshop and retreat (contacts, request for information, joint projects)
- Number of invitations to present the project in the scientific community

- Number of visiting students working on the project
- Number of papers published on the topic by others
- Number of citations of our papers by others

Objective #9: Facilitating Exploitation

As a FET project OPPORTUNITY does not aim at creating **directly** commercially exploitable results. However, the topic and the expected results are clearly highly relevant for many emerging applications such as Ambient Assisted Living, Mobile Workers Assistance, Interactive Environments, Personal Health Management and Energy Efficient Building Management. The consortium partners are involved in a whole range of projects that work towards such applications. To facilitate the future exploitation of the results of OPPORTUNITY we intend to keep close contact and information flow with such exploitation oriented projects and industrial partners. Specifically we intend to:

- Organize technology workshops with presence from application oriented projects and industrial players.
- Produce a newsletter and a brochure oriented emphasizing the technology potential of OPPORTUNITY
- Present talks at industry/technology oriented conferences/forums (e.g. Embedded World, AAL congress) and fairs.

Success Criteria. We will organize at least two technology workshops, and publish a newsletter at least twice per year reaching about 20 industrial organisations. We intend to have between 1 and 2 talks per year at a relevant technology oriented workshop/fair.

B.1.2 Progress beyond the state of the art

*The **outcomes of OPPORTUNITY** are **activity and context recognition systems that alleviate the static constraints placed on the context recognition chain**. In particular, **OPPORTUNITY will facilitate adaptivity to sensor signal degradation, adaptivity to change in system parameters, adaptivity to sensor withdrawal, and ad hoc exploitation of additional resources**. **Such properties are new and far beyond the state of the art**, not only in activity recognition but also in virtually all other sensing and pattern recognition areas. In addition **OPPORTUNITY provides systems with the ability to self manage the sensing resources, self configure the recognition chain and evolve strategies to deal with re-occurring settings and long term changes in an unsupervised manner**. Again, no system with such properties exist to date for activity and context recognition.*

*From a scientific and technical perspective, additional outcomes of OPPORTUNITY are found in the specific fields that combined make the originality of the OPPORTUNITY approach. Individually, these advances are significant contributions beyond the state of the art in their own right. They include **advances in**: **context/activity recognition**; **machine learning**; **cooperative sensor ensembles and sensor networks** (software, control and programming paradigms); **self-/semi-supervised learning**; **autonomous evolution of activity/context-recognition systems**; **embodied/situated view of activity/context recognition**; **self-supervision principles** (**system- user-interactive-** and **EEG-based-** supervision); **context/activity recognition system modelling**; **self-describing "smart sensors"**.*

*We envision for OPPORTUNITY to **have a strong explorative nature** throughout the project. It will survey, assess and learn from a variety of scientific disciplines, not limited to the key expertise of the consortium. In particular aspects of pattern recognition, adaptation, learning, and robustness are topics of research in neurosciences, cognitive psychology, behavioral sciences, to mention a few. OPPORTUNITY aims to draw from these communities **to rethink the problem of activity recognition with a vision larger than an applied machine learning problem**. Questions that will be raised include what are activities and how they are defined and understood not only from a sensing and signal processing viewpoint but from a human and user perspective, as an embodied and situated agent immersed in an ambient intelligence environment.*

***OPPORTUNITY will enable the long term autonomous evolution of AmI environments** (autonomous recruitment and training of additional sensor devices) which is key to large scale AmI environments. By reconsidering the recognition chain, **flexible activity and context recognition goals and priorities also contribute to increased application flexibility**.*

***OPPORTUNITY will pave the way to robust context and activity recognition systems suited for real-world use**. By removing current ideality and static assumptions OPPORTUNITY will improve comfort, naturalness, flexibility, and suitability to multiple goals of wearable and pervasive computing systems. This will support challenging existing and new real-world application scenarios. **As a concrete example, Ambient Assisted Living will become more convenient for elderly or persons with disabilities**.*

B.1.2.1 Baseline: State of the art

OPPORTUNITY is grounded in the field of Ambient Intelligence (AmI), specifically the development of methods to infer human activity from body-worn and environment sensors. It is also related to wireless sensor networks (WSN), which are seen here as a technology enabling opportunistic networks. Finally, it touches on issues related to autonomous operation and self-organization which is a topic of many bio-inspired computing projects.

State of the art research in human activity recognition focuses on the development of methods for the robust recognition of specific trained activities in challenging real-life environments <u>from a pre-defined</u> set of multimodal sensors. Examples of past and present related European projects are SmartIts, WearIT@Work, RELATE, ALLOW, MyHeart, MonAmi. Outside Europe key research groups are among others at MIT, GeorgiaTech, CMU, University of Washington, Intel and Microsoft. While this research is diverse both in terms of the targeted activity types and the sensors used, virtually all projects have one thing in common: they assume static, well-defined sensor configuration with constant quality, no degradation, placed at "optimal" locations on the body or in the environment. In addition, the methods are often specifically trained for the target user (user-dependent training).

These limitations are a result of the traditional activity/context recognition chain as a sense/classify problem. The traditional recognition chain consists of sensing, pre-processing, feature extraction, classification and higher level processing (e.g. decision fusion, reasoning). Once the algorithms are designed and the classifiers trained, this recognition chain is fixed, statically defined, and programmed into a system. The recognition chain does not allow for flexibility. All the components of the recognition chain require static, a-priori defined operating rules. Consequently, the traditional activity recognition chain is simply not suited for activity recognition in opportunistic networks. Within this project we remove these static assumptions by developing methods for an opportunistic, adaptive use of available sensors.

There is a networking element to the development of opportunistic activity recognition systems. Available sensors must be discovered, their capabilities must be queried, and data must be exchanged between sensor nodes (capable of doing local processing at different levels of the activity recognition chain) and processing elements (e.g. PDA). The wireless sensor network community investigates these networking aspects. Examples of European projects dealing with mobile and ad-hoc networking include e-SENSE, and ongoing projects towards an "Internet of Things" (e.g. SENSEI). Multi-agent systems also provide means for distributed autonomous agents to cooperate towards a common goal (e.g. JADE framework, EU CASCOM project). Our aim is to build on existing competencies in opportunistic WSNs [Fers06] and the systems already built towards these kinds of spontaneous networking [Fers07b][Fers08], but also to reuse technological building blocks from WSN and extend them for activity recognition in opportunistic setups.

OPPORTUNITY relies on opportunistic data gathering and processing in dynamic environments. As such it will take advantage from recent advances in adaptive middleware and composable software architectures. A number of EU research project address the issues of providing middlewares and software architectures to support context-aware applications in highly dynamic mobile environments (RUNES, MUSIC, HYDRA, MADAM, e-sense, SENSEI). In comparison to OPPORTUNITY, these approaches tend to operate at a higher abstraction level by assuming that mostly self-contained (sensor and processing) entities are able to provide contextual information that can be composed into context-aware services in a flexible way. This provides answers to robust data acquisition, flexible execution abstraction mechanisms, and the provision of services through the composition of context-aware entities. OPPORTUNITY will learn and benefit from these advances. However, OPPORTUNITY focuses on an essential underpinning of context-aware systems that is not tackled by adaptive middleware and composable software architectures, that is the problem of inferring the contextual information in opportunistic sensor data - in essence an adaptive pattern recognition problem.

The proposed opportunistic approach to activity recognition involves robust self-organization and autonomous operation of at times large ensembles of diverse sensing nodes. Analogies with biological systems are often followed to investigate and design of such systems (e.g. artificial evolution with genetic algorithms, fault-detection with artificial immune systems). Several EU research projects follow bio-inspiration. This includes BIONETS, CASCADAS and HAGGLE. While some of the objectives of these projects (self-organization, autonomous operations) bear similarities with ours, these projects do not consider the problem of human activity recognition. Activity recognition in opportunistic networks raises a specific set of challenges in signal processing, data segmentation and classification, which is the focus of this project.

In summary, state of the art activity and context recognition systems share the following limitations:

- They assume static, a-priori defined sensor configurations
- They assume that sensors do not exhibit faults or degradation

- They are not suited to use additional sensing resources discovered at run-time
- They cannot cope with change in sensor parameters (e.g. sample rate, resolution, accuracy)
- They are adversely affected by changes in sensor placement or orientation
- As a result they tend to be user-specific (sensitivity to changes in body proportions)
- In a broader sense, state of the art approaches are ill suited to enable large scale, open-ended AmI environments: as new sensor are added, or new context needs to be recognized, specific retraining is required for each sensor and context.

B.1.2.2 Advances over the State of the Art

This project goes beyond the state of the art in context/activity recognition as **it removes the up-to-now static assumptions on sensor placement, availability and characteristics, by developing methods for an opportunistic, adaptive use of available sensors**.

In particular, from an activity and context-recognition perspective it provides the following features not available with traditional approaches: **adaptivity to sensor signal degradation**; **adaptivity to change in system parameters; adaptivity to sensor withdrawal; opportunistic exploitation of additional resources**. Specific contributions beyond state of the art are detailed hereafter.

We envision OPPORTUNITY with a strong explorative nature. The current state of the art approaches will be considered in the ongoing reflexion towards opportunistic activity recognition systems. OPPORTUNITY will capitalize and embrace these approaches, but also will take inspiration from fields outside of engineering (e.g. biology, cognitive psychology) in order to stimulate the reflexion on the problem of machine activity recognition

Opportunistic context and activity recognition algorithms

Human activity recognition by means of opportunistic, spontaneous sensor ensembles poses fundamental challenges in terms of methods for dynamic adaptation of the entire recognition system according to the prevailing situation or context, relying on operational principles and algorithms from control theory, machine learning and mechanisms taking inspiration from biological and even economic systems.

Abstract intermediate features

We will develop an intermediate feature sets that abstracts classifiers from specific sensors, in order to provide sensor independence. Independence includes placement/orientation independence (depending on sensor type), operating parameter independence, and even sensor type independence). We will identify placement invariant sensors and features, as well as develop appropriate signal transformations in order to achieve placement independent operation.

This will yield to advances in "smart-sensors" capable of self-description and directly providing intermediate features that seamlessly enable activity recognition when placed into existing infrastructure (e.g. ambient or body-worn network), towards a more widespread use of activity and context-recognition systems. Inclusion of accuracy ("quality of sensing") as part of self-description enables to include reliability and accuracy of sensing and context in user-feedback.

A simple example of intermediate features are body limb trajectories. A wide range of sensors can be used for tracking limbs (accelerometers, gyroscopes, magnetic trackers, optical trackers etc.) and all of them can be mapped onto spatial trajectories of varying precision and accuracy.

Another example is a smart sensor capable of detecting body location (e.g. by generalization and extension of [Kunze05,Kunze07b]) and adjusting signal processing parameters accordingly (or even directly providing intermediate features). For example an acceleration sensor placed at the limb extremity will be more sensitive than one placed at a joint, due to the higher centrifugal force when the limb rotates around the joint. By detecting body placement the acceleration values can be normalized to a reference body location.

Further example include sensors which operate at various sample rate or resolution (e.g. for energy reasons), but provide internally the required abstraction by transforming the raw signals to intermediate features (with the corresponding tradeoffs, e.g. confidence, signal-noise ratio).

The key outcome will be a set of mappings from sensors to intermediate features. Since this is eminently sensor specific, the outcome will take the form of an exhaustive survey of sensors used in activity recognition, the characteristic components they measure, together with an investigation of suitable intermediate feature representation, their characteristics (e.g. costs/benefits), and algorithms to transform raw sensor data to intermediate features. Generic methodologies, enabling application to novel sensor domains, will be provided. As much as possible, results will be kept generic to enable application to other sensing domains.

This approach to abstract intermediate feature representation is a key contribution of OPPORTUNITY beyond state of the art.

Opportunistic classifiers

In order to make best use of available sensor data we develop new *modular opportunistic classifiers* tailored for activity recognition in opportunistic setups. These classifiers can dynamically deal with changes in the number and reliability of input features (depending on available sensors). They allow to incorporate new features without the need for complete re-training. They provide graceful degradation when the feature set is reduced. They are parameterized using a sensor self-description (e.g. sampling rate, accuracy, placement), in order to make best use of available information. They provide mechanisms for assessing reliability of their own decisions. Moreover, they are able to incorporate new knowledge in an efficient way, through online training (e.g., in the case a new sensor is added to the system). In addition, these classifiers are suited for online processing, with limited computational/memory requirements to operate in low power devices and miniature wearable systems.

In addition, we develop *opportunistic classifier fusion*. Classifier fusion methods will in the same way be modular with respect to the available number, type, and characteristics of classifiers/sensors. These methods take into account the uncertainty of each individual input stream to dynamically select the best configuration. This process will be performed in order to remove noisy or faulty channels, as well as to incorporate recently discovered sensors in the opportunistic network. This dynamical process may take also into account task-dependent constraints in terms of performance and energy consumption.

Previous work have suggested the suitability of classifier fusion in the implementation of activity recognition systems able to deal with a variable set of sensors, [Zappi07], in particular, by assessing the performance degradation upon sensor failure. However, these studies are mainly based on homogeneous sensors and do not provide any mechanism to recover from these faults, nor to incorporate new sensor into the system, nor to provide a measure of decision uncertainty.

Opportunistic classifiers and classifier fusion go beyond the state of the art along these dimensions. This translates in advances in machine learning tools for opportunistic context/activity recognition in wearable and pervasive/ubiquitous computing systems. This also yield advances in context recognition system modelling, in particular with respect to enabling the intelligent use of opportunistic resources to achieve a desired performance characteristic (e.g. power/performance tradeoffs given dynamic availability of resources).

Dynamic adaptation and long-term autonomous evolution

A critical feature of opportunistic systems is their ability to cope with dynamic environmental changes. Such changes include: signal drift/degradation (e.g. due to shifts in sensor placement/orientation), progressive changes in user activity goal - signal template linkage, and addition/removal of sensing resources. For handling such changes, OPPORTUNITY provides specific adaptation mechanisms:

Dynamic adaptation copes with rapid changes in sensor configurations or application performance goals. It relies on models relating sensor configuration and context recognition chain parameters to performance metrics. These models are formalized so that they allow for an efficient online adaptation of the sensor configuration and context recognition chain to reach a performance goal. Heuristics to find the appropriate settings for a desired performance goal are devised on this basis. Dynamic adaptation plays hand in hand with opportunistic modular classifiers and classifier fusion (see section on opportunistic classifiers).

Autonomous evolution deals with long term gradual adaptation of the system to a new environment, user or sensor configuration. On one hand, unsupervised (data-driven) techniques are applied to achieve feature and classifier adaptation. On the other hand, methods related to self-supervised (using system-, user-, and error-related EEG correlates feedback to supervise learning) and semi-supervised learning ([Chapelle06,Vapnik98,Huang06]) will be applied to take advantage of information provided by the system itself, or provided by the user in particular situations, to retrain classifiers towards a new adapted signal template. This will take into account the different uncertainty levels of the existing sensor configuration and the likelihood of changes in the sensor configuration (e.g. signal degradation vs normal activity variability).

In order to exploit opportunistically added sensing resources, the OPPORTUNITY context recognition chain will self-adapt to take advantage of new information sources. Concretely, classifiers of newly discovered sensors will be trained using information from the current system, and/or provided by the users with minimally supervised interactive feedback. This will allow an existing context-aware system to incorporate new sensors without requiring specific off-line training or calibration processes. Indeed, new, virgin sensors will in this way be trained from an already operational context-aware system.

We will capitalize on error-related EEG correlates (EEG signals automatically detected arising when a system's behavior deviates from expectations) to obtain an endogenous measure of system performance to guide system adaptation and autonomous evolution [Chavarriaga07,Ferrez08].

We will define principles for the inclusion of minimal user feedback (i.e. maximizing information gain while minimizing user disturbance) in order support interactive online adaptation. These principles will guide the choice of the feedback mechanism for online adaptation, using system-, user-, or EEG-based feedback depending on confidence values, system stability goals and user interaction costs.

Dynamic adaptation and autonomous evolution are key contributions beyond the state of the art in activity and context recognition systems. Overall this contributes to context recognition systems capable of operating in open-ended environments, i.e. environments where sensors may not all be capable of self-description, where the deployed infrastructure may change over time, or where the set of activities to recognize may change over time.

Advances in Ambient Intelligence Environments

The above advances in opportunistic context and activity recognition algorithms improve the robustness and suitability of activity and context recognition system to real-world environments.

From a user point of view, this leads to better comfort of use of activity recognition systems. The flexibility in how sensors are opportunistically used for various applications lowers the need to deploy specific sensor setups for each application. The ability of the system to adapt to various sensor placements on the body improves the wearability and user acceptance. It allows the user to change the sensor placement on purpose (e.g. the location of a sensor may be changed if it becomes uncomfortable). This approach also allows the system to cope with changes in sensor placements occurring slowly over time, or sensor failures, leading to improved robustness compared to state of the art approaches. Placement and sensor independence also leads to reduced user-dependence. This advances the state of the art since current activity recognition systems must be individually trained to achieve best performance, which makes deployment tedious.

From the point of view of the validation scenarios the outcome of OPPORTUNITY is to demonstrate that robust activity recognition can be performed, despite the usual variability in sensor placement and orientation typical of sensors placed on-body and/or integrated into clothing, mobile devices, or the environment. This natural variability is nowadays a challenge to state of the art approaches.

Advances in Opportunistic Brain-Computer Interfaces

The methods developed within OPPORTUNITY are generalizeable. In other words, advances in machine learning, dynamic adaptation, spontaneous cooperative sensing, sensor self-configuration, and robustness and fault tolerance are not confined to human activity recognition. We will demonstrate this in EEG-based Brain-Computer Interfaces, which is a complex cognitive context recognition task. EEG-based BCI typically relies on a large number of homogeneous sensors (electrodes). Sensor drift and intermittent skin contact (both normal when an EEG electrode cap is worn over long period of time) are common problems.

Despite efforts to build adaptive BCIs (see section A.1), these interfaces remain highly sensitive to sensor failures or noise. Moreover, up to our knowledge, no current system is endowed with the capability of dynamically changing the channels or features used for cognitive state recognition. The methods developed by OPPORTUNITY have the potential to improve the robustness of BCI systems by dynamically selecting the appropriate set of electrodes required to achieve successful operation and, upon detection of failure, recruit additional channels in order to minimize the performance degradation. Moreover, these systems will also be able to adapt to inherent changes in the EEG signal. Dynamic adaptation mechanisms can be used to assess the system performance and prompt an appropriate corrective action (e.g. removal of noisy channels and/or the adaptation of the classification process).

Spontaneous goal-oriented sensing ensembles

Activity and context recognition in opportunistic networks requires data acquisition about physical phenomena. We pursue **spontaneous goal-oriented sensing ensembles**, spanning software architectures, methods and control algorithms to enable self-organizing sensor networks, and programming models **to effectively implement means to acquire data relevant to activity and context recognition**.

To meet the challenges of OPPORTUNITY raised in the previous sections w.r.t. to the way services, data, and resources, are managed and orchestrated, a re-thinking of traditional middleware and service is required. OPPORTUNITY will contribute to this research in several areas, by:

- identifying an innovative model for service and data provisioning that revises the typical architecture of current middleware and service frameworks towards coordination architectures, describing the spontaneous, yet cooperative interactions among sensing entities, to overcome current limitations;
- developing a more general approach for sensor data collection, than those proposed by recent pervasive and ubiquitous middlewares and service frameworks;
- proposing innovative and more general solutions for the automatic (self-organized and self-configuring) collection, aggregation and interpretation of data, but also services, and resources, and their dynamic interactions.

Going beyond service models and middleware infrastructures that typically provide specific functionalities (e.g., sensor data fusion, context recognition, situation aware software adapters, etc.) to support application development, OPPORTUNITY will cherry-pick and extend the best and most promising solutions offered by several of these models and middleware.

Concerning approaches to model and build self-organizing/self-adaptive applications, a variety of heterogeneous proposals exist for both the basic components (e.g. reactive agents in agent based middleware architectures [Par07], and proactive and goal-oriented ones [Tum05]) and their interactions (e.g., pheromones [Par97], virtual fields [Bab06, Mam06, MamZ06], socially-inspired communication mechanisms [Jel04, JelB05, HalA06], and smart data structures [JulR06, Riv07]). Another promising research avenue is based on the recently proposed approaches for automatic service composition based on semantic, goal-oriented, pattern-matching [FujS06, Qui07, Maz07]. The basic idea in these approaches is that semantic description can be attached to services, describing what a service can provide to other services and what it requires from other services. On this basis, automatic mechanisms (typically centralized) for pattern-matching can be enforced for composing services in an unsupervised way.

Two interesting contributions related to these concepts are the work on "knowledge network" performed within the CASCADAS project [Bau07], and the work on "dynamic context-driven organizations" [Hae07]. [Bau07] proposes an approach for self-organizing contextual information into sorts of structured collections of related knowledge items, supporting services in reaching a comprehensive understanding of "situations". In [Hae07], a set of evolution rules defined in a coordination substrate determine how agents can dynamically join and leave organizations based on their actual configuration.

Research on existing formal frameworks on rewriting systems [Ban01], process algebras [Mil99], modal logics [Par05], and chemical-oriented computational models [Har86, Fis00] are interesting starting points to study how components can be flexibly and dynamically matched with each other to create composite high-level services. The approach envisioned in [But02, BeaB06], but then not fully developed, consists of code capsules injected in a sort of dense sensor network (aka "Paintable Computer"). Capsules interact by means of chemical like reactions to trigger novel and composite services. In OPPORTUNITY we will investigate and take inspiration from those approaches in the artificial chemistry area [But02, DitZB01]. Here, services, like chemical reagents, will automatically combine according to the laws of (artificial) physical forces in the environment. Coordination mechanism as they have been exhibited in CHAM (Chemical Abstract Machine) [Ban01][Ban06] appear as a potentially effective means to describe and control distributed spontaneous interactions in sensor ensembles.

One of the key outcomes of OPPORTUNITY will be to review, improve and apply some of these abstract techniques in concrete, complex settings, testing their utility in actual tasks, in particular for (sensor) data collection, aggregation and organization. With this regard, OPPORTUNITY will integrate and improve these approaches in several ways: (i) OPPORTUNITY will try to identify a general purpose architecture model that will be able to represent and subsume the above proposals under unifying abstractions. (ii) OPPORTUNITY will address self-organization and goal-oriented sensing in a world of heterogeneous components, in contrast to most of current studies that focus on ensembles of homogeneous components. (iii) The ecological perspective fostered by OPPORTUNITY fits well those ideas in related fields that consider pervasive scenarios as devices and services cooperating autonomously to form global services [Agh08]. The plethora and heterogeneity of devices, services, applications comprising such global services will be taken into account and managed by the patterns and rules governing opportunistic systems. The key innovation of OPPORTUNITY will be to actually create a prototype and test this idea of an "ecology" in concrete validation scenarios. To the best of our knowledge, up to now, this idea has been proposed only as a metaphor, OPPORTUNITY will attempt an actual implementation of this concept.

The OPPORTUNITY coordination architecture for spontaneous goal-oriented sensing ensembles will generalize methods based on semantic match-making between services as outlined above. It will put focus on formal methods to describe and control the distributed coordination of goal oriented entities from an interaction architecture point of view. In fact, artificial chemistry-like operations bear potential to be processed much more simply and autonomically than previous semantic discovery and matching services. Finally, it is worth pointing out that the OPPORTUNITY coordination architecture will follow an "ecological" perspective of sensor ensembles, respecting also an opportunistic "growing" of sensor populations. Technological progress, monotonic software growth, and communication opportunities not anticipated a-priori force to design sensor ensembles as services sustaining in an ecosystem of other services.

In summary, the OPPORTUNITY middleware architecture follows an ecological perspective allowing for self-organization of data and services, self-adaptation, decentralized deployment and exploitation of data and services. This leads to great flexibility in how data about physical phenomena can be opportunistically acquired in efficient and scalable ways for activity/context recognition.

Large scale autonomously evolving AmI environments

The contribution beyond state of the art is to consider an activity recognition system as an embodied and situated system, that autonomously evolves over time in open-ended environments. This closed-loop perspective capitalizes on self-adaptation through feedback (recurrent connections). Feedback comes from automatically detected error-related EEG correlates [Ferrez08] and from system self-supervision to achieve autonomous evolution. Principles of minimal interactive feedback are included to guide evolution by providing sporadic, minimally distractive, interactive user feedback. Environmental feedback is intrinsic in the system, since the outcomes of context recognition affect upcoming user activities. This closed-loop and self-supervised learning approach towards autonomous evolving AmI environments is strongly related to processes of cognitive development [Weng01], although operating at a high abstraction level in contrast to biomimetic approaches.

Therefore, in a broader sense OPPORTUNITY enables Ambient Intelligence (AmI) environments on a scale and with a flexibility that is not possible until now. In current AmI environments, changes in the sensor configuration, or changes in the set of activities to recognize, require to manually configure the system anew. OPPORTUNITY alleviates this limitations. An AmI environment operating with the mechanisms developed within OPPORTUNITY has the ability to learn how to make use of additional sensor modalities (e.g. when a new sensor is placed in the environment or on-body). Over time, the set of activities it recognizes can also be autonomously extended. This occurs when a device capable of recognizing a new set of activities is introduced in that environment. Upon recurring detection of an activity or context by that device, autonomous evolution enables to adjust the operating parameters of the existing sensors within the AmI environment to detect the same activity. In the same way, a mobile device may learn to recognize activities from another one; or a mobile device exchanged between two disconnected AmI environments may enable them to learn to recognize the same set of activities. Altogether, OPPORTUNITY provides mechanisms by which AmI environments can be configured and extended at run-time, potentially cooperatively by a multitude of users. This provides means to deploy and train large scale AmI environments in a flexible manner.

B.1.2.3 Performance/research indicators

Below are summarized the performance and research indicators against which the project outcomes may be assessed, categorized according to the project's objectives.

Objective #1: Self-* capabilities of sensors and sensor ensembles.

Self description Success Criteria The ability to provide adequate description of all relevant sensor parameters and variations for different sensor types in the OPPORTUNITY case studies (see objective 7) within a small microcontroller based node (8/16 bit, 4 MHz, <64kByte memory)

Dynamic sensor self-characterisation Success Criteria: Demonstration in the OPPORTUNITY cases studies (see objective 7) that we can detect degradation with a precision and recall both in the range of 90% and an accuracy (in terms of degree of degradation) of about plus/minus 20%. Examples of specific types of degradation that we will focus on are position changes of on body motion sensors, intensity variations in on body sound sensors caused by different enclosures (e.g. e mobile phone being put onto a bag) and signal strength variations in RF positioning systems.

Self Managed interaction and configuration Success Criteria: Demonstration within the OPPORTUNITY case studies of complex interactions and configurations in sensor ensembles of 100 and more sensors. Demonstrate quantitatively the benefit in terms of recognition rate.

Objective #2: Creating and Coordinating ad-hoc goal-oriented sensor ensembles.

Success Criteria. The success criterion will be the availability of a spontaneous goal-oriented sensing coordination architecture implemented in a software framework that allows to generate sensing missions (goals) from an application at run-time, that plans sensor resources need to accomplish the sensing mission, that uses this plan to acquire and solicit sensors and to configure them as an ensemble, and to coordinate the sensing mission during the whole lifetime of the application, subject to dynamic changes in the sensor population, availability, capability and semantic interoperability.

In quantitative terms we will demonstrate the functionality with up to 50 sensor nodes showing quantitative information content of spontaneous assemblies (e.g. through mutual information or test classifications) not more than 20% under the performance of hand optimized systems.

Objective #3: Variations tolerant Signal Processing and Feature Extraction

Variability tolerant signal conditioning Success Criteria: To demonstrate on specific examples that large (double percentage digits) variations in sensor parameters can be neutralized in the sense that they only cause small (<5%) degradation in recognition performance. Initially we will build on our work on body-worn sensor displacement, followed by sound sensor intensity changes, and indoor localization accuracy variations.

Abstract, sensor independent features Success Criteria: Demonstration of several (at least 8) types of abstract features and the fact that they can be computed using different sensor combinations. The recognition accuracy of the system using the abstract features should not vary by more then a few percent when different sensing modalities are used. Initially we will work with abstract features related to body motion, location, and interaction with devices.

Objective #4: Machine learning algorithms optimized for opportunistic networks

Opportunistic classifiers Success Criteria: The success criterion is the comparison of the opportunistic classifiers to state of the art dedicated classifiers on a set of realistic problems. We aim at a recognition rate comparable to the dedicated classifiers (not more than 10% to 20% below). We will do a systematic performance evaluation of the developed classifiers with respect to sensitivity to signal noise, training requirements, and their suitability for online implementations

Opportunistic Classifier Fusion Success Criteria: Again, a comparison of our system against dedicated recognition systems will be made, aiming for not more then 10% to 20% performance difference. Moreover, opportunistic decisions based on classifier fusion are expected to outperform dedicated systems in case of sensor failure or sensor network reorganization. Opportunistic fusion will be evaluated in terms of the performance degradation and fault-recovery in cases of sensor noise and sensor failure, as well as its ability to perform dynamic input selection based on the reliability of available sensors.

Objective #5: Unsupervised dynamic adaptation

System modelling of context recognition systems Success Criteria: The success criteria will be the ability of our models to predict performance gains of our system when using various sensor combinations. We aim the model to be accurate within 10%.

Objective #6: Autonomous evolution

Autonomous evolution and Interactive minimally supervised adaptation success criteria: the performance will be compared to a trained baseline system not capable of dynamic adaptation while sensor variations are introduced. Variations include: sensor addition, sensor removal, long term slow (wrt activity occurrence dynamics) changes in sensor orientation and placement (with body-worn acceleration sensors in a first step), slow (wrt activity occurrence dynamics) addition of progressively higher signal noise. Performance will be characterized along metrics introduced in this project. We aim at achieving sustained performance within the range of adaptation capabilities of the systems. The range of these capabilities will be characterized with respect to the tradeoffs intrinsic to autonomous evolution (e.g. faster adaptation speed v.s. stability, template evolution v.s. attractor strength). A success criteria is to characterize the level at which achieve autonomous evolution can proceed without user interaction and with which tradeoffs, as well as characterizing the benefits of interactive user feedback and EEG-based feedback.

Objective #7: Empirical validation

Success Criteria: The ultimate success criterion will be the empirical comparison of our system to state of the art traditional (non opportunistic) activity recognition systems.

To this end we will train our system on a large, fixed set of typical sensors. We will then dynamically change the sensor configuration. Using classical recognition methods, a new system needs to be designed and trained for each of such configurations. In contrast, our system will be expected to automatically adapt to the new configuration. For each configuration we will then compare the performance of our opportunistic system to the performance of a state of the art system specifically designed and trained for this configuration. On average we aim to achieve about 80% of the recognition rate of the dedicated system when sensor configuration is not changed. However we expect the opportunistic system to outperform the dedicated system when the configuration of the sensors is changed.

B.1.3 S/T methodology and associated work plan

B.1.3.1 Overall strategy and general description

*OPPORTUNIY pursues a high risk, yet well thought through and promising approach to the development of opportunistic activity recognition systems. It is based on a large body of previous research performed by the project partners and a thorough understanding of all the components and possible variations of a recognition system. A **hierarchical decomposition of the activity recognition problem** enables the project to claim that the **OPPORTUNITY solution generalizes well to a broad range of problems**.*

*Based on the hierarchical breakdown, **an incremental approach has been designed for the project that allows us to pursue an ambitious, high risk end goal without the risk of an 'all or nothing' strategy**. Instead we work towards the goal in incremental steps, each of them in itself representing a significant scientific advance. The breakdown is also the basis for **an incremental approach to validation which will start with simple activity components and then proceed to increasingly complex case studies** finally leading to a system demonstrator motivated by and closely related to relevant real life applications such as personal healthcare and adaptive energy management in home and office environments.*

The work is divided into work packages following a logical partitioning of work. Each work package is lead by a partner with a long history of internationally recognized research work in the corresponding area. Project deliverables and milestones ensure ambitious yet realistic project timing with well defined synchronisation points between different work packages and tasks.

The project proposes a complex, large and ambitious work program. The consortium can handle this work program with the requested resources, because a huge amount of experience, algorithms, equipment and conventional activity recognition and sensing setups already exist at the partners labs.

B.1.3.1.1 Overview

An opportunistic mobile system to recognize human activity and user context works as follows:

- **Data acquisition**: sensors providing information about the physical world (or virtual sensors) need to be discovered and networked in order to provide data for context/activity recognition; this data is brought to the context recognition system;
- **Context recognition instantiation**: A context recognition system is instanciated and parameterized according to the sensors available to convert the data into information (user context and activities);
- **Adaptation**: throughout operation the recognition system must keep track of changes in the sensing environment and operating parameters and adapt itself accordingly.

The challenges of an opportunistic recognition system stem from the fact that sensors that are discovered can:

- be in any place (in the environment, in devices, objects, on the body) and in any orientation
- be of any modality (the type of physical quantity that is measured; e.g. motion, light, sound)
- have various characteristics (e.g. sample rate, resolution, accuracy, signal to noise ratio)

Furthermore, while operating, some of these aspects can change. For instance the body location of a sensors can vary (e.g. a cellphone with a sensor may be placed in various pockets), or sensor characteristics can vary (e.g. change in sample rate according to available energy).

An efficient opportunistic system should thus: (i) make a best use of the available resources, and (ii) keep working despite - or improve thanks to - changes in the sensing environment.

We address these challenges to devise opportunistic context and activity recognition systems. The key aspects of our approach (outlined in detail in the following sections) can be summarized as follows:

1. **Opportunistic activity/context recognition.** We propose a new **adaptive, dynamic paradigm** for the recognition of context/activities that will replace the traditional static recognition chain. As described in section B.1.1.2. It consists of the following components
   - Formulation of the recognition task as a flexible, application specific goal that includes the preferences with respect to different recognition parameters (e.g. recall vs. precision) and possible simplifications of the recognition task.
   - Methods for sensor self characterization (e.g. automatic detection of signal degradation), self description and self configuration
   - Algorithms and control paradigms for autonomous emergence of cooperative, distributed sensing ensembles optimally suited to provide the optimal information for the requirements of the application specified goal in a given situation.
   - Signal processing algorithms and feature level abstractions that mask the sensor level variability from the classification stage
   - Parameterized, adaptive classification and classifier fusion methods that can deal with a broad range of variations in the sensor and feature space.
   - Methods for unsupervised adaptation of the overall system configuration (combination of and cooperation between the sensing, signal processing feature extraction and classification stages) under dynamically changing conditions.
   - Methods for long term, unsupervised evolution of the entire system to cope with open-ended environment and optimize the handling of re-occurring configurations
2. **Applicability.** To ensure that the OPPORTUNITY approach is valid for a broad range of context recognition problems, not just for few specific scenarios investigated in the project, we base our work on a hierarchical decomposition of the activity recognition problem. The decomposition is based on activity components such as location, modes of locomotion (walking, standing etc.), hand activity, interaction

with objects, and interaction with humans. Complex activities are modeled as combination of these components.

3. **Risk management.** We use the hierarchical breakdown as a basis for an incremental project structure that avoids the risks of an 'all or nothing' approach. In a first stage we deal with individual activity components. This means that we handle constrained problems for which experiments are easily and quickly assembled. The second stage we consider composite activities. Finally we validate the approach on complex example scenarios typical for real-world activity recognition systems.
4. **Generalization.** In addition, a number of methods that we develop in OPPORTUNITY are generalizeable to other context recognition systems than activity recognition. We demonstrate this by showing how specific cognitive states (e.g. attention, expectation) can be detected on the basis of EEG signals, using the approaches developed within OPPORTUNITY, towards Brain-Computer Interfaces (BCI).
5. **Work breakdown.** The project is organized in 5 scientific/technical work packages each addressing a key scientific challenge area: cooperative goal oriented information gathering, sensor level adaptation, adaptive classifiers and classifier fusion, dynamic adaptation and autonomous evolution, and empirical evaluation in case studies. Each WP is lead by a partner with a long history of research in the respective area. Deliverables and milestones have been established to ensure an ambitious yet realistic project timing. They are also synchronisation points for the work packages.
6. **Dissemination and exploitation.** Scientific dissemination is of key importance and will be handled accordingly to raise awareness on the new methods developed in the project. While OPPORTUNITY as a FET project does not aim at directly commercialisable results, the partners are in involved in a wide range of European, national and industry sponsored project in related areas. The partners will actively pursue the dissemination of results into these project to ensure maximum impact and open exploitation avenues.

B.1.3.1.2 The Problem Space

A major problem facing OPPORTUNITY is the complexity of the problem domain. In this section we discuss the key dimensions of the problem domain which the project needs to address. These are: (1) the types of variability in the sensor configuration that the system is likely to encounter, (2) different timescales and temporal patterns of the variations, and (3) different types of activity recognition problem that opportunistic systems may have to deal with.

We present a heuristic, hierarchical breakdown of the activity recognition problem into simple components. This breakdown is the basis for the OPPORTUNITY approach to generalization, complexity reduction and case study design.

TYPES OF SENSOR VARIABILITY

When speaking about dynamically varying sensor combination it is important to understand that there are several distinctly different types of variability:

1. **Signal quality degradation**. Even without changes in the sensor configuration there can be variations in the quality of information that an activity recognition system receives. They can be due to sensor misadjustment (e.g. slipping sensors on body-worn motion tracking systems), external disturbances (e.g. signal strength variations caused by moving person in WLAN based positioning systems), or situative variations that diminish the value of certain sensing modalities (e.g. a machine used in a task is exchanged changing the characteristic sound that was used for recognition). In conventional recognition systems such changes lead to rapid, often radical decrease in recognition accuracy. OPPORTUNITY will allow systems to adapt to such changes and reduce the influence of signal quality degradation on recognition accuracy. Possible strategies are dynamic changes in the weights assigned to different sensing modalities (including totally leaving out a sensor), unsupervised retraining, and dynamic addition of information from alternative sensors.
2. **Isolated failures**. Failure of a single sensor or a sensor group is a common occurrence in long time deployment of activity recognition. The challenge to opportunistic recognition systems is to develop

strategies for 'graceful degradation' in case of such failures. By comparison in the vast majority of current systems failure of one or more sensors leads to total system failure (as classifiers tend to be trained on a specific fixed dimensional feature space).

3. **Partial reconfiguration**. In principle, isolated failures described above can be seen as a special case of partial reconfiguration. However, for many reasons it makes sense to differentiate between the two. Whereas isolated failures refer to one or at most a few sensors being removed entirely, partial reconfiguration takes place when a significant amount of sensors in the system are changed. This can include removing some sensors, but also adding sensors. Typically partial reconfiguration would occur when the user changes part of his outfit and with it the integrated/attached sensors. Another example is a user with on body sensors moving from one instrumented environment to another (e.g. from home to office). Here the on body configuration stays the same while the external information sources change. Handling partial reconfiguration is more complex than just changing weights. We need adaptive classifiers, sensors independent features or appropriate classifier combination methods to handle this type of variability
4. **System change.** As an extreme case of reconfiguration we consider the exchange of the (more or less) entire system. Thus after jogging in the morning (with the sensors integrated in his sports accessories) a user would change into his business outfit and go to the office. Alternatively a user whose system primarily relies on environmental sensors for activity recognition would go from one environment to another (e.g from one office to another).
5. **High level cooperation**. In many scenarios we would be dealing with different, autonomous activity recognition systems. Such systems may share information helping each other understand what is going on. Thus, in a meeting scenario each user may have a separate, different activity tracking system. In addition the meeting room may have some sensing infrastructure. For privacy reasons such systems may not be able to share information on sensor level. Instead filtered, high level activity information (e.g. my user is most probably presenting) would be selectively shared. OPPORTUNITY will deal with such cooperation between devices as part of overall activity recognition chain.

TEMPORAL VARIABILITY PATTERNS

From the timing point of view, there are different ways in which the variation can happen:

1. **Spontaneous, random events**. The most obvious cause for change in sensor configuration is a 'spontaneous' event such as sensor error, user leaving an appliance behind, or going to a different location. Per definition spontaneous random events can not be foreseen by the system and thus the system can not proactively prepare for them.
2. **Periodically re-occurring changes**. For most users there are fixed routines that they follow. Thus, on most days, a person would for example start with a workout in a gym, then go to the office, followed by shopping, possibly dinner out and then coming back home. Each of those activities can be associated with a certain loosely defined sensor configuration. A person will mostly (of course not always) work out in the same gym, work in the same office building, shop in the same shops and live in the same house. How much variations there are to the pattern depends on the user. A salesman will for example not work in the office but be travelling to changing customers, where a clerk will spend most of his time in the same office. Thus variations in sensor configurations are not truly random but follow a probabilistically predictable pattern. Unsupervised learning with system spotting reoccurring environments and adapting to them can play an important part in dealing with this type of variability.
3. **Gradual evolution**. In some cases we can expect variations be a gradual, continuous process rather then a discrete event. This would be the case when an on body sensor begins to slip and becomes gradually more displaced. Similarly you could see the user moving away from an area with high density of WLAN access points which would lead to WLAN based positioning system performance gradually deteriorating.
4. **Continuous, random change**. Especially in situations where cooperation between systems belonging to different users is relevant (e.g. meeting or conference assistance system) change is likely to occur continuously as users come and go. Similar will be a case for a highly mobile, travelling users who continuously proceed from one environment to another (e.g. shopping and going from one shop to another) and strongly rely on the infrastructure for activity recognition

HIERARCHICAL BREAKDOWN OF THE ACTIVITY RECOGNITION TASK

Human activity recognition encompasses a broad range of applications. Examples are as diverse as tracking industrial assembly activity [Stiefmeier08], monitoring of human nutrition habits [Junker08, Amft05], recognition of different martial arts moves [Heinz06] or following the course of a meeting [Kern03], Renals07].

The key to addressing the application diversity challenge is the observation that despite their diversity many activity recognition problems can be build out of some basic, common components (see e.g. [Lukowicz02]). These are:

1. **Hands activity.** Much human activity is determined by what we do with our hands. Thus while for example industrial assembly tracking and nutrition monitoring may look like radically different domains, both involve characteristic arms motions. From technical point of view, tracking arms motions is the same problem independently of the application domain. Most current research in this direction is based on inertial sensors (accelerometers, gyroscopes, magnetic field sensors and combination thereof) placed on the arms and wrists [Junker08]. However there is a broad range of other possibilities for sensing gestures including textile bend sensors [Mattmann07], video tracking using external [Just06] and wearable cameras [Starner98], and different stationary motion tracking devices [Mitra07].
2. **General body motion and posture**. Posture and what is often referred to as 'modes of locomotion' (standing, running, waling, walking up stairs etc.) is an important piece of activity information. We are unlikely to engage in activities such as eating or doing a presentation while running. Modes of locomotion and posture recognition is among the classical and best understood activity recognition tasks. The sensing modalities are mostly the same as for gestures except that the sensor placement is more flexible (essentially anywhere on the body) and the pattern recognition problem simpler.
3. **Interaction with devices and objects**. A large category of activities involves interaction with objects and devices. Thus in an industrial maintenance task we have interaction with tools and pieces of machinery. In an Ambient Assisted Living scenario the interesting piece of information is the use of household appliances (cooker, coffee machine) and objects such as cutlery or pill boxes. Detecting such interaction works in a similar way independently of the scenario. Sensors range from wrist worn RFID readers [Patterson05], through sound (works especially good for appliances and electric tools such as coffee grinder or drill), to body worn cameras and sensors integrated in the objects.
4. **Interaction with other humans**. For many applications human interaction is an important aspect. A good example are meeting support, recording and annotation systems, that are a much researched subject [Kern03, Gatica07, Renals07]. In general audio analysis of speaking patterns (user speaking, someone else speaking, 'cocktail party effect') is a good indication of different meeting situations. User location (who is next to whom), video analysis and gestures (e.g hand shake, pointing motions, gesticulation) can also be useful information [Hung08, Zhang06].
5. **Generalized location**. User location is a crucial piece of information for most activity recognition tasks. In general the required information is not in the form of physical coordinates. Instead semantically meaningful information such as being in a restaurant, in a certain part of a flat (e.g. at the kitchen table) or proximity to other people or devices is needed. There is a multitude of ways to sense location [Hightower01]. They range from expensive and exact systems such as the UBISENSE Ultra Wide Band through simple beacon based concepts (e.g. using Bluetooth or active RFID) to video analysis, auditory scene analysis (recognizing rooms by sound) and inertial navigation. Location information is likely to be the most variable part of activity recognition and be in many cases very application specific. It will be studied in much detail by OPPORTUNITY.
6. **Background information**. In addition to the explicit sensing described in the previous points, background information about the user and the environment is often useful for activity recognition. Such information can include user habits and his agenda.
7. **Physiological parameters**. For some applications the physiological and affective state (tired, stressed, health state) may be relevant. Other applications such as health monitoring are explicitly dedicated at physiological parameters. In the former case an opportunistic may be interesting as we may for example try to infer the level of stress from varying information sources such as user motion patterns, voice,

gesture or long term behavior (deviation from routine). In the later case it is safe to assume dedicated devices to be worn as part of treatment regimen.

The above activity breakdown does not claim to be a universally valid, systematically researched taxonomy of human activity (a research challenge in its own right). Instead it is a heuristic breakdown that is based on vast experience of the involved partners with activity recognition. It is applicable to a broad range of activity recognition applications and problems which is sufficient for the purpose of OPPORTUNITY.

B.1.3.1.3 The OPPORTUNITY Approach

ARCHITECTURE

Activity and context recognition is essentially a sense/classify problem. Based on a set of physical signals the system classifies the current situation as belonging to a certain context.

The traditional approach to designing activity recognition systems leads to a system design that is static. The individual processing stages, sensors, and application goals are all tightly linked and, in general, changes in any one aspect require the entire system to be redesigned.

OPPORTUNITY proposes a ***novel, dynamic, adaptive paradigm*** to remove the **up-to-now static constraints placed on sensor availability, placement and characteristics**. The new paradigm of OPPORTUNITY is illustrated in figure 1.3.1 and explained hereafter.

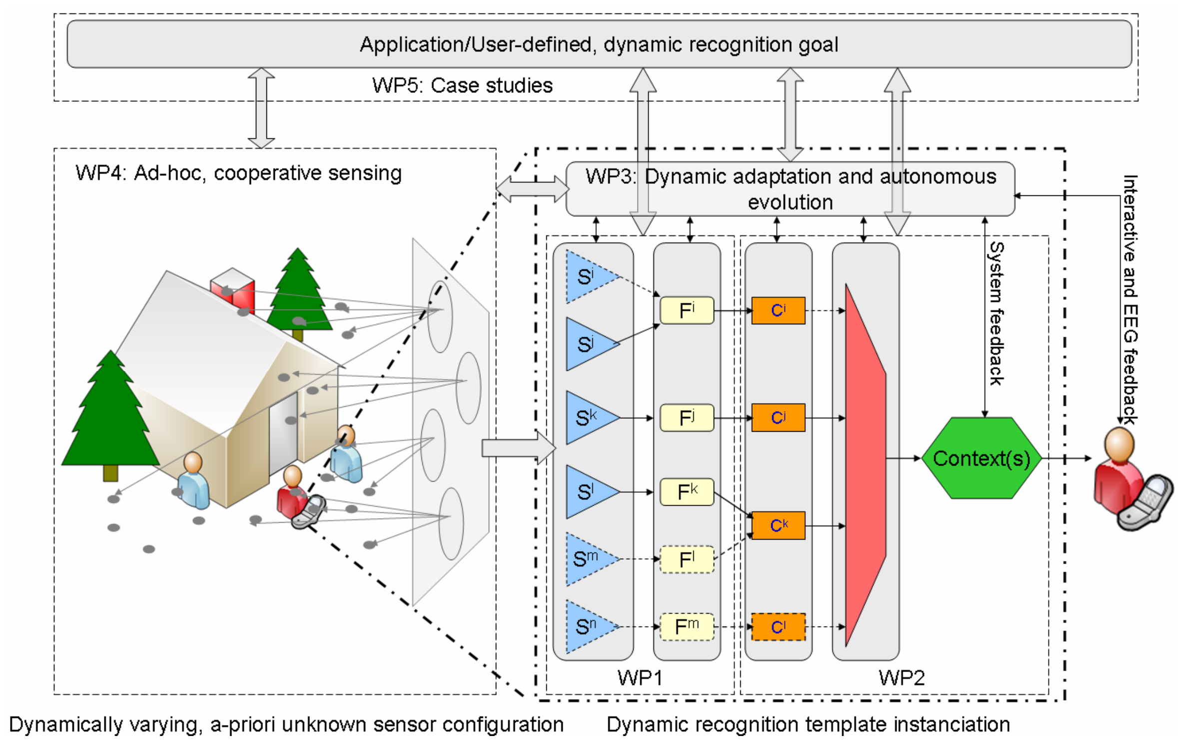


Figure 1.3.1: The approach of OPPORTUNITY to context/activity recognition. It includes ad-hoc cooperative sensing to obtain data about the user and surrounding world; a flexible and parameterizeable opportunistic recognition chain; and runtime supervision and adaptation methods to opportunistically cope with changes.

Ad-hoc, cooperative sensing: A mobile device opportunistically exploits information from sensors placed in the users outfit, in the environement and other sources of information to recognize contexts/activities. Sensors are opportunistically interconnected and enable large scale data acquisition about the user and the world surrounding him.

Opportunistic context recognition chain: The opportunistic context recognition chain is adjustable at all levels (signal pre-processing, feature extraction, classification, decision fusion, higher level processing), in contrast to traditional approaches. The number and parameters of sensors, features, or classifiers used can be dynamically adjusted according to the performance goal.

Adaptation: Finally, a key element of the opportunistic approach is dynamic adaptation and autonomous evolution on the basis of self-supervision and system/user feedback. Self-supervision and feedback, with corresponding adaptation strategies, enable to control the parameters of the opportunistic context recognition chain to adapt it to the sensor configuration at hand. This enables rapid dynamic adaptation to spontaneous changes in sensor configurations as well as long term autonomous evolution to gradual changes in sensing environments and users.

METHODS

The new paradigm introduced by OPPORTUNITY consists of these steps:

- **Recognition Goal**. Rather than just initiate the recognition with fixed properties, in the OPPORTUNITY approach the application will put forward a complex, flexible recognition goal. In addition to a specification of a set of contexts/activities that are relevant in a particular situation, parameters such as accuracy requirements, priority, known situation specific priors, and possible simplifications of the recognition task will be included. This leads to the first scientific challenge that the project will tackle:
    a. **Abstract goal formulation and interpretation**. We need to understand what for recognition goals can be formulated, and which are the relevant parameters that are useful for typical context recognition applications. The work can build on previous experience of partners (ETHZ, UP) on modelling performance tradeoffs in context recognition systems [Stäger07,Bharatula08,Anliker05] and a long history of developing context sensitive applications [Junker08, Stiefmeier08, Fers05].
- **Ad-Hoc, cooperative sensing**. In place of a static sensor setup the OPPORTUNITY approach will work with unknown and dynamically changing sensor configurations. From the recognition goal the system will formulate a Sensing Mission that is communicated to the sensors available in the environment. The sensors will collaborate to satisfy the mission as well as possible with the available configuration. This raises the following scientific challenges that will be tackled in the project:
    b. **Sensor self-description and self-configuration.** We need to investigate and develop means by which smart sensors can self-describe themselves and advertise their characteristics, so that a mobile system can self-configure to recognize specific human activity patterns and contexts. We will build on existing standards such as sensor ML and investigate what type of information needs to be stored and communicated in order to facilitate ad-hoc cooperative sensing for the recognition of complex activities. The work will build on previous experience in JKU with sensor self description frameworks [Fers07b, Fers08]. We will also include dynamic variations (e.g. changes in on body placement) in the sensor description. Thus for example in previous work UP has been able to show that acceleration sensors can automatically recognize their on-body placement [Kunze05,Kunze07b].
    c. **Spontaneous cooperative sensing systems.** We need to investigate means by which dynamic, goal-oriented sensor ensembles can arise on the basis of new algorithms for autonomous sensor and service discovery, and control mechanisms to achieve intelligent configuration. We will incorporate all the physical and virtual sensors, either body worn or near body [Fers07a], or embedded in the infrastructure and environment [Fers08]. This integration will be organized within a component based object oriented context framework architecture [fers05][Fers06].
- **Dynamic Recognition Template Instantiation**. Since the information obtained as the result of the Ad-hoc Cooperative Sensing Mission can significantly vary from situation to situation, static “one time” design of a recognition system, which is state of the art today, is not adequate. Instead, during system design we will provide a flexible, broad template of the feature computation and classification system. It will then be dynamically instantiated based on a Recognition Goal and the results of the Ad-Hoc

Cooperative Sensing mission. We will pursue the following lines of study towards such dynamically adaptive recognition system:

d. **Compensation of Sensor Variations**. We need to investigate methods for minimizing and compensating sensor variability such as sensor placement, orientation, and parameters (e.g. sample rate, resolution). Thus during the template definition we will focus on features, and signal processing algorithms that display the least variability in typical environments. In an initial study UP has for example shown that appropriate combination of accelerometer and gyroscope features can lead to invariance of the signal with respect to shits of a sensor within a body part [Kunze08]. ETHZ has done preliminary activity recognition characterization when sensor are affected by noise and orientation variations, and showed that by recruiting and fusing additional sensors implicit robustness against such faults is obtained [Zappi07]. The question is how such simple initial results can be extended to a broad range of sensors and situations.
e. **Abstract Features**. Especially for situations where not just the sensor parameters but the sensor type will vary we need to investigate the use of feature sets that abstract from specific sensors. As a trivial example consider body part motion which is among the most important sources of information for activity recognition. There is a wide range of sensors that can be used for tracking such motion (accelerometers, gyroscopes, magnetic trackers, optical trackers etc.). While each of these sensors provides different information all of them can be mapped onto spatial trajectories of varying precision and accuracy. Another example of an important abstract feature is user presence at a certain location, which can also be derived from a wide range of sensors [Hightower01,Roggen07a].
f. **Adaptive Machine Learning Methods**. Where variability can not be masked and abstract features are not available parameterized classifiers are needed that support adaptive recognition on the basis of sensor self-description. An example of such a classifier would be a support vector machine based system where the kernel is adapted according to the current situations. For example [Huynh06] combine generative models (multiple eigenspaces) with SVMs in order to improve the recognition accuracy while reducing the amount of supervision required. Moreover, approaches based on feature space segmentation (e.g. Hierarchical HMMS [Olivera04, Zhang06])—typically used to represent different activity classes or levels of interaction—can be extended to cover different situations depending on the current input characteristics. Furthermore, on-line learning approaches can be used to provide runtime adaption to changes in the feature stream [Cohen04].
g. **Adaptive Information and Classifier Fusion**. A promising way to deal with varying sensor configuration is to perform independent classification on each possible sensor and use incremental, modular classifier fusion methods to fuse the information. A trivial example of such methods is a weighted ranking of class probabilities produced by different classifiers. When a sensor drops out, the ranking is build from less values, when one is added more values are used. ETHZ has done some preliminary work in that direction [Zappi08].

- **Unsupervised dynamic adaptation**. Once instanciated, the system should adapt the activity recognition chain to the current sensor configurations to guarantee a desired performance level. Adaptation should occur at the most appropriate levels in the activity recognition chain. We will pursue the following lines of research to achieve this goal:

h. We develop **system performance models** that relate recognition chain parameters and sensors to performance metrics. Since such models are application specific, we develop generic methodologies that can be applied on a wide range of problems. Partners ETHZ and UP have done preliminary work in system performance models for single sensors [Stäger07, Bharatula08,Anliker05] and multiple sensors [Zappi08].
i. We develop **search heuristics to reach a desired performance goal** by adjusting the recognition chain parameters according to these models.

- **Long term autonomous evolution**. In many applications the context recognition systems are likely to be used over long periods of time once programmed and trained, e.g. when such systems are Ambient Intelligence (AmI) environments with significant deployment costs, or when a user has spent considerable time training the system. Keeping the initial system performance despite faults and degradation is a requirement. However, in a broader view, rather than trying to conservatively perform as well as when deployed, such systems should be able to autonomously evolve and adapt to exploit additional resources that happen to be available. Such resources may be e.g. new sensors deployed in the environment, new garments with integrated sensors, or additional background information. In other words, we wish for a context recognition system to be able to take advantage of these additional resources when available, and these resources in turn should be able to recruit additional ones. This enables operation in **dynamic and open-ended environments**. We will pursue this goal under the assumption that a shared subset of sensors (existing and newly recruited) will co-exist while a number of user activities are performed or contexts detected. Furthermore, **gradual variations in the environmental sensing infrastructure** are natural (e.g. sensors gradually degrading over time). The system should be able to track these changes (e.g. progressive sensor degradation) to autonomously adapt accordingly. This is another aspect of adaptation that we pursue under the assumption that the time scale of these changes is lower than the time scale of occurence of contexts and activities. We will pursue the following lines of study towards long term autonomous evolution:

j. **Unsupervised online adaptation.** We investigate means by which a mobile context-aware system will be able to **learn** and **adapt its operating parameters** to incorporate additional sensing modalities not capable of self-description (or with insufficient self-description), as they are discovered. The core approach is self-supervised learning (system feedback is used to supervise learning) and semi-supervised learning (with minimal "smart" interactive user input).
k. We need to investigate which **recurring correlations** between **sensor signal and activity/context** can be learned **without supervision**, and with **which costs and tradeoffs**.
l. We need to investigate **self-monitoring approaches** that provide an endogenous indication of gradual variations in the sensing infrastructure with a confidence value, and to track system runtime performance. To this end we will use: the **tracking of rough cluser of activities in the feature space**, analysis of **recurring sensor/class correlations**, detection of **error-related EEG correlates** (signal patterns occuring when a system deviates from expected behavior) as a way to automatically obtain an **endogenous measure of performance**. In addition we will use principles of minimal **interactive user feedback** (maximization of information gain while minimizing user disturbance) to occasionally obtain a ground truth measure.
m. We need to develop novel **performance metrics** to evaluate autonomous evolution performance. We consider the system from a dynamical non-linear systems perspective. Performance metrics will include aspects such as robustness, stability, adaptation speed, attractors, evolution of activity class signal templates, in addition to traditional machine learning metrics such as precision/recall or ROC curves. We will investigate which metrics are suited to describe characteristic behaviors of OPPORTUNITY, and develop new metrics as appropriate.

B.1.3.1.4 Validation and Generalization Strategy

Based on the above concepts the top level objective of OPPORTUNITY is to develop generic principles, algorithms and system architectures that allow to reliably recognize complex activities in dynamic opportunistic environments. A key aspect of the project is a systematic, empirical validation of the success towards this aim.

OPPORTUNITY bases its strategy towards validation and generalization on the problem space breakdown described in section B.1.3.1.2. Clearly we can make a convincing argument about generalization of the OPPORTUNITY approach if we can show that:

1. We are able to address all (or most) types of variability and all (or most) temporal variability patterns described in section B.1.3.1.2.

2. The OPPORTUNITY approach is applicable to and performs well on a sufficiently large set of the basic activity components.
3. The OPPORTUNITY approach still holds and performs well when we start combining the basic components into more complex activities
4. The above holds not only for trivial combinations but examples can be provides where the OPPORTUNITY approach works for complex recognition tasks motivated by real life applications.
5. The OPPORTUNITY approach, or a subset of it, still performs well when applied to a radically different problem space sharing some of the challenges of activity recognition (we will make this point on the basis of EEG-based BCI).

In the project we will provide proof of the above points. The following table summarizes how the different components of the OPPORTUNITY architecture (Project Tasks) above address the individual types of variability sketched in section B.1.3.1.2. In the next section we will describe the cases studies that will prove the success of the OPPORTUNITY method on the individual activity components.

	random, isolated events	**re-occuring change**	**gradual evolution**	**continuous, fast random change**
signal degradation	T1.1,T1.2,T1.4, T2.3, T3.2, T3.4, T4.1, T4.2	T1.1,T1.2, T1.4 T2.3, T3.2, T3.4 T4.2	T1.1, T1.2, T1.4, T3.3, T3.4, T4.2	T1.1,T1.2, T1.4, T3.2, T3.4, T4.2
isolated failures	T1.1, T1.4, T2.3, T3.2, T3.4, T4.3	*not relevant /not considered*	*not relevant /not considered*	*not relevant /not considered*
partial reconfiguration	T1.4, T2.3, T3.2, T3.4, T4.1,	T1.4, T2.3, T3.3, T3.4	T3.3, T3.4	T2.3, T3.2, T3.4, T4.3
system change	T1.3, T1.4, T3.4, T4.1	T1.4, T3.3, T3.4, T4.3	*not relevant /not considered*	T2.3, T3.2, T3.4, T4.3
high level cooperation	T2.3, T4.4	T2.3, T4.4	*not relevant /not considered*	T2.3, T4.4

THE OPPORTUNITY CASE STUDIES

The main aim of the case studies is to demonstrate the performance and generalization of the Opportunity approach. In addition the case studies will guide the project methods development and provide demonstrators that will be crucial to dissemination and facilitating exploitation.

As described in the previous paragraph, in order to prove generalization and avoid a complexity explosion the case study design is guided by the hierarchical decomposition of the activity recognition problem. They cover the following domains:

	random, isolated events	**re-occuring change**	**gradual evolution**	**continuous, fast random change**
signal degradation	Stage 1	Stage 1+2	Stage 1+2	Stage 3, BCI study
isolated failures	Stage 1	*not relevant /not*	*not relevant /not*	*not relevant /not*

		considered	*considered*	*considered*
partial reconfiguration	Stage 1+2	Stage 2+3	Stage 2+3	Stage 3
system change	Stage 1+2	Stage 2+3	*not relevant /not considered*	Stage 3
high level cooperation	Stage 3, BCI study	Stage 3, BCI study	*not relevant /not considered*	Stage 3, BCI study

Stage 1 Case Studies

Stage 1 case studies will be relatively straight forward examples of the basic 'components' of activity recognition. They are small scale, quickly assembled experiments that can be often repeated. They will give us insight into basic problems and provide quick feedback on the performance of the opportunity methods. Due to simplicity the emphasis will be on sensing and classifiers with less complex requirement in the area of service discovery and cooperation. We plan to concentrate on the following three areas (although we reserve the option to modify the case studies as research work progresses and needs for adequate verification of certain methods): (1) presence and location, (2) modes of locomotion and posture, and (3) hand gestures (see WP 5 form for exact description and rationale).

Stage 2 Case Studies

Stage 2 case studies will combine several basic components into more complex activities. The scenarios involve more time and effort to assemble and will thus be conducted less often and we will use them to verify our concepts once they are more mature. They will provide feedback on the performance of the OPPORTUNITY methods under complex conditions. In particular, due to large numbers of involved sensor and more variability service discovery, cooperation and dynamic adaptation will play a greater role then in stage. The stage two work will focus on the following two scenarios:

Stage 3 Case Studies

Stage 3 case studies built upon complex combination of basic components and demonstrate scenarios clearly motivated by and connected to real life application areas. Their main aim is to evaluate the result of the project under conditions that are as close as possible to real life application. Thus, in a way, they will be a 'end demonstrator' of the projects results. Besides complex validation they will also be crucial to exploitation by showing to interested parties the potential of the OPPORTUNITY approach.

Based on relevance, diversity and partners experience we envision the following two areas from which we will pick characteristic activities to test the OPPORTUNITY system: indoor activity recognition, and health and lifestyle management activity recognition.

The BCI Case study: Beyond Activity recognition

In addition, a number of methods that we develop in OPPORTUNITY are **generalizeable to other context recognition systems** than activity recognition. We demonstrate this by showing how specific cognitive states (e.g. attention, expectation) can be detected on the basis of EEG signals, using the approaches developed within OPPORTUNITY, towards **opportunistic Brain-Computer Interfaces (BCI)**. This addresses a challenge of reliability and robustness faced by current BCI.

In a typical non-invasive BCI setup, brain activity is acquired through a rather large number of sensors – typically 32 or 64 electrodes- located on the user scalp (electroencephalograph, EEG). These signals go through a preprocesing stage that usually consists of temporal and spatial filtering. Then, relevant features are extracted in either the time or frequency domain and feed into a classifier in order to recognize the user's mental state. Development of these systems imposes a particular challenge since EEG signals are characterized by a very low signal-to-noise ratio (SNR), are variant in time and may be affected by contextual situations (e.g. user's fatigue, lack of attention, etc). In addition, the electrical signal captured by the electrodes can be contaminated by noise generated by muscular activity [Goncharova03,Whitham07] or loose contact between the sensor and the skin.

The key points we will demonstrate are the suitability of the machine learning and sensor fusion algorithms, of dynamic adaptation, of the principles of system modelling, and of cooperating sensor ensembles. Sensor self-description and runtime signal monitoring can be used to detect failures or signal contamination (e.g. loose contact changes the electrode impedance, EMG contamination is reflected in spectral changes in the EEG signal). Upon detection of these changes, opportunistic BCI systems will adapt either by applying on-line de-noising mechanisms or by removing that channel from the classification process (and possibly adding new channels) to achieve graceful performance-degradation.

The concrete BCI study is outlined in detail in the WP 5 form, task T5.4, and rationale and background information provided in section A.1.

CHOICE OF SENSORS

A wide range of sensors can be used to recognize activities and context. We will focus on a subset of those sensors most common in activity recognition systems, according to the need of the cases studies outlined above. This includes the following modalities:

- Accelerometers, gyroscopes, magnetometers and inertial sensors (on-body and in instrumented objects) for activity recognition from motion sensing
- Beacon systems (Bluetooth, active RFID), UWB systems and GPS for localization, presence detection, and to support activity recognition (narrow the set of activities based on location) and ambient intelligence
- Instrumented appliances, sockets, switches, and presence detection for ambient intelligence
- Microphones (on-body and ambient) for activity recognition, social engagement detection, and localization
- EEG for the BCI case study and for the detection of error-related EEG correlate to support self-supervised learning and endogenous performance measures.

We will start working with the following sensors in stage 1 case studies: motion sensors (accelerometers, gyroscope, magnetometers) and location sensors (beacons, UWB and GPS). We will then extend the set of sensors in stage 2 and 3 for context and activity recognition (exact sensor set defined during execution according to exact outcome of stage 1 case studies). We will include EEG sensors in stage 2 to support self-supervised learning (using error-related EEG correlates - signals that are generated when the user perceives an erroneous action or feedback) and in stage 3 to validate the opportunistic BCI case study.

INCREMENTAL APPROACH AND RISK MANAGEMENT

Specific aspects of scientific risk management are detailed in section B.2.1.2.

The decomposition of the activity recognition problem and the structuring of the case studies according to this decomposition provides the basis for an **incremental 3 stage** approach to **the development and the evaluation** of OPPORTUNITY methods. The project stages correspond to the case study stages described in the previous paragraph. In each stage the current case studies will first "feed" the methods development with problems and provide an understanding of the key issues. They then provide an evaluation of the performance of those methods.

The incremental approach is an effective risk management strategy. The individual stages are on a direct path towards the ultimate goal of opportunistic recognition of complex real life scenario. At the same time they will on their own lead to interesting and relevant scientific results. Thus we can pursue our highly ambitious and high risk goals wile avoiding the perils of an “all or nothing” strategy.

B.1.3.1.6 Justification of project methodology and implementation rationale

Within OPPORTUNITY we tackle context/activity recognition in opportunistic sensor configurations at multiple levels: opportunistic goal oriented sensing, signal, features, classifiers, classifier fusion, dynamic adaptation and autonomous evolution. The rationale is discussed below.

Opportunistic goal-oriented sensing: Obtaining measures (signals) about physical phenomena (e.g. user activity) or from virtual sensors is the first requirement of a context/activity recognition system. In an opportunistic system, sensors that just happen to be available must self-organize efficiently in a way to provide information about the physical environment to the user's mobile device in charge of context and activity recognition. Some context-recognition research project focus exclusively on these networking aspects, considering that providing data about the physical world is already providing contextual information *per se* (which may be the case when very simple sensors, such as RFID tags, are used). However, activity recognition poses specific problems of signal processing, time series segmentation and classification. In this project, opportunistic goal-oriented sensing is a way to acquire efficiently data about the physical world. These data need to be transformed into information in the context/activity recognition chain (i.e. classification of sensor data). This justifies the joint consideration of goal-oriented sensing and context/activity recognition mechanisms within OPPORTUNITY.

Joint optimization of recognition chain elements: Optimizing a single element of the activity recognition chain (e.g. only developing novel features, classifiers, or decision fusion algorithms) does not address all the requirements of opportunistic use of sensor configurations. The choice of sensors, features and classifiers are critical in determining the overall system performance (inadequate features may lead to bad performance even with the best classifiers). Consequently the opportunistic recognition chain must be considered as a whole.

Dynamic adaptation and autonomous evolution. The optimization of the recognition chain only addresses part of the problem. Variability over time (e.g. sensor signal degradation, sensor withdrawal, sensor addition) can only be partly addressed by an improved activity recognition chain without additional adaptivity mechanisms.

The need for a system to cope with sensor withdrawal, while keeping a desired level of performance, points to the need for dynamic resource selection mechanisms. This is implemented in the project, among others, through opportunistic sensor fusion combined with models of system performance.

The need for a system to cope with signal degradation (e.g. slow change in sensor orientation/placement) requires methods to adapt activity signal templates online. The system must be able to detect when and how to adapt the signal templates it has been trained to recognize. This must take into account whether the signals that are observed are affected by long-term sensor degradation or evolution in user action-limb trajectory mapping, or whether they normally result from typical activities (with their intrinsic variability).

Furthermore an opportunistic system must capitalize on additional resources. This is best tackled by having general view of an activity recognition system an autonomously evolving system. Indeed, taking advantage of additional resources can be seen as an online autonomous (or minimally supervised) learning challenge. The knowledge embedded in the system needs to be transferred to parts newly added to the system (additional sensors). There are several way to realize this knowledge transfer. We investigate the use of the system classification result as a label to train the classifiers of newly added sensors (self-supervised learning). This bears some similarities to transductive learning. Signal-level approaches are suitable too. Sensor signal correlations can be analyzed and a decision be made as to when and how (in which part of the recognition chain) a correlated sensor may be included in the system to replace or complement existing sensors.

Thus, in order to cope with signal degradation and allow for autonomous evolution, an opportunistic system should have: (i) a mean to assess and supervise its own behaviour and sensor/system correlations; (ii) a mean to provide feedback to building blocks making up the activity recognition chain. Altogether this points to the architecture underlying OPPORTUNITY.

OPPORTUNITY ARCHITECTURE

The architecture investigated within OPPORTUNITY embeds the context recognition chain, system supervision, dynamic adaptation and system feedback. It is a generic architecture. This means that it does not limit the choice of classification, supervision, feedback and adaptation mechanisms (even though in this project we obviously focus on a specific subset of methods).

The supervisor assesses the suitability of the system at activity recognition given the instantaneous sensor configuration. It provides an indication of confidence in the classification of an activity, knowing that over time sensor signal changes may occur (long-term sensor degradation or evolution in user action-limb trajectory mapping). This confidence measure is used as a feedback to trigger system self-adaptation. Dynamic adaptation and autonomous evolution is embodied in the feedback component of the OPPORTUNITY architecture.

The architecture of OPPORTUNITY can be considered as a self-supervised learning system, where system feedback and occasional user feedback are used to supervise the system adaptation. Such approaches are not common in traditional machine learning (where "self-supervised learning" is understood as a variation of semi-supervised learning, such as in Discriminant-EM algorithms). However self-supervised learning is biologically inspired and strongly related to processes of cognitive development [Weng01].

OPPORTUNITY AND BIO-INSPIRATION

Dynamic adaptation, self-organization, fault-tolerance are some of the characteristics of opportunistic systems. Such characteristics are usually evoked as a motivation to adopt bio-inspired computing approaches such as evolutionary computation, neural networks, swarm intelligence or artificial immune systems. Moreover, opportunistic devices are situated in a dynamic environment, and their adaptation results from interactions with such environment—and with the user (e.g. with EEG-based feedback [Chavarriaga07] or interactive feedback) —, which are the characteristics of embodied cognitive systems. In the general case, bio-inspired approaches rely on an iterative process where the desired behavior emerges after some time, although the convergence towards this appropriate behavior cannot be guaranteed. Moreover, the iterative solution search process may lead the system towards unpredictable behavior, violating standard usability principles. Such unpredictability in the interaction process may be detrimental to the system’s performance [Hook99,Jaimes07]. Although we will evaluate the suitability of some bio-inspired techniques for the development of opportunistic activity recognition system (c.f WP3 Task 3.1), we will not restrict the scope of our research to these types of methods. Indeed the architecture of OPPORTUNITY, that considers feature extraction and classifiers as elementary building blocks, can be seen as a higher level of abstraction compared to typical bio-inspired or bio-mimetic approaches. Yet it does not limit the scope of approaches that can be investigated to realize these building blocks. Nevertheless, the scalability to complex phenotypes are challenging issues frequently reported in evolutionary computation literature [Roggen07b], and supports our choice of organizing OPPORTUNITY around higher level architectural building blocks.

On another line of thought, we will take into account recent psychophysical and neurophysiological findings suggesting that multimodal sensory fusion and sensory-motor learning in humans and primates are performed in a Bayesian way [Battaglia03 ,Knill04, Körding04]. Following this hypothesis, the brain would represent information in the way of probability distributions, as a way to deal with uncertainty in the sensory channels. Such findings, added to the previous development of activity recognition systems using the

Bayesian framework [Moore99,Garg00,Zappi07], make this approach a promising alternative for the development of robust, opportunistic systems.

B.1.3.2 Timing of work packages and their components

B.1.3.2.1 Workpackage breakdown

Overall the project is organized in 5 technical workpackages (WP1-5) accompanied by a Management workpackage (WP6) and a Dissemination/Exploitation (WP7) workpackage.

The project is organized around 4 key functions: **efficient large scale sensing** (WP4); **opportunistic context/activity recognition chain** (WP1 and WP2); **dynamic adaptation and autonomous evolution** (WP3); and **validation scenarios** (WP5).

The section below describe the interplay between the workpackages. The coordinator of the WP is indicated in parenthesis.

LARGE SCALE OPPORTUNISTIC SENSING

Within WP4 (JKU) the algorithmic and technological building blocks are developed to acquire opportunistically data from sensors that happen to be in the environment of the user. Doing so on a large scale, opportunistically, require novel ways of conveying a sensing mission and collecting data. Activity/context recognition requires multiple acquisition modalities (e.g. data streaming, event detection) that must be supported by the opportunistic data collection framework.

The process of information acquisition via sensors is induced by mission goals and performed by the sensing entities. Sensing entities are configured into orchestrated ensembles according to the mission goals, the individual sensing capabilities of the entities, their availability, mobility and reliability. Goal-oriented sensing allows to efficiently fulfil a sensing mission or respect constraints (e.g. sensing may be limited to the neighbourhood of the user, or to a geographical area). Challenges that are addressed include devising coordination architecture and control algorithms for spontaneously accessed sensors capable of goal-oriented, cooperative sensing.

The outcome of this workpackage are means to efficiently, and opportunistically collect information from the user's surroundings, or from body-worn sensors, with the appropriate mechanisms to discover additional devices, report device removal, and support sensor self-description (described later).

OPPORTUNISTIC CONTEXT/ACTIVITY RECOGNITION CHAIN

WP1 (UP) and WP2 (EPFL) deal with the development of a context recognition chain optimized for opportunistic sensor configurations.

WP1 is devoted to sensor, signal processing and feature level methods for opportunistic activity recognition. Methods are developed to allow a dynamic sensor self-description that can be advertised in a network and used by an context/activity recognition system to self-configure accordingly. This WP investigates the properties that must be advertised to support self-configuration. It develop means to detect dynamical properties automatically. Such dynamical properties include e.g. body-placement and orientation of sensors. This WP also develops means for sensors (or groups of) to provide features invariant to typical sensor parameter variability, in particular on-body motion sensor placement. Finally this WP investigates abstract sensor independent features, that allow the rest of the activity recognition chain to abstract from the precise physical signals that are sensed, effectively allowing to transparently combine heterogeneous sensors measuring the same activity/context in different domains.

The outcome of this WP is a sensor self-characterization and self-description mechanism, variation tolerant signal conditioning methods, and a set of intermediate, abstract features that are used as input to WP2.

WP2 is devoted to the development of classification techniques suitable for opportunistic activity recognition systems: modular classifiers and opportunistic decision fusion algorithms. Modular classifiers will be in charge of segmenting the input features stream and its posterior classification into activity classes. These classifiers can incorporate variations in the feature space (e.g., as a result of changes in the sensor placement or sensor failures). They offer graceful performance degradation in the case of unreliable or missing inputs; support online learning mechanisms in order to cope with gradual and sudden changes in the sensor network; and provide a measure of reliability of their decisions. They will be devised taking into account the computational/memory constraints of wearable systems. Decisions from multiple classifiers will be combined in a second classification stage. This classifier fusion will be able to deal with changes in the number, type or reliability of classifiers available for activity recognition. This enables the combination of heterogeneous input channels taking into account their reliability.

Classifiers and classifier fusion algorithms will receive features from WP1 and a feedback signal controlling dynamic adaptation from WP3.

DYNAMIC ADAPTATION AND AUTONOMOUS EVOLUTION

In WP3 (ETHZ) methods are developed for dynamic adaptation and autonomous evolution of the OPPORTUNITY activity recognition system to new sensor setups. This WP address the following type of dynamic adaptation: adaptation to changing resources (addition/removal of sensors); and adaptation to sensor signal degradation (due to changes in sensor characteristics or on-body sensor orientation / placement). With respect to signal degradation due to variation in on-body sensor placement/orientation, the methods developed in this WP complement those of WP1. WP1 attempts to detect explicitly on-body placement and to compensate for it. WP3 assumes slows, progressive, changes in sensor characteristics (incl. placement and orientation) and applies different techniques towards the same adaptivity goal.

This WP considers two dynamic adaptation principles. The first one is to maintain a desired multiparametric performance goal (e.g. accuracy, ROC curve, number of sensors used) despite changes in sensor availability or confidence, in order to achieve fault-tolerance by self-repair. This is done by dynamic resource selection on the basis of performance models linking sensor configurations to system performance. These performance models are developed in this WP. Since they tend to be application or sensor dependent, generic methodologies will be developed that can be instanciated on different problem domains.

The second dynamic adaptation principle supports long-term autonomous evolution of the context/activity recognition system. It enables the system to take advantage of additional sensing resources and to cope with sensor signal degradation. It is based on two ideas. First, the existing knowledge of a trained activity recognition system should be transferred to the classifiers corresponding to newly added sensor nodes. Second, when sensor signal degrade, the signal template characteristic of an activity changes. This is detected and the classifiers are re-trained on the new signal templates.

This second dynamic adaptation principle is implemented by a supervisor module that infers autonomously a measure of the system performance from correlations among sensors, tracking of the rough clusters of activity classes in the feature space, error-related EEG correlates, and limited "optimal" interactive user feedback. This supervisor controls the re-training of the opportunistic classifiers. The labels (ground truth) for the retraining are provided by the system itself (self-supervised training) and/or through minimal user intervention.

The input of the methods developed in this WP are: low level signals/features (WP1); activity classes and confidence values (WP2); availability of sensors (WP4). The method developed in WP3 result in feedback to provided to classifier and decision fusion algorithms (e.g. classifier retraining, runtime selection of sensors), and to the opportunistic sensing layer (WP4) to recruit or select appropriate sensors.

VALIDATION SCENARIOS

WP5 deals with case studies to assess and characterize the methods developed in this project. These case studies pursue 4 objectives: guiding the methodology and algorithms oriented research of WP 1 to 4; quantitatively validating the results of the research conducted by WP 1 to 4; assessing and facilitating the generalization of the methods developed by OPPORTUNITY; and up to some extent facilitating the exploitation of the project results.

These scenarios follow 3 stages in a "divide and conquer" approach to handling the complexity of the activity recognition problem domain. In a first stage simple activities are considered (e.g. manipulative gestures).

In a second step composite activities are considered (e.g. manipulative activities occurring simultaneously as other whole body physical activities).

Finally complex activities are considered, taken from real-world scenario (indoor activity recognition, health and wellness oriented activity monitoring). In this stage the approaches are also applied to a complex cognitive context recognition task (EEG-based BCI) in order to assess the generality of the methods developed within the project. Opportunistic BCI systems will be tested on experimental protocols ranging from the detection of evoked and event-related potentials linked to the user cognitive state, to the recognition of user modulated brain rhythms. These protocols were chosen taking into account the previous development of BCI systems for these signals by several groups (including EPFL). These studies give us baseline performance measures to compare the benefits of applying the OPPORTUNITY principles. In addition, these protocols provide labelled feedback data that allow us to reliably measure the system performance and its adaptation capabilities.

MANAGEMENT, DISSEMINATION/EXPLOITATION

WP 6 under the lead of the coordinator will manage the project throughout it's execution and WP7 (contributed to by all the partners) executes dissemination and exploitation plans throughout the project. The management and dissemination/exploitation strategies are outlined in detail in sections 2.1 and 3.3 respectively.

B.1.3.2.2 Workpackage timing

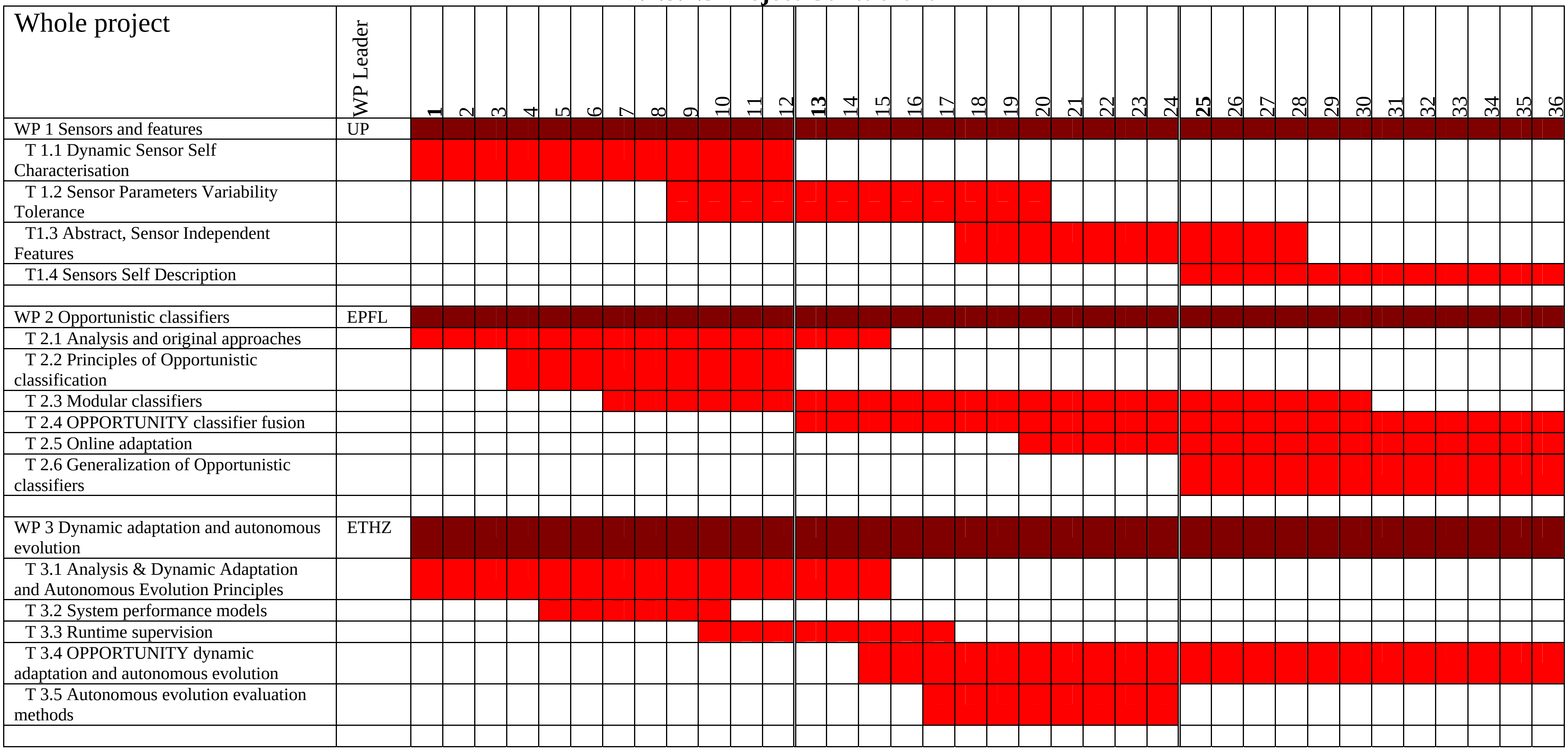
Timewise, the workpackages (see Gantt and Pert charts) are set up as follows:

- Scientific investigation in WP1-4 continues uninterrupted from project start to project end. Work is differentiated by tasks, with simpler tasks (lower risk) executed first, and more complex tasks (higher risk) building upon previous results. In other words, the methods developed in WP1-4 will at first address simpler problems of opportunistic activity recognition. As the project advances, the complexity of the methods developed will be increased to match more complex problems. The methods developed in WP1-4 will be validated in the case studies presented by WP5 below.
- Validation in case studies (WP5) follows the 3 stage approach outlined earlier and runs in parallel to WP1-4. The objective is for the methods developed in WP1-4 to be applied to the case studies in WP5. A single workpackage deals with each validation stage in a specific task. Therefore when the stage 1 case studies runs, the methods developed in WP1-4 will be applied to this case study. Consequently, as time passes, methods developed in WP1-4 will be applied to increasingly more complex problems, and they will need to be combined and jointly applied.
- Management and dissemination and exploitation run throughout the project. Key milesones of the expoitation are technology transfer workshops that will be organized to explain the OPPORTUNITY concepts and potential to relevant players.

It is important to note that method development (WP1-4) and validation (WP5) runs in parallel (and not sequentially, where a first method would be developed then validated). This is required given the continuous need to validate the algorithms that are developed from project start. A parallel structure is thus more appropriate. We envision WP5 as setting up a framework for validation (which activities must be considered at which stage), and the methods developed in WP1-4 are applied against this framework.

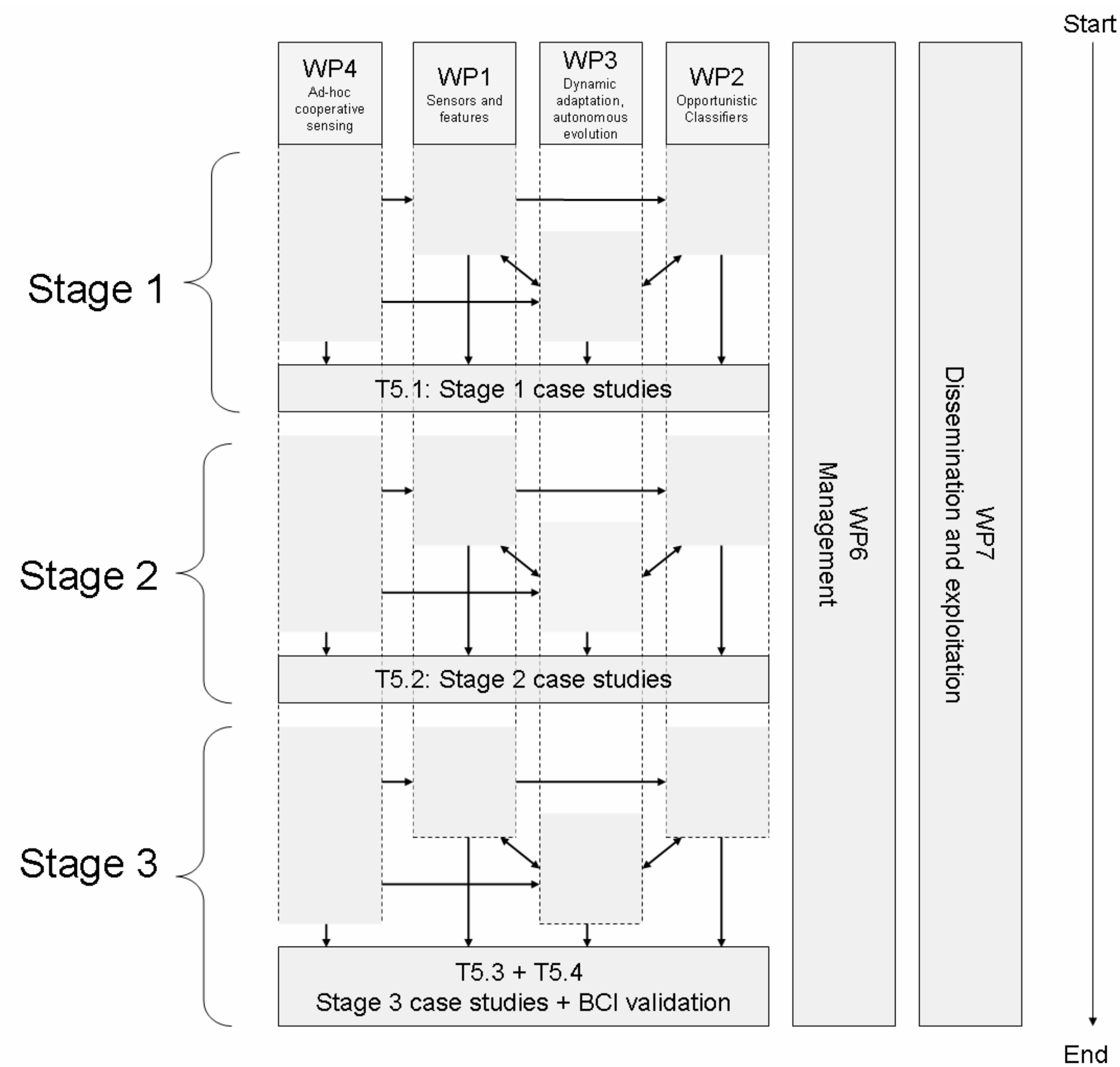
Nevertheless, to ensure progress and convergence of methods developed in WP1-4, three validation milestones (stage 1, stage 2 and stage 3) are set at months M18, M30 and M36. They serve as a way to synchronize all the workpackages. By the milestone due date, all the methods of WP1-4 should be jointly applied to the corresponding case study. Based on the result assessment, the project will continue as planned or solutions will be investigated to cope with issues that may arise.

B.1.3.2.3 Project Gantt chart



Whole project	WP Leader	**1**	2	3	4	5	6	7	8	9	10	11	12	**13**	14	15	16	17	18	19	20	21	22	23	24	**25**	26	27	28	29	30	31	32	33	34	35	36
WP 4 Ad-hoc cooperative sensing	JKU																																				
T 4.1 Analysis and original approaches																																					
T 4.2 Spontaneous Cooperative Sensing Model																																					
T 4.3 Sensors with Self-* Capabilities																																					
T 4.4 Goal-Oriented Sensing Ensembles																																					
T 4.5 Ensemble Coordination Architecture																																					
WP 5 Case studies	UP																																				
T 5.1 Stage 1 case studies																																					
T 5.2 Stage 2 case studies																																					
T 5.3 Stage 3 case studies																																					
T 5.4 Opportunistic BCI validation																																					
WP 6 Project management	ETHZ																																				
WP 7 Dissemination and exploitation	ETHZ																																				

B.1.3.2.4 Project Pert diagram



B.1.3.3 Work package list /overview

Work package list

Work package No[1]	Work package title	Type of activity[2]	Lead beneficiary No[3]	Person-months[4]	Start month[5]	End month[6]
1	Sensor and features	RTD	2	40	1	36
2	Opportunistic classifiers	RTD	4	45	1	36
3	Dynamic adaptation and autonomous evolution	RTD	1	46	1	36
4	Ad-hoc cooperative sensing	RTD	3	33	1	36
5	Case studies	RTD	2	33	1	36
6	Project management	MGT	1	6.5	1	36
7	Dissemination and exploitation	RTD	1	9	1	36
	TOTAL			212.5		

1 Workpackage number: WP 1 – WP n.
2 Insert one of the following 'types of activities' per WP (only if applicable for the chosen funding scheme – must correspond to the GPF Forms):
RTD = Research and technological development including scientific coordination applicable for collaborative projects and NoEs
DEM = Demonstration - applicable for collaborative projects
OTHER = Other activities (including management) applicable for collaborative projects, NoEs, and CSA
MGT = Management of the consortium - applicable for all funding schemes
COORD = Coordination activities – applicable only for CAs
SUPP = Support activities – applicable only for SAs
3 Number of the beneficiary leading the work in this work package.
4 The total number of person-months allocated to each work package.
5 Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.
6 Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

B.1.3.4 Deliverables list

List of Deliverables – to be submitted for review to EC[7]

Del. no. [8]	**Deliverable name**	**WP no.**	**Lead bene-ficiary**	***Estimated indicative person-months***	**Nature**[9]	**Dissemi-nation level** [10]	**Delivery date**[11] **(proj. month)**
D1	First generation opportunistic context recognition chain	1,2,3	UP	39	R	PU	12
D2	Second generation opportunistic contextrecognition chain	1,2,3	ETHZ	45	R	PU	24
D3	Third generation opportunistic context recognition chain incl. opportunistic BCI	1,2,3	EPFL	47	R	PU	36
D4.1	Self-description mark-up language, self-aggregation and self-composition algorithms	4	JKU	12	R	PU	12
D4.2	Goal description language and coordination architecture for decentralized self-management,	4	JKU	10	R	PU	24
D4.3	Validation of OPPORTUNITY Framework	4	JKU	11	R	PU	36
D5.1	Stage 1 case study report and stage 2 specification	5	UP	10	R	PU	12
D5.2	Stage 2 case study report and stage 3 specification	5	UP	11	R	PU	24
D5.3	Stage 3 (incl. opportunistic BCI) case study report	5	UP	12	R	PU	36
D6.1	Annual Report 1st Year	6	ETHZ	2	R	CO	12
D6.2	Annual Report 2nd Year	6	ETHZ	2	R	CO	24

7 In a project which uses 'Classified information[7]' as background or which produces this as foreground the template for the deliverables list in Annex 7 has to be used

8 Deliverable numbers in order of delivery dates: D1 – Dn

9 Please indicate the nature of the deliverable using one of the following codes:
R = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

10 Please indicate the dissemination level using one of the following codes:
PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

11 Month in which the deliverables will be available. Month 1 marking the start date of the project, and all delivery dates being relative to this start date.

D6.3	Annual Report 3rd Year	6	ETHZ	2.5	R	CO	36
D7.1	Project Presentation, poster, leaflet & Web Site	7	ETHZ	2	R	PU	6
D7.2	Mid-term Exploitation and Dissemination Report and Plan	7	ETHZ	4	R	CO	18
D7.3	Final plan for the use and dissemination of Foreground, and report on awareness and wider societal implications	7	ETHZ	3	R	CO	36
			TOTAL	212.5			

B.1.3.5 Work package descriptions

Work package number	1		**Start date or starting event:**			Month 1				
Work package title	Sensors and features									
Lead beneficiary	2									
Activity Type[12]	RTD									
Participant id	1	2	3	4						
Person-months per beneficiary:	7	**18**	6	9						

Objectives

This work package is devoted to sensor, signal processing and feature level methods for opportunistic activity recognition.

Description of work

T1.1 Dynamic Sensor Self Characterisation

Variations in sensor parameters can be divided into static and dynamic ones. Static variations refer to the fact that sensors with parameters different by design can be used to acquire the same physical quantity. Thus, for example, microphones can differ in frequency range, sampling rate, amplification dynamic range, and signal to noise ratio. Such static parameters are known a priori and need merely to be coded into the sensor self description to enable an Opportunistic system to take them into account.

This task is primarily devoted to automatic characterization of dynamic variations. Dynamic variations are caused by the way sensors are deployed and by environmental factors. Thus, for example, a mobile appliance with an accelerometer (e.g. mobile phone or an MP3 player) can be placed in a trousers pocket, in a chest pocket, on a belt or on the upper arm. Each location will lead to a different signal for the same type of activity. A microphone can be obstructed when e.g. covered by clothes or in a pocket. A WLAN location system can be influenced by a large number of people moving in the area. Automatic discovery and self characterization of such dynamic variations is crucial for opportunistic recognition systems. In previous work we have had some initial success in this area. Thus in [Kunze05,Kunze07b] we have shown how an acceleration sensor can automatically detect on which body part it is worn. In [Amft05] we have shown how a mobile phone equipped with a vibration motor, a speaker, a microphone and an acceleration sensor can detect if it is in a pocket, in the hand or which type of surface it has been placed on. These are isolated examples that indicate the feasibility of self characterization and point to possible approaches. These are:

1. Spotting of sudden events followed by a signal being consistently different (e.g. scaled) on a

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[12] For all FP7 Projects each workpackage must relate to one (and only one) of the following possible Activity Types

RTD = Research and technological development including scientific coordination applicable for collaborative projects and NoEs
DEM = Demonstration - applicable for collaborative projects
OTHER = Other activities (including management) applicable for collaborative projects, NoEs, and CSA
MGT = Management of the consortium - applicable for all funding schemes
COORD = Coordination activities – applicable only for CAs
SUPP = Support activities – applicable only for SAs

certain axis while the overall statistics remains the same

2. Study of statistical signal properites in known situations. This can either be very obvious situations that can be detected in a variantion independent way or situations about which the sensor gets information in a feedback loop from the recognition system. In [Kunze05] we used location idepdendent spotting of walking to detect sensor placement.

In the project self description methods will be developed and tested for a broad range of sensors and sensor combinations relevant for activity recognition.

T 1.2. Sensor Parameters Variability Tolerance

Beyond mere characterization of sensor parameter variations we intend to investigate measures to reduce their impact on the recognition chain. Thus, sensor nodes shall provides features which are less sensitive to variations typical for the particular sensor type than the raw signals. This is particularly interesting for compound features based on co-located sensor groups where different variations impact different sensors in a different way.

The idea is best illustrated on a specific example from recent work of UP [Kunze08]. The aim of the work was to reduce the sensitivity of motion sensor based (accelerometers and gyroscope) activity recognition to sensor displacement. Today, most systems dealing with complex activities (this does not include such trivial tasks as detection of walking or running) are trained with a sensor placed at a narrowly defined location and any deviation from this location leads to a dramatic drop of recognition performance. An example of such systems from is the tracking of complex arm activities during car manufacturing [Stiefmeier08].

The work in [Kunze08] assumes that a sensor is placed on a specific body part (upper arm, lower arm, leg, hip etc.) but allows the sensor to be freely moved within this body part. The body part can be known either from the device type (a watch will not be worn on the leg, a sensor integrated in a sleeve of a garnment will always be on the lower/upper arm.) or using methods previously developed to identify on which body part a device is placed from an acceleration signal [Kunze05]. Past work has also shown how rest periods (identified by low variance of the acceleration signal norm) can be used to identify the orientation of three axis accelerometer with respect to a body part. What then remains to be dealt with is the linear displacement within a body part. Thus a sensor on a lower arm could be placed near the elbow or near the wrist. It could be on the inner or outer surface of the arm.

Our approach to dealing with such displacement is based on the following:

1. The signal of a body worn accelerometer is the sum of three components: acceleration due to rotation, acceleration due to translation and acceleration due to orientation with respect to gravity. Of the three only the first one: acceleration due to rotation is sensitive to sensor displacement within a single body part.
1. It is possible to identify, with high probability, accelerometer signal segments which are dominated by rotation and thus possibly 'contaminated' with displacement related noise.
2. Gyroscope signals are insensitive to displacement within a single body part but their signal contains only information on rotation and ignores translations and vertical orientation.

From the above it follows that combining a gyroscope with an accelerometer and having the accelerometer ignores all signal frames dominated by rotation can remove placement sensitivity while retaining most of the relevant information. In fact, sometimes just an accelerometer ignoring the rotation 'contaminated' frames can be enough for reasonable, placement invariant recognition.

In experimental evaluation on a set of gym exercises performed with a sensor on the lower arm our method raised the displaced recognition rate from 24% (a displaced accelerometer which had 96% recognition when not displaced) to 82 %.

The above is an isolated example that illustrates the principle. In the project we will extend the basic idea to other sensor combinations relevant for activity recognition and develop additional and more robust invariant features. This will provide the following stages of the recognition chain with the parameters needed for the instantiations and the adaptation of the classifiers.

T 1.3. Abstract, Sensor Independent Features

In general, opportunistic systems have to deal with sensor configurations that not only differ in their performance parameters, but sense different physical quantities altogether. This task is devoted at shielding the following stages of the recognition chain from such variations. It is based on the observation that in many cases different physical quantities are sensed to infer the same abstract information. Thus for example, accelerometers, gyroscopes, magnetic tracking systems, textile integrated elongation and bend sensors, and visual tracking of body parts all provide information related to trajectories of body parts. They do so using different physical signals and as a consequence produce different levels of detail, reliability and accuracy. Acceleration signals provide information about vertical orientation (and changes thereof) as well as information about trajectory changes (velocity vector changes caused by acceleration). Magnetic trackers on the other hand provide exact trajectories.

T 1.4. Sensors Self Description

Sensor self description has been extensively studied from the point of view of the description formalism. Sensor ML has recently been established a de facto standard. Partners involved in the project (in particular JKU) have considerable experience working with Sensor ML and the project will use it as formalism without any further research in this direction.

Instead the core research in this task will be devoted to the sort of information needs to be encoded in the sensor self description to facilitate opportunistic context and activity recognition. A particular challenge is incorporating the dynamic sensor self description information (Task T1.1), information about the degree of variability tolerance (Task 1.2) and about the type of features that a particular sensor/sensor combination can detect (Task 1.3). Research is needed on what information to include, how to structure it, how to efficiently, dynamically adapt it (in particular across sensor groups) and how to efficiently advertise and query it.

Deliverables (brief description), including month of delivery and associated number of person-months

Contributes to D1 "First generation opportunistic context recognition chain" M12 13

- Methods for dynamic sensor self characterisation

Contributes to D2 "Second generation opportunistic contextrecognition chain" M24 14

- Methods to abstract and cope with sensor parameter variability

Contributes to D3 "Third generation opportunistic context recognition chain incl. opportunistic BCI M36 13

- Sensors and features report for opportunistic context recognition

Work package number	2		**Start date or starting event:**				Month 1				
Work package title	Opportunistic classifiers										
Lead beneficiary	4										
Activity Type	RTD										
Participant id	1	2	3	4							
Person-months per beneficiary:	11	**10**	6	18							

Objectives

The objective of this WP is the development of classification techniques suitable for OPPORTUNITY activity recognition systems. These techniques should be able to

- combine heterogeneous input channels taking into account their reliability
- Provide online learning mechanisms in order to cope with gradual and sudden changes in the sensor network (e.g., sensor quality degradation and addition of new sensors, respectively).
- provide a measure of reliability of their decisions

In general terms, opportunistic classifiers are responsible to construct a *cooperative sensing mission* that require information from available pertinent *sensing ensembles*, and achieve activity recognition by combining multimodal heterogeneous abstract features. This process will take into account the estimated reliability of such features, and will provide in turn a measure of the reliability of the decisions it takes.
In this project we will improve state-the-art machine learning techniques for activity recognition in order to fulfil the requirements of the OPPORTUNITY approach. Namely, these applications require classifiers that provide graceful performance degradation in the case of unreliable or missing inputs. Moreover, application-specific constraints from pervasive and wearable computing will also be taken into account in the design of the classifiers, particularly its implementation in low-power devices and the ability of learning from a small number of samples.
We will adopt a hierarchical approach where several *modular classifiers* are combined into a single decision (i.e. decision fusion approach). Modular classifiers will be in charge of segmenting the input features stream and its posterior classification into activity classes. These classifiers should be able to incorporate variations in the feature space (e.g., as a result of changes in the sensor placement or sensor failures).
Decisions from multiple classifiers will be combined in a second classification stage. This classifier fusion will be able to deal with changes in the number, type or reliability of classifiers available for activity recognition. We will compare different approaches for fusion like voting or Naive Bayesian combination in terms of its ability of incorporate new sensors, as well as its robustness in case of errors. Based on this comparison we will develop fusion techniques suitable for dynamically changing network of classifiers (*sensing ensembles*).
In this WP we will first assess the performance of current activity recognition systems –based on pre-defined static sensor configurations— in dynamically changing scenarios (Task 2.1). Based on this results we will formally define the principles of opportunistic classifiers. The ultimate goal of this WP is the development of techniques for classification and classifier fusion according to these principles (Task 2.2 and 2,3 respectively). In addition, we will study how this classifiers can efficiently adopt the mechanisms for dynamic adaptation devised in WP3 (Task 2.4). From initial results, further generalization of Opportunistic classifiers will be pursued to enable application to wider range of problem domains, such as cognitive context recognition scenario (Task 2.5).

Description of work

T2.1 Analysis and original approaches

This task of explorative nature questions the pattern recognition problem that is activity recognition in a broader sense. It draws from disciplines related to the understanding of human activity and pattern recognition (such as cognitive psychology, neurosciences, behavioral science, linguistics, etc) and establish links to sensor-based recognition of human activities. The outcome will be set of original approaches or perspectives on activity recognition, with an analysis of their potential applicability and benefits to machine recognition of human activities. The underlying ideas will feed into other tasks (in particular task 2.2) and aims at enriching the scope of the approaches that will be considered.

T2.2 Principles of Opportunistic classification

In order to properly define the requirements for opportunistic classifiers, we will evaluate the performance of existing classification techniques in activity recognition systems. This evaluation provides a baseline performance that will be used to assess the performance of the opportunistic systems developed in the project. A set of specific tasks commonly used in the field of activity recognition (e.g., gesture recognition) will be selected for benchmarking existing techniques and further applied to validate Opportunistic classifiers. Particular emphasis will be put on assessing performance degradation in case of dynamic changes in the sensor network.
The results of this comparison will be used to formally define the requirements and quantitative performance targets for OPPORTUNITY systems. These requirements will state the definition of an Opportunistic classifier, clearly separating between general principles of the approach and specific application-dependent constraints.

T2.3 Modular classifiers

In this task we will improve state-of-the-art classification techniques for activity recognition, taking into account the requirements of the OPPORTUNITY approach. Based on the evaluation of state of the art classifiers (Task 2.1) for activity recognition we will propose improved algorithms in order to avoid the current assumption of a fixed sensor network configuration, and to allow on-line system adaptation (online/incremental training).

An interesting approach for activity recognition are the Dynamic Bayesian Networks, which can be used to implement Hierarchical HMMs. HMMs have been largely used for activity recognition based on time series, while the Bayesian framework incorporates uncertainty information. However, these techniques typically require to be trained using a large amount of data. Alternatively, less demanding techniques for segmentation and classification based on string matching have been recently proposed [Stiefmeier07]. These techniques, as well as detection techniques to identify meaningful segments on the input stream [Chavarriaga08], will be extended to allow on-line adaptation as required by the OPPORTUNITY approach.

Moreover, these classifiers should be robust with respect to changes in the sensor parameters propagated through the abstract feature extraction process. These parameters may include the sampling rate, accuracy, coordinate system. Robustness can be achieved in two ways; on the one hand, these parameters may be explicitly considered for classification (e.g. confidence measure on the feature value); on the other hand, classifiers can provide graceful performance degradation to sensor noise (e.g. redundant integration of multiple feature streams).

T2.4 OPPORTUNITY Classifier fusion

Opportunistic activity recognition is based in the combination of multiple heterogeneous input streams. We will adopt the classifier fusion approach for the development of OPPORTUNITY systems. These approach aims at improving the performance of single classifiers through the combination of decision from several of them. Besides this, experimental studies have shown that this method is tolerant to failures on single streams [Zappi07]. This WP will extend these studies and propose a mechanism that fuses a set of classifiers that change dynamically. Besides the addition/removal of single classifiers these mechanism may also deal with changes in the classifier characteristics (e.g. reliability).

Based on previously proposed fusion techniques (Naive Bayes models or voting systems) [Moore99, Zappi07], we will propose methods that can deal with changes in the availability or reliability of input classifiers. This methods should also provide a mechanism of dynamic input weighing that integrates feed-forward information from the modular classifiers with feedback information (WP3).

T2.5 Online adaptation

A characteristic feature of opportunistic systems is it ability to adapt to changes in the sensor setup. This requires the system to be able to track its own performance (c.f. WP3), and, based on this information, prompt an appropriate action to maintain a given level of performance. This action may be performed either off-line or online.

Opportunistic systems will mostly rely on online adaptation of its classifiers. This adaptation process may take place at two stages. On the one hand, at the level of classifier fusion, by changing the relative weighting of the different input streams. On the other hand, a particular classifier can be updated using user-generated information (supervised learning) or information from other classifiers (self-supervised learning). Algorithms developed in this task will decide at which level the learning process will take place, and propagate supervisory signals to the appropriate module to be updated.

T2.6 Generalization of Opportunistic classifiers

This task will be focused on further generalizing the OPPORTUNIY classifiers developed in tasks 2.2 and 2.3 to a wider range of problem domains, including the implementation of Brain-computer Interfaces.

Deliverables (brief description), including month of delivery and associated number of person-months

Contributes to D1 "First generation opportunistic context recognition chain" M12 11
- Benchmarking of SoA classifiers for activity recognition

Contributes to D2 "Second generation opportunistic contextrecognition chain" M24 16
- On-line study of Opportunistic classification

Contributes to D3 "Third generation opportunistic context recognition chain incl. opportunistic BCI M36 18
- Dynamic adaptation of Opportunistic classifiers

Work package number	3		**Start date or starting event:**			Month 1						
Work package title	Dynamic adaptation and autonomous evolution											
Lead beneficiary	1											
Activity Type	RTD											
Participant id	1	2	3	4								
Person-months per beneficiary:	**18**	8	10	10								

Objectives

This WP addresses the following type of adaptations:

- Adaptation to changing resources: addition of sensors (newly discovered sensors), removal of sensors (e.g. due to faults, or sensors out of range)
- Adaptation to sensor signal degradation: slow (long term) changes in sensor characteristics (e.g. due to ageing), slow (long term) changes in on-body (or ambient) sensor orientation / placement
- Adaptation to slowly changing user activities templates (i.e. human activities can be carried out by progressively varying body motion trajectories, e.g. due to improved proficiency at carrying out a task as is often seen in repetitive activities carried out in industrial production settings [Stiefmeier08], or due to physical deficiencies). We consider this as a type of "signal degradation" that is addressed in the same way as for changes in sensor characteristics.

In this WP we develop methods for the **unsupervised dynamic adaptation** and **autonomous evolution** of the OPPORTUNITY activity recognition system to new sensor setups. We characterize these methods, and we seek to understand the tradeoffs of dynamic adaptation and autonomous evolution in context and activity recognition systems.

The methods in this WP form the feedback loop of the opportunistic context-recognition chain - and interact with WP1,WP2 to control the recognition chain, and WP4 to receive updates about the sensory environment and inform of sensing needs.

Unsupervised dynamic adaptation deals with the challenge of maintaining a desired multiparametric performance goal (e.g. accuracy, ROC curve, number of sensors used) in order to achieve robust fault-tolerant operation. This is done by unsupervised adaptation of the activity recognition chain, typically through dynamic resource selection and is used to address changing performance goals or cope with rapid environmental changes (e.g. sensor loss, decrease in sensor confience). It is tightly linked with WP2 and classifier fusion.

Autonomous evolution deals with the long term adaptation challenge to changing sensing environments and users. This includes capitalizing on additional sensing resources at run-time and coping with long term sensor signal degradation. We envision the context recognition system as an embodied and situated system and will pursue this adaptation on the basis of self-supervised learning.

Principles underlying dynamic adaptation and autonomous evolution are first reviewed and refined in task 3.1

A first challenge of dynamic adaptation is to link sensor configuration to performance metrics. This is tackled in task 3.2 by developing performance models.

A second challenge is the lack of ground truth to supervise autonomous evolution. Users may be prompted to annotate activities sporadically if needed (resulting in fully interactive labelling or semi-supervised approaches), however in the general case such systems should be able to adapt to new conditions without user intervention. Our approach is to infer autonomously an endogenous measure of the system performance from correlations among sensors, tracking of the rough clusters of activity classes in the feature space, EEG-based feedback, and limited "optimal" interactive user feedback. This is done by runtime system supervision in task 3.3.

In task 3.4 we develop the dynamic adaptation and automous evolution methods:

- Dynamic adaptation relies on performance models (task 3.2) to select appropriate parameters of the recognition chain (e.g. appropriate set of sensors) to achieve a desired performance goal. It feeds back to classifier and classifier fusion methods in WP2 (T2.2 and T2.3) and WP1.
- Autonomous evolution consists of an online learning system that uses feedback from the system and limited interactive user feedback to train itself. In other words, existing sensor signals, and activities interactively annotated by the user, are used as feedback for the system to adjust its operating parameters (typically to update activity cluster in the feature space through online classifier training). This is interesting for scenarios where the user periodically repeats activities in different locations with a shared subset of sensors to learn how to use additional resources. The general idea to cope with signal degradation is that the rough clusters of activity classes in the feature space change slowly over time. These changes can be recognized, and a classifiers can be re-trained on updated activity signal templates. It feeds back to classifier online adaptation (T2.4).

We develop evaluation methods to characterize and measure dynamic adaptation performance in task 3.5. They will be used throughout the project to comparatively characterize opportunistic systems.

At the start of the WP we will use features, classifiers and activity classes well studied in previous research with activity recognition systems not capable of dynamic adaptation or autonomous evolution [Zappi07,Zappi08,Stiefmeier08]. The initial problem domain will be manipulative gestures sensed from body-worn acceleration sensors. At first we will consider isolated gesture recognition using Hidden Markov Models (HMM). On this basis we will assess dynamic adaptation to changes in number of sensors, and slow changes in sensor placement and orientation using the methods developed in this WP. In the course of the project, once the specific sensors, features, classifiers and application scenarios of OPPORTUNITY are defined, we will use these instead.

Description of work

T 3.1. Analysis & Dynamic Adaptation and Autonomous Evolution Principles

It is useful to perform a critical and comparative review of the literature on dynamic adaptation and autonomous evolution in context aware systems. This task is of explorative nature. It questions the nature of adaptation, evolution, and autonomy in wearable and pervasive computing systems by establishing links to and drawing from disciplines such as evolutionary biology, neurosciences, control theory, nonlinear dynamic systems. The outcome will be set of original approaches or perspectives on adaptation and evolution, with an analysis of their potential applicability and benefits within the context of wearable and pervasive computing. The underlying ideas will feed into other tasks (in particular task 3.4) and aims at enriching the scope of the approaches investigated within OPPORTUNITY.

Specific issues that will be scrutinized include: adaptation to changing resource availability (in particular addition/removal of sensors); adaptation to changing sensor characteristics (in particular signal degradation, e.g. from changes in sensor placement/orientation).
On the basis of this review, we will identify the most promising adaptation principles and refine the OPPORTUNITY adaptation strategies outlined in this WP.
The outcome of this task is a set of adaptation principles that will be realized within the remaining tasks for the specific application domains of OPPORTUNITY.

T 3.2 System performance models

We develop a methodology to devise models linking sensor configurations and recognition chain parameters to performance parameter goals. These models are instanciated based on empirical data, and are used to support dynamic adaptation (task 3.3) via (among others) dynamic resource selection. In its simplest form such models indicate how many sensors need to be used to achieve a desired recognition accuracy. In a broader view, this has to take into account confidence in sensor, type of features and classifiers and multiparametric performance goals. We will identify the required performance models on the basis of the OPPORTUNITY case studies.

T 3.3. Runtime Supervision

Due to the lack of absolute ground-truth, it is necessary for an opportunistic system to autonomously infer a measure of its own performance at run-time, in order to control adaptation (task 3.4).
In this task we develop methods to assess system performance at run-time without supervision or with limited (intelligent) user supervision.
Several dimensions are considered:

- We investigate **error-related EEG correlates** (signal patterns occurring when a system deviates from expected behavior) as an endogenous, automatically detected, measure of system performance. We detect these patterns with approved BCI methods. The occurrence of error-related EEG correlates indicates that the system behavior deviated from expected behavior. This can be used as a performance monitoring approach and as a way to support classifier re-training.
- In order to adapt to sensor signal degradation, we investigate and develop a performance metric based on the tracking **of the rough clusters of activity classes in the feature space**. These clusters change slowly over time, i.e. when sensors degrade due to ageing, due to slow changes in sensor placement/orientation. We will develop a performance metric based on spread and trend assessment within these clusters. This metric will indicate whether dynamic adaptation is required and the confidence to place in the system feedback.
- In order to cope with changes in available resources (number of sensors) we will investigate performance metrics derived from the **observation of repeated correlations** between existing and newly added sensors. These correlations may be assessed at the signal, feature or classifier level. We will at first consider correlations at classifier level between existing sensors/classifiers, and newly added sensors and the corresponding classifiers trained using system feedback. This performance metric will represent the confidence/reliability of the linkage between sensors classifier output and the actual activity class, in a form similar to a confusion matrix. The result is a metric that allows to select and weight at run-time available sensors to achieve a desired performance target (in task 3.4).
- We consider means by which **user interactive feedback** may be queried at run-time in an efficient way. We will investigate, from an information theoretical viewpoint, under which conditions the system may ask for user input, so as to maximize the information gained from this interaction, while at the same time minimizing the number of user interventions.

The result of this task is a set of runtime performance supervision methods. With empirical data for parameter identification, they are used to support system dynamic adaptation (task 3.4), and to support sensor fusion with appropriate weights (task 2.4), and to control sensing goals (WP4).

T 3.4. OPPORTUNITY dynamic adaptation and autonomous evolution

In this task we develop the dynamic adaptation mechanisms of OPPORTUNITY capitalizing on models devised in task 3.2 and runtime performance supervision developed in task 3.3. We will comparatively investigate various approaches and characterize them using the evaluation methods of task 3.5.

Dynamic adaptation: We wish to select an optimal set of resources to achieve a desired performance criterion. This approach will enable self-repair when sensors are lost (e.g. when sensors fail or are out of range). The performance metrics developed in task 3.2 identify the linkage between system performance and sensor sets. We will investigate at first methods that allow to dynamically select, at run-time, the appropriate set of sensors to achieve a desired system performance. This will require to develop appropriate heuristics that minimize computational load. Methods involving dynamic feature selection or a combination of sensor and feature selection will be investigated in a second step.

Autonomous evolution enables the system to adapt its operation to long term changes in the sensing environment and user, thereby enabling application in open-ended environments. In our approach we view the context recognition system as an embodied, situated system. We rely on self-supervised learning as a key mechanism to enable autonomous evolution:

- We will start with the problem of incorporating information from newly added sensors in the activity recognition system. At first we will consider how activities detected by the system on the basis of available sensors can be used to provide a ground truth to train the classifiers of newly detected sensors. Other methods we will consider include signal and feature correlation or mutual information between existing and added sensors.
- We will then tackle the problem of signal degradation by using the same self-supervised approach. Runtime system supervision (task 3.3) will provide an indication as to how much activities deviate over time from their template. On this basis we will investigate how and up to which extend the system can retrain itself (adjust activity templates) to cope with signal degradation. At first we will consider a single source of changes (sensor orientation or position) before considering combinations of factors.
- Finally we will extend these methods to use interactive feedback according to the principles devised in task 3.3.

<u>T 3.5. Autonomous evolution evaluation methods</u>

We investigate and develop means to characterize the autonomous evolution algorithms developed in this WP. OPPORTUNITY systems will be non-linear dynamical systems due to the use of self-supervised learning. It is important to assess aspects such system stability, adaptation speed and learning convergence rate (wrt activity timescales), scalability and robustness. This needs to take into account information uncertainty (of existing and newly discovered sensors, and of the system itself), number of activity classes, number of training instances, confusion matrices, as well as feature characteristics and type of classifier. We will use methods such as entropy measures, wrapper approaches, symbolic dynamics, as well as other methods from non-linear system analysis to characterize the dynamic adaptation of OPPORTUNITY.

The output of this task will be a set of key performance criteria, and methods to measure them, that can be used throughout this project to characterize and compare the dynamic adaptation mechanisms of OPPORTUNITY in various scenarios and for various parameters.

Deliverables (brief description), including month of delivery and associated number of person-months

Contributes to D1 "First generation opportunistic context recognition chain" M12 15

- Dynamic adaptation and autonomous evolution principles and performance modelling

Contributes to D2 "Second generation opportunistic contextrecognition chain" M24 15

- Preliminary dynamic adaptation and autonomous evolution, self-supervision and evaluation methods

Contributes to D3 "Third generation opportunistic context recognition chain incl. opportunistic BCI M36 16

- Dynamic adaptation and autonomous evolution: methods and characterization

Work package number	4		**Start date or starting event:**				Month 1			
Work package title	Ad-hoc cooperative sensing									
Lead beneficiary	3									
Activity Type	RTD									
Participant id	1	2	3	4						
Person-months per beneficiary:	6	6	**18**	3						

Objectives

The role of this WP is to frame the foundational basis of the OPPORTUNITY cooperative sensing framework, identifying the model of ad-hoc sensing ensembles and its methodological implications on the development of algorithms, infrastructure, and applications. The main ingredients and novelty aspects of the project will be introduced, studied, and become part of a new wireless sensing model, which will take into account aspects such as:

- the spontaneous formation, management and control of sensor ensembles,
- a goal oriented and quality-of-service controlled sensing mission strategy,
- a distributed coordination architecture for orchestrated cooperative sensors,
- dependable, reliable, fault-tolerant and trustworthy context-awareness,
- and live semantic interactions with the respective applications.

The OPPORTUNITY project proposes an ad-hoc sensing model, resembling the way in which a-priori unknown sensor configurations influence the dynamics, the evolution and the self-organisation character of sensing scenarios, or in a single word: sensing ecosystems. As such, an application is seen as a large set of sensing entities, i.e. a collection of embedded electrical, magnetic, optical, acoustic, chemical etc. sensors to gather information on the environment like humidity, temperature, light, noise-level, air-pollution, the physical condition of a person like the metabolic rate, breathing activity, rigidity and spasticity of muscles, surface tension, or the identity, location, geoposition, orientation, acceleration of objects, etc. The process of context information acquisition is induced by sensing mission goals derived from the application, and performed by an ad-hoc formation of sensing entities. Sensing entities are configured into orchestrated ensembles according to the sensing challenges imposed by the sensing mission goals, the individual sensing capabilities of the entities, their availability, mobility, reliability, trustworthiness and mission readiness.

The activities of this WP are organized around four inter-related tasks.

First, in T4.1, the OPPORTUNITY general model for ensemble oriented sensing (*spontaneous cooperative sensing model*) will be defined and assessed, which will evolve during the project lifetime through the feedbacks and experience gained in other WPs, particularly the findings delivered in T2.1 (Principles of Opportunistic Classification), and T3.1 (Analysis & Dynamic Adaptation and Autonomous Evolution Principles). Ultimately, the role of the OPPORTUNITY ensemble sensing model is to serve as a backbone foundation for all the main research activities of the project. It will contribute to the development of means and mechanism for *self-* capabilities of sensors*, elaborated in T4.2, and *goal oriented behaviour*, elaborated in T4.3. An abstract design of the *OPPORTUNITY coordination architecture* as a virtual distributed engine description of orchestrated cooperative sensors will form a blueprint to be turned into the concrete design of the OPPORTUNITY middleware framework, T4.4. The framework itself will represent the ground basis for the design, analysis and implementation of systems able to recognize complex activities and contexts, and at the same time represent the testbed and development environment for fully functional cooperative sensing applications. Finally, since a new wireless sensing paradigm is concerned, the model will ground a new methodological approach for the development of systems, tackling issues such as ad-hoc configuration, self-organisation, goal oriented autonomic behaviour, context awareness and dynamic adaptation. Both these aspects will be demonstrated *and validated* in carefully designed scenarios in WP 5.

This workpackage reframes the traditional concept of “context-awareness”. Traditionally, ideas of adaptivity and self-organization have assumed the capability of services to adapt to the current context of execution based on their possibility of “accessing” contextual information. In OPPORTUNITY, the idea of *spontaneous cooperative* sensing, i.e. sensing goals established and managed at run time, makes context-awareness an inherent property of composed/aggregated services. Contextual information is not longer something external to a service, but the sensing ensemble that represents some contextual information becomes part of the overall dynamics of the service ecology, and inherently affects the behaviour of all those services that somewhat “bond” with such contextual information.

This WP will closely interact with WP 1 (supporting the advertisement of dynamic sensor self-characterisation), WP 2 (opportunistic classification) and WP 3 (informing methods of WP3 about changes in sensing infrastructure).

Description of work

T4.1 Analysis and original approaches

This task of explorative nature questions the nature, means and approaches underlying goal-oriented cooperative sensing. It draws from disciplines related to the understanding of "cooperation of multiple entities" with a particular emphasis on the challenged of self-organization towards a goal.
This task will reach out to other disciplines sharing this challenge. This includes e.g. biological models, as self-organization is an underlying observation in living organisms (multicellular growth and differentiation controlled by gene regulatory networks), swarm intelligence, multi-agent systems, as well as chemical (pheromones and chemistry based systems) and mechanistic (virtual force fields) approaches.
The outcome will be set of original approaches or perspectives on activity recognition, with an analysis of their potential applicability and benefits to goal-oriented sensing. The underlying ideas will feed into tasks 4.2-4.5 and aims at enriching the scope of the approaches that will be considered.

Task 4.2 Spontaneous Cooperative Sensing Model

Starting with the state-of-the-art sensing technologies used in WSNs, a typology of sensors will be assessed with respect to their technological adequacy, mobility and wearability, accuracy, sampling frequency, data management and energy efficiency. It will be important already at this stage, that the notion of a sensors covers a broad spectrum of resources (hardware and software) able to deliver “sensor data”. A second consideration will be the spontaneous availability and accessibility of such abstract sensor data sources, in a formalized, structured and automated way. This will certainly have to do with metadata modelling of sensor systems, and the mapping of such models to the activity and context ontologies. With that in hand, “knowledge-sharing” and goal-oriented ways for the automatic (self-organized and self-configuring) collection, aggregation and interpretation of “sensor data” will be developed, respecting the availability, dependability, trustworthiness and quality-of-service of the sensor resources involved in a sensing mission. Clearly, goal-orientedness in sensing will have to be designed along abstract goal representation formalisms, the reasoning and negotiation upon such goals, the distribution and sharing of goals, the management of achievements towards such goals and consequently the induced dynamics of interaction among the sensing entities.

The outcome of this task hence is a model of reference for spontaneous cooperative sensing, clearly defining the methodological, algorithmic and architectural aspect of the ad-hoc sensing paradigm. The so developed model will serve as the frame of reference for all the development work arising within this project, and will be referred to as the OPPORTUNITY framework.

Task 4.3 Sensors with Self-* Capabilities

This task is mainly devoted to develop methods and algorithms to allow for a self-managed interaction among sources of sensor data, so called sensor entities, in spontaneous ensemble configurations. The three related classes of “self-*” mechanisms that will be investigated in this task include:

- Self-description of sensor entities. This will consider metadata formats for the typology and interoperability of sensors (like the markup languages SensorML, PML, etc.), will investigate on the necessary metadata processing facilities (like e.g. XML parsing for very small execution platforms, similarity analysis and semantic interoperability of sensor systems), and elaborate a sensor ontology particularly addressing scenarios of opportunistic sensing.

- Self-aggregation and self-composition. Here the possibility for distributed sensor entities to “bond” with each other so as to form a coherent network of sensors, possibly linked with each other according to some semantic relations, and, consequently, defining a sort of sensing cluster (*ensemble*) that is capable of serving in an orchestrated and robust way, and thus, ready to take over and autonomously performing a sensing mission.

- Decentralized self-management and control. This subtask will study the self-management features of traditional self-organizing and self-composition algorithms, in order to allow for the implementation of autonomous sensing entities, semantically bond to each other for the purpose of executing the sensing mission. To this end, both the capability of answering distributed sensor detection queries, as well as goal recognition, negotiation, distribution and execution mechanisms (as developed in T4.3), will be needed as the operational logic of each sensor entity.

Above that, the task will address scalability and protocols to spontaneously configure large sensing ensembles, i.e. investigate algorithms and protocols for redundant and fail safe sensing involving many sensors, and develop utility models for sensor ensembles relating the resource effort (number of sensors, energy and powering, deployment strategy) to the quality of sensing. Furthermore, inconsistency and uncertainty protocols for sensing ensembles will be developed to cope with faulty, stale, or just unavailable sensing entities. Utility based reliability and dependability mechanisms able to guarantee cooperative sensing at least at certain levels of quality of service will be integrated into the self-manageability properties of sensing entities.

The result of this task, considering the sub model of each individual sensing entity within OPPORTUNITY, will be a set of design principles for the implementation of sensing entities ready to spontaneously engage into, and autonomously contribute to ensemble sensing missions. These principles will steer the reference implementations conducted in T4.4.

Task 4.4 Goal-Oriented Sensing Ensembles

This task will be concerned with the understanding of sensing missions as goal oriented explorations of an ensemble of sensors. Gathering and understanding every piece of information that describes the context (e.g. of an application) demands to involve sensing entities of the right number, capability, mobility and sensing technology. Mechanisms will be investigated that, based on goals derived from a postulated sensing mission, can induce to form up orchestrated configurations of sensing entities, i.e. sensing ensembles. To this end, the individual sensing activities within the ensembles need to be aligned according to the information demands coming from the respective application. Formally described goals need to derived from those information demands, and negotiated, distributed and executed within the cluster. Each and every sensing entity, thus, will at any time adhere to the sensing goals, and cooperatively attempt them.

Within this task, OPPORTUNITY will develop *goal representation languages* and mechanisms for *goal processing*. Techniques will be considered to represent (knowledge and) goals in appropriate metadata formats, and mechanisms for storing and retrieving such goal descriptions will be established. A goal generation, goal processing, goal distribution and resource configuration engine will be designed, able to steer cooperative sensing in dynamic ensembles. A software architecture will be developed, addressing the implementation of a goal extraction and sensor data capture kernel, which, once implemented (Task 4.4), will be able to physically collect data in a goal/utility driven way.

The task will further develop solutions for cooperative *sensing mission management* by first studying methods to extract goals from application request and encode them in the respective goal representation language, then develop protocols for the identification, execution and harmonious adjustment of individual sensing efforts towards the accomplishment of a sensing mission goal, and finally develop a framework for the formation of sensing missions involving sensors able to contribute to the ensemble sensing goals, respecting utility, resource effort and quality of service.

The result of T4.3 is another building block in the OPPORTUNITY framework, solving the goal and utility related issues of cooperative sensing. The algorithms, methods and components established in T4.3 will then integrate into the coordination architecture of T4.4.

Task 4.5 Ensemble Coordination Architecture

In our goal oriented, cooperative sensing approach, coordination is the identification, execution and harmonious adjustment of individual sensing efforts towards the accomplishment of a larger mission sensing goal.

The OPPORTUNITY coordination architecture, ultimately, defines the middleware and software component abstractions that make the OPPORTUNITY framework ready for implementation. It will describe in a formalized way how the activities and interactions among sensing entities in applications or use scenario are organized from an architectural viewpoint. Mechanisms will be developed for Peer-to-Peer based goal oriented sensing in heterogeneous ensembles, particularly on how to form up orchestrated configurations of sensing entities, and how to coordinate their sensing activities so as to achieve the overall sensing mission goals [Fers07b][Fers08]. Interaction principles among sensing entities will be identified and the respective communication policies and technologies, able to operate spontaneously and to cope with dynamic and changing operational conditions, will be established. Based on these principles, cooperative sensing patterns (e.g. cooperative activity recognition) will be elaborated. Both performance as well as dependability optimized templates of communication protocols will be developed.

Targeting the implementation of the coordination architecture in software, the task will also address the definition of software components. The following modules will be considered as building blocks for a reference implementation:

- Sensor Discovery: Based on the sensor self-description language (T4.2), this component will implement protocols and mechanisms for distributed sensor querying, particularly respecting scalability, dependability, quality-of-service, inconsistency and uncertainty constraints.

- Sensor Ensemble Management: This component is responsible for supporting the dynamic participation (join, leave, re-join) of individual sensor entities, while sustaining the ensemble sensing mission.

This task is concerned with the design and prototyping of a software infrastructure for the OPPORTUNITY framework, as novel form of lightweight middleware for goal oriented cooperative sensing, and will deliver prototypical implementations of the components of the coordination architecture. A set of core libraries distilling the “self-*” capabilities contribution of T4.2, and the “goal oriented sensing ensembles” contribution of T4.3 will be integrated in the basic execution infrastructure. The resulting concrete implementation of all the concepts, ideas, and algorithmic solutions being studied in OPPORTUNITY will serve as the proof that our concept can be indeed implemented and be effective in real systems. Also, it will serve as a testbed for application experiments in scenarios as envisioned in WP5.

Deliverables (brief description), including month of delivery and associated number of person-months

D 4.1 Self-description mark-up language, self-aggregation and self-composition algorithms M12 12

- Early analysis of opportunistic classification (WP2) and dynamic adaptation (WP3)
- OPPORTUNITY framework draft and early assessment

D 4.2 Goal description language and coordination architecture for decentralized self-management M24 10

- Lineup with WP2 and WP3 principles
- Final framework definition

D 4.3 Validation of OPPORTUNITY Framework M36 11

- Validation of the self-* algorithms
- Validation of goal management algorithms and protocols
- Detailed analysis of core coordination principles

Work package number	5	**Start date or starting event:**		Month 1						
Work package title	Case studies									
Lead beneficiary	2									
Activity Type	RTD									
Participant id	1	2	3	4						
Person-months per beneficiary:	8	**9**	8	8						

Objectives

The Opportunity Case Studies pursue four objectives:

1. Guiding the methodology and algorithms oriented research of WP 1 to 4 by providing specific examples of configurations and problems which opportunistic context recognition systems need to deal with. This is crucial as much of the methods that the project will develop will necessarily be heuristics and approximations (exact solution are in many case NP-complete). Such heuristics and approximations are in general closely tied to certain problem types.
2. Quantitatively validating the results of the research conducted by WP 1 to 4 by comparing the performance of the OPPORTUNITY algorithms with dedicated sensing solutions on realistic problems from relevant domains. The quantitative validation will compare non opportunistic systems specifically designed for a given recognition task with the performance of methods developed by OPPORTUNITY. The latter, per definition will not be specifically designed for the situation, but will automatically adapt.
3. Assessing and facilitating the generalization of the methods developed by OPPORTUNITY. As stated above many of the methods and algorithms will be heuristics tuned to specific problem types. It is important to make sure that these heuristics are not too narrowly focused on individual problem instances. Instead they should be applicable to broad problem classes and we should have a clear abstract description of what type of problem which methods apply to. In this context it is also interesting to at least briefly look at related problems outside the activity recognition domain.
4. Facilitating the exploitation of the project results. While OPPORTUNITY as a FET project does not target product development, the partners of OPPORTUNITY are involved in a number of national and European project where selected OPPORTUNITY technology could be applied. Through such projects the partners also have contact to industrial partners who would benefit from OPPORTUNITY technology. By choosing and scenarios that are relevant to the topics of such projects and demonstrating clear performance benefits resulting from OPPORTUNITY methods, we will ensure that the project results will have a practical impact.

Description of work

The opportunity case studies design is based on the notion explained in section B.1.3.1.2 that most complex activities can be composed of simple building blocks. From our experience with context sensitive applications the most important such building blocks are: (1) hands gestures, (2) general body motion (modes of locomotion) and posture, (3) interaction with devices and objects, (4) presence and location

As already stated in section B.1.3.1.2 the above do not claim to a be a consistent, complete and systematically proven taxonomy of human actions. The development of such taxonomy (or rather different such taxonomies depending on the actual aim) is an open research subject in areas such as cognitive and behavioural science, or ergonomy. Clearly it is beyond the scope of the proposed project. Instead, the above is a pragmatic heuristic that experience has shown to be valid and useful in a wide range of applications. The use of this heuristics in opportunity case studies design has two aims:

1. "Divide and conquer" incremental handling of complexity. We start by developing and testing opportunistic methods for the recognition of simple activity components, next we look at increasingly complex combination of such components and then finally we look at activities drawn from real application scenarios.
2. Facilitating and demonstrating the generalization of the OPPORTUNITY methods to a broad range of activity recognition applications. Since many relevant activity recognition problems can be decomposed into such basic components, dealing with them is a perquisite to a broad range of complex problems.

From the above considerations, this workpackage will be performed in three increasingly complex stages as mentioned in point 1 above. There is an individual work package devoted to the designing, conducting, and evaluating each of this stages (two tasks for the last stage).

T 5.1. Stage 1 Case Studies

Stage 1 case studies will be relatively straightforward examples of the basic 'components' of activity recognition described in section B.1.3.1.4 and summarized above. *They are small scale, quickly assembled experiments that can be often repeated. They will give us insight into basic problems and provide quick feedback on the performance of the OPPORTUNTIY methods. Due to simplicity the emphasis will be on sensing and classifiers with less complex requirement in the area of service discovery and cooperation*. We plan to concentrate on the following three aspects (although we reserve the option to modify the case studies as research work progresses and needs for adequate verification of certain methods) .

1. **Presence and Location**. Presence, and as a generalization location, are the most basic type of context information. Knowing that a user is in the room is the perquisite for activation of services (e.g. switching on lights or other devices) and further attempts at activity recognition. Presence/location seems a very simple type of information at first hand, but its complexity can be modulated to assess the abstract feature described in Task T1. The simplicity is one of the reasons to pick it as a first case study. The second reason is the diversity of possible, increasingly complex interpretations of presence. This starts with binary information related to a very broadly defined location, up to relative presence in narrowly defined vicinity of another person (which effectively amounts to exact location). This means that presence and location are an excellent possibility to study graceful degradation of information and variations of application defined goals. Such study can build on a wide range of sensors that can be used to detect presence and location. The partners have in their labs most common sensors including such elaborate devices as the UBISENSE Ultra Wide Band (UWB) system. The have performed a considerable amount of work in the areas [Bauer08,Pilger07,Fers06, Kunze07].
2. **Modes of locomotion and posture**. Modes of locomotion (standing, sitting, walking, walking up, walking down, running) is a 'prototypical' activity recognition problem for on body systems. The 'default' sensing modality is an accelerometer. For a simple version of the problem (distinguishing standing, walking and running) a simple accelerometer placed anywhere on the body is sufficient and commercial step counter system exist that perform very well. However, for more complex tasks such as distinguishing going up or down stairs, or transitions between standing and sitting, the sensing requirements are more complex. They are even more so for rehabilitation applications were subtle difference in gait are relevant. If a single acceleration sensor is used then it is better placed on the leg. Leg mounted gyroscope as well as combinations of accelerometers and gyroscopes, have also been shown to be useful. Much information can also be extracted from mechanical force sensors in the shoes. Elongation or bend sensors in the clothing, as well as force sensors on the muscles have also been used. In summary modes of locomotion and posture is a problem of scalable complexity (from trivial to very complex in case of the gait analysis) for which a wide range of on body sensors exist which can be used stand alone or in combination. This makes it an ideal case study to assess the simpler adaptation means of OPPORTUNITY. The partners in the project have a large body of experience with different variants of the problem [Lukowicz02,Junker03,Lukowicz06]
3. **Hand gestures.** Hands motions are the basis of much human activity. At the same time tracking hand gestures with simple sensor setups is a difficult problem (more difficult than modes of locomotion). Hands motions are often recognised on the basis of body worn motion sensors. The

most common sensors are accelerometers, gyroscopes, magnetic field sensors and various combinations thereof. In addition, video tracking, muscle activation monitoring, ultrasonic hand tracking, stationary magnetic tracking and various textile sensors (bend, elongation, pressure) have been used in previous work. The consortium partners have previous experience in working with most of these techniques [Barry07,Stiefmeier06,Ward06,Stiefmeier08] and have all sensors and equipment needed to perform further experiments in their labs. We will study the recognition of every day task related gestures such as described in our previous work in [Junker08, Ogris07, Bailador07, Zappi07, Ferscha06, Ferscha07, Ferscha08]. These range from simple gestures such as picking up a telephone, shaking hands, opening a book, to more complex ones such as taking a coin out of a purse and inserting it into a coin machine. Thus the case study will be representative for a wide range of applications.

T 5.2. Stage 2 Case Studies

Stage 2 case studies will combine several basic components into more complex activities. The scenarios involve more time and effort to assemble and will thus be conducted less often and we will use them to verify our concepts once they are more mature. They will provide feedback on the performance of the OPPORTUNITY methods under complex conditions. In particular, due to large numbers of involved sensor and more variability service discovery, cooperation and dynamic adaptation will play a greater role than in stage 1. We currently envision two scenarios.

1. **Simple activities involving object manipulation and device use**. Many activities fall into this class. They include activities of daily life (eating, house making) as well as professional domains such as production or maintenance. As an example consider such a simple action as taking a pill from a pill dispenser and swallowing it with a sip of water from a glass. It involves specific hand gestures (needed to operate the pill dispenser, put the pill in the mouth and grasp a glass), manipulation of two ‘passive objects’ (pill, glass) and the operation of a device (the pill dispenser). It requires the user to be at a certain location while performing certain hand actions and interactions (near the pill dispenser). In general the person would be standing or sitting wile taking the pill (certainly not running). Thus the action involves a combination of different basic activity components of the type investigated in stage 1. As described in task T5.1 the components themselves already include a large degree of possible sensor combinations and parameters variations. Accordingly, there is huge potential variability in the possible sensor configurations for the action as a whole. Available setups could range from a single sensor in a pill dispenser to a combination of several on body sensors for gestures and modes of locomotion, indoor localization, and sensors in the cup and the pill dispenser. These could be combined with background knowledge (e.g. time of day).
2. **Simple social interactions and cooperation between humans.** Meeting recording and collaboration support are among the classical applications of context sensitive systems. A key piece of information that such systems require is the interaction between humans. In this case study scenario we will focus on basic interaction building blocks such as discussion, presentation, having a drink together or just greeting a person. They require basic activity components such as presence, location, modes of locomotion and posture and vocal interaction (speaking not speaking). In addition we are likely to see cooperation not just on the level of sensors, but in general each user would have his own context recognition system and part of the cooperation would be conducted on high level information being exchanged among systems. With people joining and leaving meetings this scenario will involve a large degree of random, complex changes in the system configuration.

T 5.3. Stage 3 Case Studies

Stage 3 case studies built upon complex combination of basic components and demonstrate scenarios clearly motivated by and connected to real life application areas. Their main aim is to evaluate the result of the project under conditions that are as close as possible to real life application. Thus, in a way, they will be an ‘end demonstrator’ of the projects results. Besides complex validation they will also be crucial to exploitation by showing to interested parties the potential of the OPPORTUNITY approach.

Based on relevance, diversity and partners experience we envision the following two areas with the first being less, the second more complex to implement:

1. **Indoor activity monitoring for energy efficient building management**. It is well known that considerable amount of energy could be saved in homes and offices without reduction in comfort and efficiency if the system could reliably predict user needs. Since much human activity in home and office environments is dictated by routine, such prediction is not unfeasible. However it implies that a system can detect basic activity that determines such needs. In any average office there is information available on device activation (building automation, instrumented appliances), presence of people (with different accuracy) and background such as meeting schedules. In addition we can assume microphones and motion sensors that detect different types of activity as well as sensors (e.g. accelerometers) in devices that people carry with them. The system needs to work not just in one single office with a fixed sensor configuration but needs to evolve as sensors and information sources change, are added, and removed. It needs to adapt as users have with them different devices on different days and users come and go. Thus this scenario includes most of the basic activity types from stages 1 and 2, and displays most of the possible types of variability described in section B.1.3.1.2. at the same it is highly relevant. It is also similar to another important application area: ambient assisted living, in which every day activities in home (or nursing home) environment need to be tracked.
2. **Health and Wellness Oriented Lifestyle Monitoring.** The ability to monitor human behaviour with systems that are unobtrusive enough to allow long term use in every day situations opens new applications in healthcare, diagnostics, prevention and wellness [Lukowicz04, Lukowicz08]. There has been much research both on European and national level in this direction and the OPPORTUNITY partners are involved in several such projects (e.g. MyHearth, Austrian HITT projects). We pick our case study from prevention and wellness oriented lifestyle monitoring, specifically monitoring the long term balance between diet, physical exercise and possible stress related situations. Thus the system should monitor the eating habits (when, how much and possibly what), how much a person moved during the day (and what type of motion it was) and possibly evaluate what type of situations he was in (work, leisure, conflict). From the point of view of evaluating opportunistic activity recognition systems the appeal of this application lies in the diversity of task and possible sensor configurations. Dietary monitoring involves hand gestures, sound from chewing, interaction with object location and modes of locomotion. Previous attempts have involved complex systems of body worn sensors (see [Amft05, Junker08] for previous work by consortium partners) as well as instrumented environment. One could also look at location (at a restaurant) and use background information from credit card payment for the food that a person ordered. There is also much room for cooperation between systems of different users as they could try to figure out which part of the order was eaten by whom. Another interesting aspect of this scenario is the fact, that for practical wide spread use, OPPORTUNISTIC sensing is the only option. Fixing dozens of sensors at precisely defined body location and instrumenting every object related to food intake is not an option in real life. The down side is the complexity of the application. However, because there is a huge body of experience and existing system and setups in the partner labs, we believe that a demonstrator that is constrained, yet still demonstrates realistic complexity can be defined and implemented. It will combine e.g. a constrained dietary monitoring task with long term physical activity monitoring and distinction between work and leisure activity.

T 5.4 Opportunistic BCI (Brain Computer Interfaces) validation

For a complete description of the BCI validation, see section A.1.

The BCI study is a parallel orthogonal path of investigation that checks the generalization of the OPPORTUNITY methods to problems beyond activity recognition. This task is aimed at the application of OPPORTUNITY methods to the development of robust adaptive BCI systems. This forms part of complex cognitive context recognition.

A first experimental paradigm we will use is the detection of Error-related EEG correlates. These signals are generated when the user perceives an erroneous action or feedback. This signals will be studied in speed-response protocols or human-computer interaction to assess recognition of brain activity related by errors committed by the person himself [Parra03], or generated during the interpretation of the user's decisions [Ferrez08]. This activity is typically localized in frontocentral areas and appears 100 to 300 ms after the error. Previous classification attempts have achieved classification performances above 75% [Chavarriaga07,Ferrez08,Parra03], based on temporal features. In a similar way, we will also apply the OPPORTUNITY principles to the recognition of EEG signals related to anticipatory processes, where the user awaits the appearance of relevant events based on predictive stimuli. Previous studies at EPFL achieve classification performance of these signals above 70% [Garipelli07]. These classifiers rely strongly on a limited number of electrodes, which makes them extremely sensitive to sensor failure. In both cases, we will start by quantitatively assessing the classifier's sensitivity to changes in the sensor configuration, and then apply OPPORTUNITY adaptive methods to ensure robust recognition of these signals in dynamic situations.

An exploratory study of the opportunistic approach to BCI systems decoding motor imagery and other mental tasks will be performed. This study will be particularly focused on the assessment of the opportunistic techniques to track variations in the incoming EEG signal both *within* and *across* recording sessions. For comparison purposes we will adopt an experimental paradigm similar to the one used in [Buttfield06] where three different mental tasks (left and right hand movement imagination and vocabulary search) were identified using as a features the power spectral density of eight centro-parietal electrodes and Gaussian classifiers.

In a first stage, offline experiments will be performed with and without OPPORTUNITY adaptation during several sessions. This recordings will allow us to evaluate the capabilities of an opportunistic system to track changes in the EEG signal by comparing the performance of the opportunistic classifier to the performance of a static classifier (i.e. a classifier trained using only the data of the first session). Similarly, the system's performance will also be compared to the accuracy obtained using a temporal k-fold cross-validation[13]. This measure provides an estimation of the variability of the system by comparing classifiers that are trained using information from the overall system operation (including past and future samples), with classifier's that only take into account previous samples as is the case in real-time operation of a BCI. The off-line analysis give us the opportunity to fully characterize the system performance and fairly compare several adaptation mechanisms using the same datasets. Taking into account that the goal of this scenario is to assess the genericity of the OPPORTUNITY methods, and the time constraints of the project, rather than developing a full operative BCI applications we will perform the study of BCI systems based on motor imagery in a simulated scenario using off-line acquired data.

In the case of event-related potentials related to cognitive states, after the validation in off-line simulated scenarios, we will implement on-line opportunistic BCIs, where the user receives feedback corresponding to BCI decisions. As done in the off-line case we will compare classification performance of both static and adaptive classifiers.

Similarly, we will systematically assess the robustness of the developed BCI systems w.r.t. to channel signal quality by offline addition of noise to previously recorded data. This will allow us to thoroughly characterize performance degradation. Online analysis will be performed by physical manipulation of the electrodes (e.g. electrode removal, displacement) during the system's operation.

Deliverables (brief description), including month of delivery and associated number of person-months

D 5.1 Stage 1 case study report and stage 2 specification	M12	10

[13] In this case each fold is constructed by taking separate recording blocks respecting the original sample time order.

D 5.2 Stage 2 case study report and stage 3 specification	M24	11
D 5.3 Stage 3 (incl. opportunistic BCI) case study report	M36	12

Work package number	6			**Start date or starting event:**				Month 1		
Work package title	Project Management									
Lead beneficiary	1									
Activity Type	MGT									
Participant id	1	2	3	4						
Person-months per beneficiary:	**5**	0.5	0.5	0.5						

Objectives

- To manage and monitor the project and to ensure that it is running efficiently
- To establish effective project management procedures
- To enhance the communication flow both within the consortium and between the consortium and the EC project officer
- To guide the dissemination activities and exploitation of the results of the project
- To organise the kick-off and subsequent consortium meetings
- To develop quality control procedures
- To identify and recover from any possible risks that could affect the project (in terms of results achievement, schedule, effort…)

Description of work

Project management will be in charge of coordinate the work, report to the EC and manage deviations. The management structure will be a steering committee chaired by the project coordinator. The latter is responsible of ensuring the daily management operation applying proven methods and procedures. The steering committee will include the main representatives of each organisation. The management will be supported by communications tools, quality procedures and risk and contingency measures.

- Organisation of periodical status meeting including a kick-off meeting
- Contract administration (including consortium agreement)
- Financial administration and liaison with the Commission
- Solution of conflicts and overcoming problems that may arise in the course of the project
- Reporting of project meetings
- Production of management reports and integrated cost statements
- Processing deliverables through the project QA procedures and submitting to the EC
- Creation and maintenance of a project management guide, including: quality assurance procedures for the production of reports and other required deliverables; recommendations on how reports should be formatted and presented; version control of documents, e.g., the procedure for changing a draft version of a report into a final version, which is a deliverable, etc.
- Advisory Committee

Deliverables (brief description), including month of delivery and associated number of person-months

D6.1 - Annual Report 1st Year	M12	2
D6.2 - Annual Report 2nd Year	M24	2
D6.3 - Final Management Report	M36	2.5

Work package number	7		**Start date or starting event:**		Month 1						
Work package title	Dissemination and exploitation										
Lead beneficiary	1										
Activity Type	RTD										
Participant id	1	2	3	4							
Person-months per beneficiary:	**3**	2	2	2							

Objectives

- Disseminate and exploit the project's results.
- To build a scientific community around the concept of opportunistic systems
- To organise the dissemination activities in terms of methodology and approaches
- To analyse the state of the art
- To outline the exploitation strategies after the evaluation of the first prototypes and demonstrators released at the end of this cycle
- To reach out to interested industry

Description of work

This WP deals with the dissemination and exploitation activity management.

In order to support scientific cooperation at the FET-Open level and broad public awareness of project achievements, consortium members will ensure within the areas of interest of the project:

- Publication of project results throughout the duration of the project in widely accessible and, where available, openly accessible science and technology journals, as well as through conferences and through other channels, including the Web, reaching audiences beyond the academic community.
- Publication of periodic press releases, and other means of disseminating project progress to a wider audience e.g. via video.
- Participation in FET-organised events, for example conferences, dedicated workshops & working groups, consultation meetings, summer schools, online fora, etc.
- International Co-operation - contribution to relevant national and international activities (ex. Joint workshops, calls, etc… for example with NSF…).

The above activities will be reported in the project's Dissemination Plan and in periodic progress reports. In addition, the consortium agrees to include the following reference in all project-related publications, activities and events:

"*The project OPPORTUNITY acknowledges the financial support of the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission, under FET-Open grant number: 225938*".

Further dissemination and exploitation strategies are outlined in section B.3.2. In particular we have for goal by month 36:

- to publish at least 12 journal papers, including at least 2 journal paper per partner focusing on its specific domain, and at least 2 additional papers presenting the joint results of the consortium.

- to **publish a book** about opportunistic activity and context recognition systems, to disseminate the knowledge acquired during the project with the highest scientific standards.
- to have at least two publications per partner per year in the top conferences in the respective field (top defined as acceptance rates below 30%).
- to release 3 software packages under GPL
- Organize an interdisciplinary retreat to stimulate thinking about the challenges of human activity recognition by machines, not only from an applied pattern recognition problem, but in a multidisciplinary manner including views e.g. from cognitive psychology, linguistics or behavioral sciences, as a way to explore new concepts for activity recognition and reach a dissemination audience beyond the wearable and pervasive computing communities. Each partner engage itself to invite one to two participant from outstide the core field of expertise of the consortium at this retreat event.
- Organize a technical workshop alongside a visible conference to disseminate the project's results.

Metrics to quantify the effect of our community building efforts are gived in Objective 8 in section B.1.1.3.

Deliverables (brief description), including month of delivery and associated number of person-months

D 7.1. Project Presentation, poster, leaflet & Web Site	M06	2
D 7.2 Mid-term Exploitation and Dissemination Report and Plan	M18	4
D 7.3. Final plan for the use and dissemination of Foreground, and report on awareness and wider societal implications	M36	3

B.1.3.6 Efforts for the full duration of the project

Workpackage[14]	WP1	WP2	WP3	WP4	WP5	WP6	WP7	TOTAL per Beneficiary
ETHZ	7	11	**18**	6	8	**5**	**3**	58
UP	**18**	10	8	6	**9**	0.5	2	53.5
JKU	6	6	10	**18**	8	0.5	2	50.5
EPFL	9	**18**	10	3	8	0.5	2	50.5
	40	45	46	33	33	6.5	9	212.5

14 Please indicate in the table the number of person months over the whole duration for the planned work , for each work package by each beneficiary

Activity Type	ETHZ	UP	JKU	EPFL	TOTAL ACTIVITIES
RTD/Innovation activities					
WP1 Sensors and features	7	**18**	6	9	40
WP2 Opportunistic classifiers	11	10	6	**18**	45
WP3 Dynamic adaptation and autonomous evolution	**18**	8	10	10	46
WP4 Ad-hoc cooperative sensing	6	6	**18**	3	33
WP5 Case studies	8	**9**	8	8	33
WP7 Dissemination and exploitation	**3**	2	2	2	9
Total 'research'	53	53	50	50	206
Demonstration activities					
Total 'demonstration'	-	-	-	-	-
Consortium management activities					
WP6 Project management	**5**	0.5	0.5	0.5	6.5
Total ' management'	5	0.5	0.5	0.5	6.5
Other activities					
Total 'other'	-	-	-	-	-
TOTAL BENEFICIARIES	58	53.5	50.5	50.5	212.5

B.1.3.7 List of milestones and planning of reviews

List and schedule of milestones					
Milestone no.	**Milestone name**	**WPs no's.**	**Lead beneficiary**	**Delivery date from Annex I** [15]	***Comments***
M1.1	Dynamic sensor self-characterization	**1**	**2**	**12**	Can sensor advertise their body placement and orientation? Were all the sensors used in activity recognition exhaustively considered?
M1.2	Sensors tolerant to parameter variations	**1**	**1**	**24**	Do sensors provide features that are less sensitive to typical variations (noise, placement, orientation)? Were variations and sensors exhaustively considered?
M2.1	Principles of Opportunistic classifiers	**2**	**4**	**12**	Are the desired modes of operation of opportunistic classifiers explained? Were type of features considered? Were type of dynamic adaptation mechanism considered? Was online training considered?
M2.2	Adaptive Opportunistic classifiers and fusion	**2**	**4**	**24**	Are classifiers suited for online training? Are classifiers suited for low-power devices? Do classifiers and fusion algorithms provide confidence output? Do classifiers provide for robustness against changing feature space dimensionality? Do fusion algorithms allow for dynamic weighted sensor selection?

[15] Month in which the milestone will be achieved. Month 1 marking the start date of the project, and all delivery dates being relative to this start date.

M3.1	Dynamic adaptation and autonomous evolution principles and performance modelling	**3**	**1**	**12**	Were the principles of dynamic adaptation and autonomous evolution described at an architectural leve? Does adaptation apply to all levels of the activity recognition chain? Are basic adaptation needs considered (signal degradation, variability in orientation and placement)? Are autonomous evolution principles suited for heterogeneous sensors? Are autonomous evolution principles able to cope with addition of sensors? Are they coping with slow changes in activity signal template? Are methods for performance modelling considering multiparametric performance goals? Are they considering sensor and classifier confidence values? From a computational viewpoint are they suited for dynamic adaptation heuristics?
M3.2	Initial dynamic adaptation and autonomous evolution methods	**3**	**1**	**24**	Was dynamic adaptation and autonomous evolution demonstrated on synthetic signals and simple activities? Were various realistic signal degradations considered? Was sensor addition considered? Were the tradeoffs outlined? Was adaptivity to changing of activity signal-template considered?
M4.1	OPPORTUNITY Framework Handbook	**4**	**3**	**12**	Is the framework fully described so that partners in other workpackage can understand it?
M4.2	OPPORTUNITY basic infrastructure, goal description language and management kernel, self-* algorithms and	**4**	**3**	**24**	Is the basic infrastructure available so that partners can use it in other workpackages? Has documentation been written? Has interoperability been tested? Are reference design available? Does it fit the primary needs identified by other WPs? Are algorithms available for large scale opportunistic data collection? Was scalability, fault-tolerance, robustness considered? Can sensing goals be efficiently described and distributed through the network? Have the interfaces been provided so that WP1-3 can use the system?

M4.3	OPPORTUNITY Coordination Architecture Middleware	**4**	**3**	**36**	Is the final OPPORTUNITY architecture and middleware functional? Has documentation been written? Has interoperability been tested? Are reference design available? Does it fit the primary and secondary needs identified by other WPs?
M5.1	Stage 1 validation	**1,2,3,4,5**	**2**	**12**	Were the methods of WP1-4 combined to address a common problem? Were they successfully applied to simple "stage 1" activities? Was the amount of adaptivity quantified, and related to each WP 1-4 methods? Were limitations identified and plans to address these limitations devised? Were guidelines to strengthen integration between these methods devised?
M5.2	Stage 2 validation	**1,2,3,4,5**	**2**	**24**	Were the methods of WP1-4 combined to address a common problem? Were they successfully applied to composite "stage 2" activities? Was the amount of adaptivity quantified, and related to each WP 1-4 methods? Were limitations identified and plans to address these limitations devised? Were guidelines to strengthen integration between these methods devised?
M5.3	Stage 3 validation	**1,2,3,4,5**	**2**	**36**	Were the methods of WP1-4 combined to address a common problem? Were they successfully applied to complex "stage 3" activities and to opportunistic BCI scenario? Was the amount of adaptivity quantified, and related to each WP 1-4 methods? Were limitations identified and plans to address these limitations devised? Were guidelines to strengthen integration between these methods devised?
M6.1	Project startup	**6**	**1**	**6**	Has the project kick-off meeting been carried out? Has the workplan for the first year been approved?
M6.2	Submission of Final report	**6**	**1**	**36**	Was the report submitted? Does it include all administrative and financial elements needed to consider the project as completed?
M7.1	Initial dissemination material	**7**	**1**	**6**	Is the web site and presentation material available? Has the newsletter format been defined, including target audience, diffusion mean, periodicity?

M7.2	Retreat event	**7**	**1**	**24**	Was the retreat held? Did feedback from participants indicate that the dissemination activity was well suited to the audience (message clarity, scientific content, exploitation content)? Did new ideas ariste from this interdisciplinary event?
M7.2	Dissemination workshop	**7**	**1**	**36**	Was the workshop held? Did feedback from visitors indicate that the dissemination activity was well suited to the audience (message clarity, scientific content, exploitation content)?

Tentative schedule of project reviews

Review no.	**Tentative timing, i.e. after month X = end of a reporting period** [16]	***planned venue of review***	***Comments , if any***
1	After project month: 13	**Zürich**	
2	After project month: 25	**Linz**	
3	After project month: 36	**Passau**	

[16] Month after which the review will take place. Month 1 marking the start date of the project, and all dates being relative to this start date.

B2. Implementation

B.2.1 Management structure and procedures

The project will be managed according to established best practice proecdures with all necessary instruments needed to ensure smooth execution. There are clear plans for conflict resolution, risk management, IPR management strategy, quality management and regular project meetings. All precedures and responsibilities will be laid down in the consortium agreement. The management structure takes into account small project size and aims at simple procedures avoiding unnecessary overhead. The stucture includes a steering committee running the day to day operations (composed of project coordinator and WP leaders) and a supervisory board with highest legal representatives of all partners for making strategic decisions. The coordinator has a long experience in European and nationally funded R&D projects. The WP leaders are also experienced in running large, collaborative research projects. The partners insituttions have dedicated offices to support the financial and administrative management of European projects.

B.2.1.1 Management Structure

High priority and attention will be given to the crucial area of project management. The project partners are fully committed and agree to work together with the utmost co-operation for the timely fulfilment of their responsibilities.

Given the small consortium size (4 partners) the management structure can be optimized such as to minimize management overheads, while still ensuring efficient coordination of the project at the *scientific level* and *administrative level*.

The project coordinator, ETHZ has extensive experience coordinating international research projects. ETHZ will be responsible for the overall project strategy, ensuring that all parties within the consortium know exactly what is expected from them, as described in the individual work-packages.

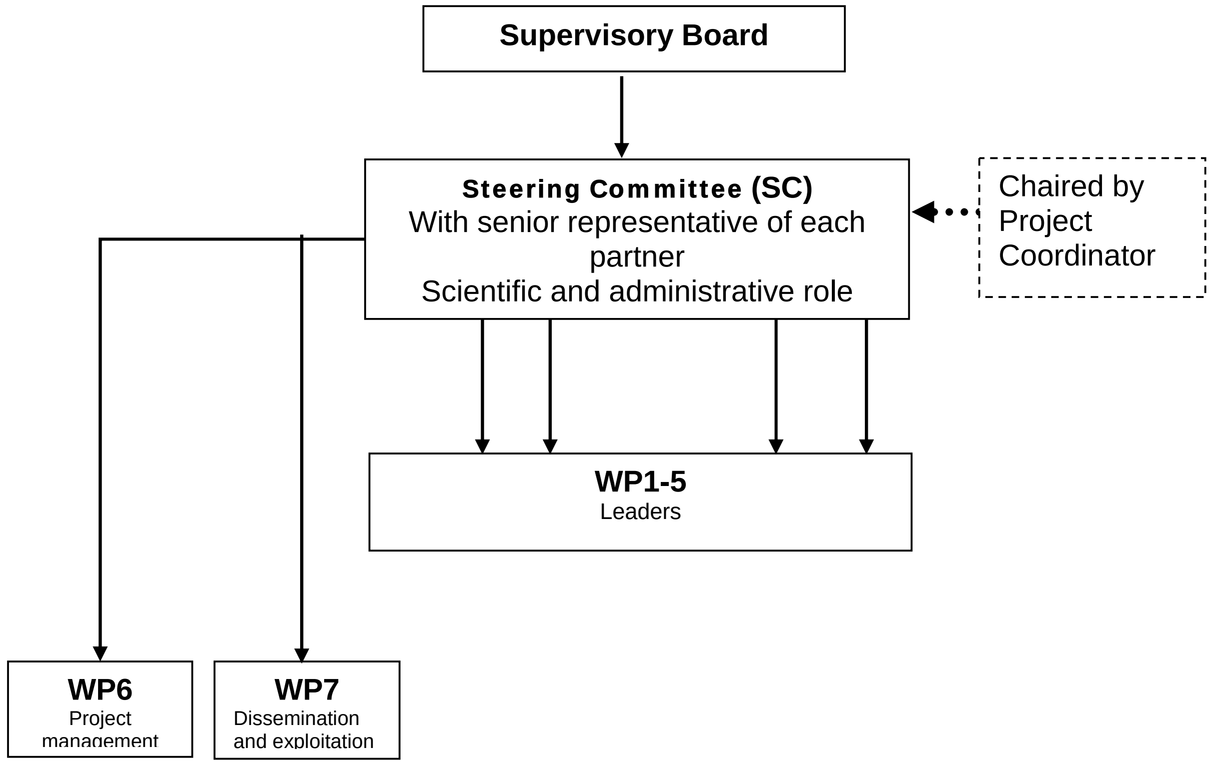
Furthermore, ETHZ will be responsible for ensuring all objectives are met and that all costs and milestones are in-line with the budgets and the provided Gantt Chart. Any deviation will be immediately communicated to the consortium members and the EC Project Officer.

ETHZ will also be responsible for the technical co-ordination and supervision of the work-packages, planning and control of activities and preparation of deliverables, as well as collecting contributions from other partners participating in the project.

The OPPORTUNITY management structure will be organised as represented in the diagram below.

OPPORTUNITY will be managed and monitored in a clear and effective manner. When the project will commence, the proposed management structure will be put in place, and will start taking responsibility and communicating with the partners. This section will try also to identify (or predict) the possible points to failure in the project and suggest ways and corrective actions to implement in order to put the project back on track.

The management structure is made of the *Supervisory Board* and the *Steering Committee* chaired by a *Project Coordinator*, and *Workpackage Leaders*. The roles of each are described below.



This Project management structure has been proved very effective in past similar projects, as there are two crosschecking managerial action lines. A vertical one, throughout all tasks of the same WP, which is undertaken by WP leaders, and a horizontal one, throughout all tasks of all WPs through the Steering Committee.

It has been demonstrated – from past experience of the consortium members - that the needed interventions during the lifecycle of the project can be accurate, fast and efficient. On the one hand, all participants have a very good knowledge on their expertise field situation and thus, can swiftly facilitate the needed intervention and on the other hand, the WP leaders can also timely and effectively help implement the most appropriate intervention.

Supervisory Board

The *Supervisory Board* is composed of the highest-ranking officials of each Contractor (one person for each Contractor). This officer must have the legal authority to officially conduct business on behalf of the legal entity they represent. The Chair of the Board represents the Coordinator. The *Supervisory Board* has the obligation to ensure that the Consortium functions properly. The Board does not meet regularly. Extraordinary meetings may be called by the Chair whenever necessary.

The *Supervisory Board* decides on matters relating to:

- All budget-related matters,
- The structure and restructuring of the Work-packages,
- The alteration of the Consortium Agreement, and
- The premature completion / termination of the Project.

Steering Committee (SC)

The *Steering Committee* is the core scientific, organisational and decision making body. It will be responsible for the successful completion of the project and the exploitation of its results.

Steering Committee	
Organisation	**Representative**
Project Coordinator=Chair	Dr. Daniel Roggen
Scientific Coordinator	Prof. Gerhard Tröster
ETHZ	Prof. Gerhard Tröster (in absence Dr. Daniel Roggen)
UP	Prof. Paul Lukowicz (in absence: Georg Ogris)
JKU	Prof. Alois Ferscha (in absence: Dr. A. Riener)
EPFL	Prof. José del R. Millán (in absence: Dr. Ricardo Chavarriaga)

The SC consist of a representative appointed by each partner (see table for foreseen appointments). will be chaired by the Project Coordinator. The scientific coordinator participates as the scientific authority in the steering committee. In this way the SC joins expertises in the various scientific and technical fields relevant to the OPPORTUNITY project, thus being, in practical terms, the scientific guidance to guarantee successful advancement. The *Steering Committee* will report and be accountable to the *Supervisory Board*.

Non-voting members may be invited to the Committee by the Chair.

The Steering Committee has two roles: a **Scientific role** and an **Administrative/Project management role**.

Scientific role

In its scientific role, the *Steering Committee* duties include, but are not limited to:

i) Co-ordinate activities covering more than one scientific/technical area
ii) Contribute to the overall scientific/technical affairs of the Consortium

It shapes the strategy to be followed, based on the approved by the European Commission for ICT Project description of goals and methods. It decides the required modifications and changes due to unexpected findings or events during the course of the OPPORTUNITY Project implementation.

Administrative and project management role

In its administrative role, the *Steering Committee* represents the Consortium in all related affairs. The duties include, but are not limited to:

i) Preparation of all documents (financial, reporting, audit, etc.)
ii) Management of knowledge
iii) Communication between the Consortium and the Commission
iv) Communication between the Consortium and third parties
v) Publicity
vi) Establishment and overview of intellectual property procedures
vii) Preparation of detailed work plan
viii) Steering of the Consortium

Meeting schedules and voting

The *Steering Committee* will meet in person at a minimum at six monthly intervals. In addition every 3 month at least a phone conference will be organized to follow project advancement. The Project Coordinator calls the *Steering Committee* to a meeting. Face to face meeting will be favoured, typically adjacent to consortium meeting. However if a face to face meeting is not possible, alternate means will be used, such as phone and video conference.

At least 3/4 of the members of the *Steering Committee* is required to conduct a meeting (quorum). A simple majority is required to make formal decisions. Decisions regarding the project will be made by vote with each partner having a single vote. In cases of a tie, the Project Coordinator will have a casting vote. A veto provision is included in the CA.

Given the small size of the consortium, we will favour decision making in the presence of all voting members as far as possible, and seek to reach constructive decisions from a project perspective.

European Commission Representative

The European Commission may participate as an observer at the meetings of the *Steering Committee*.

Project Coordinator

As the Coordinator, ETHZ is the *single point of contact between the European Commission and the Consortium*. ETHZ will appoint a person as *Project Coordinator*. The Project Coordinator *will be responsible for the management of the project and execution of the contract.*

Specific obligations of the Coordinator include:

a) Sign the Contract with the European Commission;
b) Ensure accession to the contract by the other contractors;
c) Ensure the communication between the Consortium and Commission;
d) Receive and distribute the EC contribution;
e) Collect from all Contractors the cost and other statements for submission to the European Commission;
f) Prepare, with the support of the members of the *Steering Committee*, the reports and project documents required by the European Commission;
g) Ensure prompt delivery of all hardware, software and data identified as deliverable items in the Contract or requested by the European Commission for reviews and audits, including the results of the financial audits prepared by independent auditors.

ETHZ is authorised to execute the project management and appoints a Project Coordinator. It shall report and be accountable to the project *Steering Committee* (which shall in turn report and be accountable to the *Supervisory Board*). ETHZ will also be responsible for the preparation of the meetings and decisions and the chairing of the *Steering Committee.*

The Project Coordinator approves all outputs and reports, is the prime external interface. The Project Coordinator will work closely with the *Steering Committee* and chairs the *Steering Committee* meetings.

Project management activities - The Project Coordinator is responsible of the project management activities**.** Over and above the technical management of individual work packages, a management framework linking together all the project components and maintaining communications with the Commission will be established.

Following activities (administrative and financial) belong to the responsibilities of the Project Coordinator:

- Co-ordination of the technical activities of the project;
- The overall legal, contractual, ethical, financial and administrative management of the project;
- Preparing, updating and managing the consortium agreement between the participants;
- Co-ordination of knowledge management and other innovation-related activities;
- Overseeing the promotion of gender equality in the project;
- Overseeing science and society issues, related to the research activities conducted within the project;
- Obtaining audit certificates (as and when required) by each of the Contractors;
- Preparation of project documents like progress reports, final reports
- Supervision of project objectives and timeliness of the work plan
- Monitoring of resources
- Decisions on documentation standards
- Collection of financial reports
- Setting up appropriate communication channels within the consortium: internal fluent communication is foreseen to maximize project efficiency, and timely identify unexpected problems and handle them effectively
- Making sure that decisions taken in the full meeting are line with the project objectives and future developments

Project Office - A Project Office will be established by the Project Coordinator which will provide the necessary support for day-to-day project management for the *Steering Committee* as well as reporting activities to the European Commission.

Workpackage leaders

The OPPORTUNITY partners will contribute a wide variety of relevant and sometimes exclusive knowledge, expertise and experience. To ensure the optimal use of this expertise and to maximise fertile interaction between partners, work is divided in workpackages (WP) each of them under the responsibility of a WP leader from one of the Partners. Each WP will ultimately be the responsibility of the WP leader. The work of WP leaders lasts as long as the WP is in progress. They are responsible for keeping the time schedule and the appropriate implementation related to their WP. It is also within their duties to make the necessary contacts with leaders of other WPs and to the Steering Committee when their activities depend on or are related to another WP work. In this way, the OPPORTUNITY partners will always be informed as to the state of affairs within every WP.

B.2.1.2 Risks and other critical factors

All the partners have already been part of international projects and are aware that innovative and prototypical work like this is subject to a number of risks. This constitutes a good reference for the Steering Committee which will oversee and monitor the developments throughout the project.

The consortium will identify the factors that are critical to the smooth execution and final success of the project and control these factors. For this purpose, the consortium will define methods and procedures to identify, assess, monitor and control areas of risk. The challenge underlying the project has been carefully analysed. Significant risks and contingency plans have been already identified, and for each one a possible contingency solution has been selected. If necessary, this plan will be re-assessed and updated throughout the execution of the project in order to reflect more flexibility and adjustment to changes that may occur in the dynamic environment that surrounds the project (both external and internal).

As will be seen below on selected examples the key, effective element of risk management is the iterative strategy that we pursue, where the complexity of the problem under investigation is incrementally increased. Instead a 'go for broke' strategy we ensure that the most ambitious goals can be achieved in a step by step manner with each step being a significant scientific advance by itself.

Scientific risks

Risk description	Evaluation	Resolution
Performance of activity recognition system below expected values (see quantified specific objectives)	*Impact low, Prob. medium* Given the novelty of the approach pursued by OPPORTUNITY it is difficult to estimate the future performance of such a system. While we expect to outperform traditional state of the art systems when sensor configuration changes, it is difficult to estimate by how much, and it is difficult to estimate what are the costs of adaptation in situations where sensor configurations do not change. This is part of the research we conduct in OPPORTUNITY.	The 3-stage approach allows us to regularly validate the OPPORTUNITY methods in case studies. The specification of the following stage case study reflects the outcomes of the previous one. As a consequence, the case study may be adjusted to better investigate unexpected aspects of the methods outcomes, and/or emphasize specific positive outcomes (e.g through complexity reduction, or design of specific case studies to address one adaptation method). The staged process allows us to understand the limitations of the approaches. It guides the following research efforts in a way to characterize the approach (operating conditions), and address these issues.
Failure to achieve autonomous evolution of the context recognition system due to insufficient endogenous supervision.	*Impact medium, Prob. medium* Autonomous evolution requires an endogenous measure of system performance. We expect self-supervised (system feedback) learning to provide the required ground truth and runtime supervision to provide a confidence value in it (e.g. does the system observe normal variability, or trends in degrading sensors?). In the same way, we expect EEG-based feedback to support self-supervision by pointing out unexpected system	We may rely on user supervision as a way to decouple the problem of "adaptation methods" and "self supervision methods". In this way we will analyze the adaptation methods first and assess their limits and tradeoffs. Afterwards we will consider the challenge of replacing user supervision by system self-supervision (or EEG-based supervision). This enables

	behaviors. It remains open up to which extent such endogenous measures can be used for autonomous evolution. This reflects in a trade off between system stability, robustness and adaptation speed and is the scope of the research programme of OPPORTUNITY. Analysis may be simplified as indicated in the next column.	analysis on problems of reduced complexity by investigating how the system behaves (and errs) after self-supervised learning by requesting sporadic user interaction.
Failure for opportunistic activity/context recognition methods to be applicable in real-world problems	*Impact medium, Prob. very low* The opportunistic activity/context recognition methods address a subset of all the type of variability present in a real-world application. The benefit of the approach will be shown along the aspects considered. Despite this, a partial failure to show real-world benefits might occur, although it is unlikely to happen on all dimensions considered. Shall this occur, there would remain an important contribution to understand the key challenges and limitations of opportunistic systems in such problems.	The project objectives are to understand the advantages and limitations of the type of opportunistic methods introduced here. The limitations would be characterized and linked to the choice of adaptation principles and new principles would be outlined on this basis and investigated.
Failure to develop generic approaches limiting the applicability of the projects result to other domains	*Impact low, Prob medium* There are limits as to how much methods can be generic, due to assumptions on the characteristic of signals, type of sensors, and application domains. We develop generic approaches within the problem domains. We seek to have them generalize across problem domains, but a failure here does not limit the significance of the results in the primary problem domain.	Primarily, the limitations of the approaches are investigated and characterized. On this basis we will draw conclusion as to the suitability of the initial principles for generalization wrt to operating limits.
Failure to integrate the models into a coherent framework	*Impact medium, Prob. low*	The iterative strategy (dealing with incrementally more complex problems with first independent then combined building blocks) will allow us

		to learn starting with simpler integration. Stepwise integration will mean that even if we fail to integrate all approaches some integration will be achieved.
Failure of one the workpackage to achieve its end objective	*Impact low, Prob. low* The project has been organized in such a way that workpackages tackle iteratively more complex problems. Thus, even if the end objective is challenging, there are reasonable chances of success for the earlier, lesser challenging objectives. These constitute advances beyond the state of the art in their own right. The complete failure of a workpackage is thus unlikely. There is a high likelihood that the simpler objectives will be reached. These will be sufficient to allow the other workpackages to proceed. Furthermore, workpackages are not blocking: other workpackages could proceed, albeit with a reduction of the system functionalities. Nevertheless the remaining advances would be sufficient and clearly beyond State of the Art.	The incremental approach ensures at least partial success of the workpackage. Efforts will proceed, depending on the assessment, either on enhancing the method developed successfully up to that point using an alternative approach, or adding assumptions to simplifying the end problem.
Failure of a "stage N" case study milestone	*Prob. low, impact low* The goals of the milestones after each case study stage are to synchronize the advances in all the WPs and apply all methods jointly to specific problems. As such it is not expected for such a milestone to "fail as a whole" but rather for various methods to be more or less suitable for the problem domain. On the basis of result analysis, lessons can be learned as to which adaptation method is more suited for which type of variability.	Shall insufficient results be reached by the milestone, the definition of the following stage case study would be reframed accordingly to focus on these simpler cases where the OPPORTUNITY approaches demonstrate adaptivity. Increasing problem complexity would build up from there.

Cohesiveness of the Consortium

Risk description	Evaluation	Resolution
Consortium is too numerous to be easily co-ordinated.	*Impact High, Prob. very low* Should this problem occur its impact on the project would be significant. However the probability of occurrence is low due to the existing background of experience in such project by all the partners, and the small consortium size (4 partners).	The designated project manager has great experience in co-ordinating research project. The steering committee is representative of all partners and will maintain the correct efficiency and operability.
Consortium has no harmony.	*Impact High, Prob. Low* There are many reasons to believe that harmony will be the key to ensure cohesion within the consortium, ranging from personal friendships to recent experiences between partners. Lack of harmony may arise when the plan of activities is not fully understood by all participants or personal incompatibilities arise during the work.	In case of need, the Steering Committee will work closely with specific partners in order to ensure their working in harmonisation. External mediation may be sought. In rare cases, if it will not solve the problem, and partner is seriously defaulting, they will be excluded from the consortium and replaced.
Poor quality of deliverables and delay in meeting the deadlines.	*Impact High, Prob. Low*	The progress of the project will be assessed at frequent intervals to predict possible delays and act accordingly. The Steering Committee will also invest efforts in ensuring that the content is scientifically adequate.

Dissemination and Exploitation risks

Risk description	Evaluation	Resolution
Failure to get relevant papers and tutorials or workshops accepted at high profile venues	*Impact high, Prob. Very low* Partners have a history of high quality publications	Active publication strategy: planning publications well ahead of deadlines with senior researchers directing the work with a focus towards specific venues
Results unsuitable for practical application in the areas related to	*Impact medium, Prob. low* Strong involvement of partners with expertise in the respective	The iterative approach will allow for adaptation and corrective action. Partners will bring in their expertise from

application scenarios	areas should ensure relevance. Also, direct practical applications will not be the main envisioned result of this FET project, and can be explored later.	related, more application oriented, projects.
Difficulties in handling the IPR issues	*Impact high, Prob. very low*	To lower this risk a Consortium Agreement will be signed before the start of the project.

B.2.1.3 Conflict Management

Conflicts are part of everyday life and occur while working together in international projects, also for reasons of different cultural backgrounds. Therefore, possibilities that are available to reduce conflict potentials will be pursued such as cooperative leadership in the project and the different working teams. Communication between consortium members will be facilitated in meetings, telephone and web conferences so that they get to know each other intensively and appreciate cultural differences. All project data will be documented and made available on the shared workspace. If conflicts arise, they will be firstly internally (by voting) and if necessary externally solved via mediation techniques (involving a neutral person). In case of persisting conflicts the issue will be discussed with the Project Coordinator who is entitled to overrule all prior voting or moderated results. This way, it can be guaranteed that the project is able to make decisions any time.

Conflict Resolution - Pragmatic negotiation will be the basis for the consortium conflict resolution approach. Typical conflicts, which can arise in the project, can be due to a lack of productivity/and or quality, missed deadlines and personality and cultural clashes. It will be the responsibility of the Coordinator – who is an experienced mediator in dispute resolutions, to identify these conflicts at an early stage and take steps to talk to the involved parties to quickly resolve the conflict. Negotiation and decisions taken by consensus will be the main tools to resolve conflicts. Should this approach and a majority decision not be achievable by the parties involved and the rest of the Consortium, an independent referee will be appointed by the Project Coordinator, such as the EC Project Officer or another external expert.

B.2.1.4 Change and configuration management

Even a small-size project like OPPORTUNITY may involve the necessity to re-configure the structure, scheduling or even part of the objectives during the project duration. Shall this be required, this will be undertaken under the initiative of the Steering Committee, and the EC Project Officer will immediately be informed. These changes would have for objective to maximize the project's overall success.

B.2.1.5 Methods of monitoring, evaluating and reporting progress

The Steering Committee will use different methods for monitoring in form of analyses like the Milestone trend analysis or the earned value analysis for cost controlling. Each partner is requested on a regular basis (every month) to report on progress and deviations from expected deployed resources. All information will be summarized by the Project Coordinator and distributed to the partners with remarks and countermeasures in case of major deviations.

The work progress of the OPPORTUNITY Project will be constantly monitored and supervised by the Steering Committee according to the quality management requirements. An internal peer review will be performed for each document produced. Each WP leader will submit all the produced documents to an appropriate expert internal to another partner organisation to check for the quality of the documents produced.

Finally, as part of the evaluation process we will apply a risk management approach assessing risk in technical, operational and human resources, the probability that they happens and the impact they will have in the project. Risk will be assessed within the Steering Committee and actions to reduce the threats and to solve the situations when these threats will be deployed.

B.2.1.6 Communication flow

Ensuring a good communication among project partners and towards outside entities represents an important key of success for the project and a fundamental practice to manage the project at its best. This can only be achieved through the intensive use of electronic communications (e.g. email, web based exchanges). A project website will also be used to enable fast and efficient exchanges of information.

The Project Coordinator will set up the communication channels for use by the consortium. This will be implemented, among others by:

- 1-2 day kick-off meeting to guarantee in-depth knowledge exchange
- Regular physical consortium meeting (at least once in every 6 months)
- Monthly written progress reports: will be requested by the Project Coordinator who will compile the reports in a Project Monthly Progress Report for distribution in the consortium
- Phone and e-mail interchanges (day to day cooperative working infrastructure)
- Additional regular communication means will be decided upon project start; this may include regular phone conference to discuss project advancement and next steps (at least once in every 3 months).

The external communication includes (external communication is detailed in the Dissemination and Exploitation section of this document):

- the dissemination through publications
- project website
- Attendance at conferences
- Attendance at events, workshops.

It is well known that systematic and timely implementation of information flow is central for any Consortium based project. Nevertheless, overflow of information should obviously also be avoided.

The OPPORTUNITY Project Coordinator has the duty to communicate on a systematic and frequent basis even if no problems are identified with all WP leaders during the lifecycle of their WP to assure the smooth flow of OPPORTUNITY Project activities.

All ordinary messages related to a certain workpackage will be communicated among all partners involved in that workpackage. Nevertheless, any special important issues or problems within the frame of a WP, are going to be forwarded to the WP leader (if the message is not initiated by him/her) and to the Steering Committee members.

As it has been described above the number of meetings should be minimised to a certain extent, but the interaction among partners which is brought up during these meetings is considered of crucial importance, thus it has been planned to have, at least, 6 meetings of the Steering Committee along the 36 months of project life cycle.

The experience in running other research projects, the good relationships and mutual knowledge of the partners as well as the previous working together successfully for most of the partners, almost ensures the inexistence of problems regarding communication and information flow along the development of the OPPORTUNITY Project.

B.2.1.7 Statement of Quality

The OPPORTUNITY Consortium recognizes that a dedication to quality is vital to the OPPORTUNITY project. Therefore the Consortium agrees on developing a Statement of Quality with regards to its work.

The OPPORTUNITY Consortium has been dedicated to the pursuit of excellence since the inception of the OPPORTUNITY Project. The primary responsibility for achieving excellence rests with each person participating in the OPPORTUNITY Project. In addition the consortium members agree to pay particular attention to the following sets of principles, which inform the OPPORTUNITY project quality approach. These are:

- All OPPORTUNITY partners are responsible for quality. OPPORTUNITY partners aim to assure the very highest quality in all the information and analysis it will provide, both *internally* and *externally*.
- Deliverables will be peer reviewed internally and improved according to feedback.
- Quality of publications will be ensured by internal peer review on a voluntary basis and proactive publication planning.
- In all outside communication of OPPORTUNITY quality issues will be considered. This includes: presence at events and workshops; web presence; dissemination material.
- OPPORTUNITY Consortium recognize that one important factor in assuring quality is a constant re-examination of our own work against the needs of planned objectives. In this way we can assure ourselves that we are maintaining appropriate standards and also demonstrate accountability to the Commission and the public in general of our work.

B.2.1.8 Management of knowledge and Intellectual Property and other Legal Aspects

We foresee that a number of knowledge management, legal and IPR aspects discussed in this section may not need to be applied during project execution due to the nature of project and the composition of the consortium, made up exclusively of scientific institutions. Nevertheless it is important to outline the agreement of the consortium on basic principles, shall the need to address specific issues arise during the project.

The legal aspects (e.g. intellectual property, regulations, confidentiality and safety) will be handled according to the relevant EU regulations and laws. The Steering Committee is committed to follow this aspect and to help the partners find a satisfactory agreement. This agreement will be concerned about the issues that can arise around management of knowledge, specifically:

- Confidentiality among project internal and external institutions.
- Knowledge transfer and results ownership both individual and collective for future exploitation.
- Management of special cases like pre-existing knowledge, commercial exploitation, sublicenses, legal protection like patents and others.

The Project Coordinator will perform the following tasks (as a minimum) in order to ensure good management of knowledge and intellectual property handling:

- Ensuring that all IPR produced by OPPORTUNITY are protected according to the policy of the consortium agreement.

- Construct licensing arrangements between the partners of the consortium (if required).
- Constantly review OPPORTUNITY dissemination strategies to ensure the best possible results for Exploitation.
- Ensure writing articles in scientific/technological journals and conferences, for press releases and general media exposure.
- Ensuring the OPPORTUNITY web site is constantly up-dated.
- Be responsible for the supply of information to CORDIS.
- Be responsible for the incorporation of the OPPORTUNITY results in exhibitions where the partners participate.

The project participants have already agreed on the following Intellectual Property issues:

a) All information provided by a Contractor to other Contractors within the project is confidential unless:

i) It was already known to the Contractor before the negotiations started, or

ii) The information provided is public property, or

iii) It is explicitly specified otherwise by the originator of the information.

b) Contractors agree to use the information provided only for the purposes of conducting the project. Any disclosure of confidential information to a third party requires the explicit consent of the originator of that information.

c) Proper records, indicating the originator and the date of the transfer, must be kept when information is transferred between Contractors.

d) When more than one Contractor claims joint ownership of newly produced intellectual property, the Contractors involved should make provisions to clarify the terms of joint ownership among them.

e) Contractors are not restricted in any sense regarding the rights associated with the ownership of any intellectual property they produce while conducting the project activities.

B.2.1.9 Consortium Agreement

The first task of the Coordinator will be to construct a consortium Agreement between all the partners. This will be done immediately after receiving the project approval by the commission. The consortium agreement will be agreed and signed before any of the partners start working on the project.

The consortium agreement will cover the following issues, as a minimum:

- The internal organisation and management of the consortium
- Collective Responsibility of the partners
- Intellectual property arrangements either generated during the project or existing prior to or acquired in parallel with the project;
- Roles in the consortium
- Financial viability and audits
- Exploitation of the project results and Commercial considerations.
- Settlement of internal disputes, change in consortium membership, potential solution to problems relating to technical implementation and solution to potential financial problems;

B.2.2 Beneficiaries

B.2.2.1 ETHZ Zürich, Wearable Computing Laboratory, Switzerland

The Wearable Computing Laboratory at the ETHZ in Zürich, Switzerland (http://www.wearable.ethz.ch) led by Prof. G. Tröster is a large interdisciplinary research laboratory with about 15 PhD students and two post-docs and additional technical staff, with background in computer science, electrical engineering, signal processing, machine learning, bio-inspired computation, physics and textile engineering.
Our expertise on technology and algorithms allow us to define, design, implement and test state-of-the-art wearable and pervasive computing system and context-aware systems for a wide-range of applications. Our activities include miniaturization and integration of distributed wearable systems (including system modelling, architecture design, and platform implementation); body and personal area networks; low-power context aware computing; modelling of wearable and pervasive computing systems, smart textiles (textile sensors, textile integration); energy generation micro-systems; novel HCI interfaces (focus-free retinal displays, EOG-based interfaces); reconfigurable computing.

Applications include worker's assistants, healthcare assistants, entertainment in addition to supporting basic research.

A core research focus is the development of activity recognition algorithms using multi-modal sensor fusion with wearable and ambient sensors. We investigate offline as well as novel online machine learning methods to segment and classify activities from multimodal sensor data. We investigate adaptive context recognition algorithms adjusting their operation to sensing resources, user parameters, and capable of coping with variability in open-ended dynamic environments. Based on our expertise in system modeling we design low-power, context-aware systems with adjustable power-accuracy trade-offs in single sensor systems as well as in (wireless) sensor networks. We envision symbiotic interactions between context aware systems and users towards embodied context aware systems. As such we investigate adaptation, learning and feedback principles, and we seek to achieve a "human like" perception of context driving such feedback. We pursue this goal through novel sensors technologies and context recognition algorithms towards cognitive-affective context recognition, in addition to physical activities and social context. We rely on our expertise in technology to devise systems for long-term recording in real-world situations of multi-modal data to drive algorithm development (physical activity, context, and physiological parameters).

The laboratory is an active member of the community, organizing or hosting many conferences including recently ISWC 2006 (International Symposium on Wearable Computers), ARCS 2007 (Architecture of Computing Systems), EuroSSC 2008 (European Conference on Smart Sensing and Context), and Pervasive Health 2009.

EU and national research projects.

The laboratory has a large experience of collaborative research projects. The laboratory was involved in the following EU research projects. In AMON we developed a health monitoring device worn at the hand joint. In MyHeart we develop sensors and methods to detect of nutrition phases to support healthy lifestyle. In Daphnet we develop a context-aware platform for long-term recording of physical and physiological signals. In SEAT we develop a smart seat improving passenger comfort by sensing and biofeedback. In wearIT@work we develop wearable context-aware computer systems to empower workers in industrial manufacturing. In e-sense and SENSEI we develop a framework for context awareness in dynamic and heterogeneous wireless sensors & actuator networks.

In the nationally funded projects "Functional Electrostimulation" and "SensorShirt" we are active in the development of clothing-integrated textile electrodes and noise reduction.

Key Participants
Dr. Daniel Roggen received his M.S. in microengineering in 2000 from the EPFL (Swiss Federal Institute of Technology) in Lausanne, Switzerland. Before starting his PhD he worked for VisioWave (now General Electrics) in the optimization of wavelet-based video compression algorithms for video surveillance on Itanium and IA-32 architectures. He received his PhD degree in 2005 from the EPFL where he developed bio-inspired electronic circuits with fault-tolerance, learning, and developmental capabilities that were applied to the control

of autonomous mobile robots and to signal processing. This work was carried out in context of the EU FP5 FET project POEtic.
Since 2005 he is Senior Research Fellow in the Wearable Computing Lab at ETHZ Zürich. His activities include context recognition algorithms, embedded wearable systems, sensor fusion, and learning and adaptivity in wearable systems with the objective of achieving collaborative . He has published several peer-reviewed conference and journal papers.
Dr. D. Roggen is general chair of EuroSSC 2008 (European Conference on Smart Sensing and Context), and was program committee of ARCS 2007, and local chair of ISWC 2006 (International Symposium on Wearable Computers).

Prof. Gerhard Tröster received the M.S. degree from the Technical University of Karlsruhe, Germany, in 1978 and the Ph.D degree from the Technical University of Darmstadt, Germany, in 1984, both in electrical engineering. He is a Professor and head of the Electronics Laboratory, ETHZ Zürich, Switzerland. During the eight years he spent at Telefunken Corporation, Germany, he was responsible for various national and international research projects focused on key components for ISDN and digital mobile phones. His field of research includes wearable computing, reconfigurable systems, signal processing, mechatronics, and electronic packaging. In 2000, he initiated the ETHZ Wearable Computing Lab as a Centre of Excellence, supported by the ETHZ management with 2 Mio CHF. He authored and co-authored more than 100 articles and holds five patents. In 1997, he confounded the spin-off u-blox ag.
Recently, Prof. G. Tröster was general chair of the ARCS 2007 conference (Architecture of Computing Systems), and is general chair of the Pervasive Health 2009 conference.

Selected Publications

2. T. Stiefmeier, D. Roggen, G. Ogris, P. Lukowicz, G. Tröster. **Wearable Activity Tracking in Car Manufacturing**. In: *IEEE Pervasive Computing Magazine*, April-June, 2008.
3. J. Schumm, M. Bächlin, C. Setz, B. Arnrich, D. Roggen, and G. Tröster. **Effect of movements on the electrodermal response after a startle event**. *Methods of Information in Medicine*, 47(3), 2008.
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B.2.2.2 University of Passau

The University of Passau (UP) will participate in the project with the Embedded Systems Lab (ESL). The Lab is devoted to research on adaptive, intelligent systems seamlessly integrated in the environment. This includes wearable computing, sensors and sensor networks, activity and context recognition, software tools, system models, and a wide range of pervasive computing applications. We are particularly interested in large scale systems that self organize to cooperate in dynamic, opportunistic configurations. In the application area ESL has a strong emphasis on health and wellness related systems [13].
Most notable previous work on activitiy recognition includes:

- tracking activities such as sawing, hammering, screw-driving, drilling etc. during a wood workshop assembly procedure using a set of accelerometer [1]
- monitoring a bike repair procedure consisting of 20 individual activities with a combination of several inertial sensors and an ultrasonic hand tracking sytem (in cooperation with the group at ETH) [7]
- using microphones in the users ear to detect food intake and distigiush between different kinds of food [3]
- spotting of activitiy related hand motions using motion sensors [5]

Other previous and current work relevant for opporunity are studies in the use of different innovative on body sensing modalities activitiy recognition [4,7,11] and modelling the ustility and performance tradeoffs of different sensor combinations [2,6,9,12]
Recently the focus of the work has increasingly shifted away from complex, custom designed sensor configuration to system to activitiy recogniton with systems and devices commonly found in every day use. This included using the accelerometer and microphone in a conventional mobile phone to self-locate it [14] and demonstration of accelerometers automatically detecting their on body location [15].
The Lab has a well equipped electronic hardware workshop, a wide range of sensors and wearable devices, and considerable experience in using such devices for complex context related experiments
The group has developed a software framework for adaptive, distributed context recognition systems [10] and a number of applications including a wearable assistant for doctors

Related EU Projects
The Lab is currently involved in 4 FP6/FP7 projects in which it is in charge of context and activity recognition related issues:

- WearIt@Work: A large IP devoted to industrial uses of wearable computing. Our group leads the context recognition work.
- RELATE: A FET STREP project dedicated to relative position between smart objects.
- MonAmi: An IP on applying pervasive technology, including activity monitoring to Ambient Assited Living Systems
- Allow, an FP7 FET STREP devoted to use of context awarness in adaptive workflows

In addition an industrial project with FLAKE AG (sports clothing manufacturer) is devoted to using on body FSR sensors (forse sensitive resistors) for muscle activity detection.

Key Participants
Prof. Dr. Paul Lukowicz
Paul Lukowicz has a MSc (Diplom) in Computer, a MSc (Diplom) in Physics and a Ph.D in Computer Science all from the University of Karlsruhe in Germany. After his Ph.D Paul Lukowicz went to ETH Zurich where built up the wearable computing group with a strong focus on activity and context recognition. He then went on to Professorship in Computer Engineering at the University of Medical Informatics and Technology in Hall in Tirol, Austria (UMIT) where his group worked on health related applications of pervasive computing and context recognition. This included leading a large project focused on activity tracking in nursing sponsored by the Austriann HITT (Health Infrmation Technology) competence centre. Paul Lukowicz has also been involved with numerous European FP5 and FP6 projects including being a coordinator of a medium size STREP. Paul Lukowicz is engaged in the international ambient intelligence Community through a variety of program committees and being a ememebr of the editorial board of the IEEE Pervasive Computing Magazine where he is responsible for the Wearable Computing Department.

Georg Ogris is a doctoral candidate and a member of the research staff at the Embedded Systems Laboratory at the University of Passau. His research interest is in embedded time series analysis with the focus on context aware computing. He was engaged in several EU funded projects including the following: DETECT in object detection in video broadcasts; RELATE in relative positioning of mobile objects in ad hoc networks;

wearIT@work in development of wearables and wearable processes for industrial applications. His focus within these projects was both on software/algorithm and hardware development. He received a master's degree in computer science from UMIT, Austria and an engineer's degree in electronics from Technikum Wien, Austria.

Selected Publications

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15. Kunze, K., Lukowicz, P.: Using acceleration signatures from everyday activities for on-body device location . In: Proc. of the 10 th International Symposium on Wearable Computing. ISWC 2007, Boston, USA.

B.2.2.3 Johannes Kepler Universität Linz

The University of Linz. The Johannes Kepler University Linz is the largest research and teaching institution in Upper Austria, and thus as a centre of knowledge transfer, the university contributes to the maintenance and the development of the region. It participates in centres of competence and develops spin-off programs supporting business start-ups. JKU has also close links with business and industry and an international network of partner and cooperations. The Faculty of Engineering and Natural Sciences has 49 Departments, 5 Areas of Study (Computer Science, Mechatronics, Technical Mathematics, Technical Chemistry, Technical Physics, Economics –Technical Chemistry, Teacher Training for Secondary Schools), more than 230 academic staff and more than 4 300 graduates since the creation of the faculty. Since 2000 it hosts the Excellence Initiative “Pervasive Computing”, headed by Prof. Ferscha, consolidating the effort of 12 computer science research departments towards the field of Pervasive and Ubiquitous Computing. The Excellence Initiative is also the host of international conferences and events in the field, like PERVASIVE 2004, or ISWC’09.

The Department of Pervasive Computing has a strong tradition in identifying and addressing basic research problems and strategic research fields emerging from the evolution of a globalising information and knowledge society – as done in various consultations for the European Commission like for the BEYOND-THE-HORIZON (Ferscha was heading WP1 “Pervasive Computing and Communications”) or InterLink. In the recent FP7 project PANORAMA, Ferscha is responsible for the WP Research Agenda. Aside this, Ferscha has a strong background in simulation, interactive simulation and parallel and distributed simulation techniques (General Chairs of PADS’97, Program Chair of PADS’98, Program Chair of MASCOTS’99 and Program Chair of DS-RT 2008). This expertise in formal methods and algorithms for distributed and interactive simulation, as well as the engagement in the pervasive and ubiquitous computing domain will also drive the OPPORTUNITY challenges.

Key Participants

Prof. Alois Ferscha was with the Department of Applied Computer Science at the University of Vienna at the levels of assistant and associate professor (1986-1999). In 2000 he joined the University of Linz as full professor where he heads the Excellence Initiative “Pervasive Computing”, the department of Pervasive Computing, the Research Studio Pervasive Computing Applications (as Part of ARC Austrian Research Centers, Seibersdorf) and RIPE (Research Institute of Pervasive Computing). Ferscha has published more than a hundred technical papers on topics related to parallel and distributed computing. Currently he is focused on Pervasive and Ubiquitous Computing, Embedded Software Systems, Wireless Communication, Multiuser Cooperation, Distributed Interaction and Distributed Interactive Simulation. He has been a visiting researcher at the Dipartimento di Informatica, Universita di Torino, Italy, at the Dipartimento di Informatica, Universita di Genoa, Italy, at the Computer Science Department, University of Maryland at College Park, College Park, Maryland, and at the Department of Computer and Information Sciences, University of Oregon, Eugene, Oregon, U.S.A. He has been the project leader of several national and international research projects. Some of his recent involvements in projects are InterLink (funded by IST FET), BEYOND THE HORIZON (funded by IST FET), CRUISE NoE – Creating Ubiquitous Intelligent Sensing Environments (IST FP6), SPECTACLES (Autonomous Wearable Display Systems) in cooperation with Silhouette International, INSTAR (Information and Navigation Systems Through Augmented Reality) (2001-2003), Siemens München, AG, CT-SE-1, BISANTE, EU/IST, Broadband Integrated Satellite Network Traffic Evaluation (1999-2001), Peer-to-Peer Coordination (2001–), Siemens München, AG, CT-SE-2, Context Framework for Mobile User Applications (2001–), Siemens München, AG, CT-SE-2, WebWall, Communication via Public Community Displays, Connect Austria (2001-2002), VRIO, Virtual Reality I/O, with GUP JKU, IBM Upper Austria (2002-2003), MobiLearn, Computer Science Any-Time Any-Where, (2002-2004), Mobile Sports Community Services, (SMS Real Time Notification at Vienna City Marathon 1999, 2000, 2001, 2002; Berlin Marathon 2000, 2001, 2002), etc. He has served on editorial boards of renowned international scientific journals (e.g. Pervasive and Mobile Computing (Elsevier), Transactions of the Society for Computer Simulation), on steering and programme committees of several conferences like PERVASIVE, UMBICOMP, ISWC, WWW, PADS, DIS-RT, SIGMETRICS, MASCOTS, MSWiM, MobiWac, TOOLS, Euro-Par, PNPM, ICS, etc. to name a few. His activities and recognition in the parallel and distributed simulation community is expressed by his being the General Chair of the IEEE/ACM/SCS 11th Workshop on Parallel and Distributed Simulation (PADS’97), has served on the committees of several conferences, the Program Committee chair for the PADS’98, Program Committee chair for the Seventh International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS’99), and recently the 12-th IEEE International Symposium on Distributed Simulation and Real Time Applications (DS-RT 2008).

Selected Publications

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2. Ferscha, A., Hechinger, M., dos Santos Rocha, M., Mayrhofer, R., Zeidler, A., Riener, A., Franz, M.: **Building Flexible Manufacturing Systems Based on Peer-its**. In: Special Issue on Embedded Systems Design in Intelligent Industrial Automation, EURASIP Journal on Embedded Systems. October 2007.
3. Holzmann, C. and Ferscha, A.: **Towards Collective Spatial Awareness Using Binary Relations.** Proceedings of the 3rd International Conference on Autonomic and Autonomous Systems (ICAS 2007), IEEE CS Press, Athens, Greece, ISBN: 0-7695-2859-5, pp. 36, June 2007.
4. Ferscha, A.: **Informative Art Display Metaphors**, in Proceedings of the 4th International Conference on Universal Access in Human-Computer Interaction (UAHCI 2007), Springer LNCS, Beijing, China, vol. 4555, pp. 82-92, July, 2007.
5. Ferscha, A., Resmerita, S.: **Gestural interaction in the pervasive computing landscape**. In: e & i Elektrotechnik und Informationstechnik. No. 1-2, Vol. 124, Springer-Verlag Wien, February, 2007, pp. 17-25.
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8. Ferscha, A., Holzmann, C. and Resmerita, St.; **Human Computer Confluence**. Proceedings of the 9th ERCIM Workshop on User Interfaces for All (UI4All 2006): Interaction Platforms and Techniques for Ambient Intelligence, Springer LNCS, Königswinter, Germany, Vol. 4397, ISBN: 3-540-71024-8, pp. 14-27, September 2006.
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11. Ferscha, A., Vogl, S., Beer, W.: **Context Sensing, Aggregation, Representation and Exploitation in Wireless Networks** Scalable Computing In: Practice and Experience, SWPS, Parallel and Distributed Computing. No. 2, Vol. 6. ISSN: 1895-1767, June 2005, pp. 77-81.
12. Ferscha, A., Vogl, S.: **Pervasive Web Access via Public Communication Walls**, Proceedings of the 1st International Conference on Pervasive Computing (Pervasive 2002), Springer LNCS, Zurich, Switzerland, vol. 2414, pp. 84-97, August, 2002.
13. Mayrhofer, R., Radi, H., Ferscha, A.: **Recognizing and Predicting Context by Learning from User Behavior**. In: Special Issue on Mobile Multimedia: Journal of Communication Engineering. No. 1, Vol. 1. ITB Press, Radiomatics. ISSN: 1693-5152, May 2004, pp. 30-42.
14. Ferscha, A., Johnson, J., Turner, S.: **Distributed Simulation Performance Data Mining**. In: Journal of Future Generation Computing Systems. No. 1, Vol. 18. Elsevier Science, North Holland, 2001, pp. 157-174.
15. Ferscha, A.: **Adaptive Time Warp Simulation of Timed Petri Nets**, In: IEEE Transactions on Software Engineering. No. 2, Vol. 25, IEEE Press, April 1999.

B.2.2.4 Ecole Polytechnique Fédérale de Lausanne, Switzerland

***Remark:** consortium beneficiary #4 is the research laboratory led by Prof. José del R. Millán, formerly affiliated with the IDIAP Research Institute (www.idiap.ch) until end of 2008, and now affiliated with the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. In this transition process all the laboratory, equipment and personnel will be transferred from IDIAP to EPFL. The profile provided below describes the state of the group at IDIAP, with the understanding that the group once the transfer to EPFL is complete will take over the same role, with the same group members, expertise, and laboratory setups.*

Consortium beneficiary #4 is the research laboratory led by Prof. José del R. Millán, formerly affiliated to the IDIAP research institude located in Martigny (Switzerland), and now affiliated to the Ecole Polytechnique Fédérale de Lausanne.

The IDIAP Research Institute (www.idiap.ch) is an independent, not-for-profit, research institute located in Martigny (Switzerland), and affiliated with the Swiss Federal Institute of Technology at Lausanne (EPFL), and the University of Geneva. Primarily funded by the Federal Government, the State of Valais, and the City of Martigny, IDIAP is involved in numerous national and international (EU and US) projects, as well as in multiple collaborative projects with the industry. With a research staff of more than 75 scientists (including EPFL professors, seniors, postdoctoral researchers, PhD students and developers), the primary missions of IDIAP are research, education, and technology transfer in the areas machine learning, speech and audio processing, computer vision, information retrieval, biometric authentication, multimodal interaction, and multiple multimodal research activities across these disciplines. At the national level, IDIAP is also the “Leading House” of the National Centre of Competence in Research (NCCR) on “Interactive Multimodal Information Management” (IM2). At the EU level, IDIAP is involved in numerous projects and Networks of Excellence, In particular IDIAP is part of the PASCAL network (Pattern analysis, statistical modeling and computational Learning, renewed into PASCAL2) and the integrated project BACS (Bayesian approaches to cognitive systems) and is currently managing two Integrated Projects (AMIDA and DIRAC). In the US, IDIAP is partner of a large DARPA project (GALE) and coordinator of a DTO project (Roadmap, as part of the VACE program). IDIAP will mainly contribute to Opportunity its expertise on developing robust machine learning techniques for Human-machine interaction, and its longstanding experience on the development of Brain-Computer Interfaces.

Key Participants

Dr. Ricardo Chavarriaga is a scientific researcher at the IDIAP Research Institute in Martigny, Switzerland. He received an engineering degree in electronics from the Pontifcia Universidad Javeriana in Cali, Colombia in 1998, and a PhD in Computational Neuroscience from the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland in 2005. At IDIAP, his work is focused on the analysis of brain electrical signals and the design of brain-computer interfaces. In particular, he is interested on the study of neurophysiological correlates of human cognitive processing and its potential use in Human-machine interaction. Dr. Chavarriaga participates actively in several multi-partners projects such as the Swiss NCCR (IM2) and the European BACS project.

Prof. Dr. José del R. Millán is a senior researcher at IDIAP Research and an adjunct professor at the Ecole Polytechnique Fédérale de Lausanne (EPFL). His current research interests are the use of brain signals for multimodal interaction and, in particular, the development of non-invasive brain-controlled robots and neuroprostheses. In this multidisciplinary research effort, Dr. Millán is bringing together his pioneering work on the two fields of Brain-Computer interfaces (BCI) and adaptive intelligent robotics. Prior to joining IDIAP, he has been a research scientist at the Joint Research Centre of the European Commission in Ispra, Italy, and a visiting professor at the EPFL. His research on BCI was nominated finalist of the European Descartes Prize 2001 and he was named “Research Leader 2004” by the journal Scientific American for his work on brain-controlled robots. The journal Science has reviewed his work as one of the world’s key researchers in the field of BCI. Dr. Millán is the coordinator of a number of international projects in the field of BCI (notably the European projects ABI, 1998-2001, and MAIA, 2004-2007) and also is a frequent keynote speaker at international events. His work on BCI has received wide media coverage around the world.

Selected Publications

1. Ricardo Chavarriaga, Ferran Galán, and José del R. Millán **Asynchronous detection and classification of oscillatory brain activity**. *European Signal Proc Conf. EUSIPCO*, 2008
2. Nicolas Bourdaud, Ricardo Chavarriaga, Ferran Galán, and José del R. Millán **Characterizing the EEG Correlates of Exploratory Behavior.** *IEEE Trans Neural Syst Rehab Eng*, to appear
2. José del R. Millán, Pierre W. Ferrez, Ferran Galán, Eileen Lew, and Ricardo Chavarriaga, **Non-Invasive Brain-Machine Interaction**, *International Journal of Pattern Recognition and Artificial Intelligence*, 2008.

3. Pierre W. Ferrez and José del R. Millán. **Error-related EEG potentials generated during simulated Brain-Computer interaction**. *IEEE Trans Biomed Eng*, (55)923-929, 2008
4. Sebastian Marcel and José del R. Millán. **Person Authentication using Brainwaves (EEG) and Maximum A Posteriori Model Adaptation**. *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 29(4): 743–748, 2007
5. Ricardo Chavarriaga, Pierre W. Ferrez, and José del R. Millán. **To err is human: Learning from error potentials in Brain-Computer interfaces**. *International Conference on Cognitive Neurodynamics*, Shanghai, China, 2007
6. Xavier Perrin, Ricardo Chavarriaga, Céline Ray, Roland Siegwart and José del R. Millán. **A comparative psychophysical and EEG study of different feedback modalities for Human-Robot Interaction**. *ACM/IEEE Conf on Human-Robot Interaction HRI08*, Amsterdam, Mars 2008
7. Gangadhar Garipelli, Ferran Galán, Ricardo Chavarriaga, Pierre W. Ferrez, Eileen Lew and José del R. Millán. **The use of Brain-Computer Interfacing in Ambient intelligence**. *European Conf Ambient Intelligence (AmI'07)*, Darmstadt, Germany, Nov 2007.
8. Ferran Galán, Pierre. W. Ferrez, Francesc Oliva, Joan Guàrdia, and José del R. Millán. **Feature extraction for multi-class BCI using canonical variates analysis**. In IEEE International Symposium on Intelligent Signal Processing, 2007
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12. José del R. Millán. **Adaptive brain interfaces**. *Communications of the ACM*, 46(3):74–80, 2003
13. José del R. Millán and Josep Mouriño. **Asynchronous BCI and local neural classifiers: An overview of the Adaptive Brain Interface project.** *IEEE Trans Neural Syst Rehabil Eng*, 11(2):159–161, 2003
14. José del R. Millán, Josep Mouriño, Marco Franzé, Febo Cincotti, Markus Varsta, Jukka Heikkonen, and Fabio Babiloni**. A local neural classifier for the recognition of EEG patterns associated to mental tasks.** *IEEE Trans Neural Networks*, 13(3):678–686, 2002

B.2.3 Consortium as a whole

The first and foremost criterion when assembling the OPPORTUNITY consortium has been to bring together partners that cover the expertise needed to conduct the project research agenda and who are internationally recognized leaders in their respective fields. Second we made sure that there is a sufficient overlap between the partners' competencies to provide a sufficient degree of redundancy and ensure smooth cooperation and communication.

As explained in detail below we have sensing and signal processing part of the context recognition chain primarily covered by UP, machine learning and classification by EPFL, unsupervised adaptation by ETHZ and cooperation, coordination and control in complex sensor networks and embedded systems by JKU. However, as an example, ETH and JKU also have know how in sensing and signal processing, UP and ETH have strong applied pattern recognition credentials, and EPFL has a lot of work in unsupervised, adaptive systems to show. General topics such as Ambient Intelligence, Wearable Computing, Embedded Systems and Self-Organization in general are each covered by at least 3 of the 4 partners.

Among themselves the groups involved in OPPORTUNITY have in recent years published well over a hundred articles in top journals (including IEEE PAMI, IEEE Computer, IEEE Trans. In Bio. Med. Eng.) and conferences (including UBICOMP, Pervasive, IJCAI with acceptance rates at times below 20%). They are members of key program committees and editorial boards (e.g. IEEE Pervasive Magazine) in the field.

An important aspect of the consortium is the fact that all partners have a lot of experience with European projects (see section 3.2.1) and have in their labs the infrastructure and experienced personnel required to carry out the OPPORTUNITY project (see 2.4). This will ensure smooth and efficient project execution.

Finally the partners have strong industrial contacts and are involved in a variety of application projects that can exploit OPPORTUNITY results. Again there is strong complementarity with e.g. Linz working more in interactive environments, Passau in AAL systems, ETH in Personal Lifestyle Mangement and EPFL in Brain Computer Interfaces. This will facilitate broad dissemination to potential exploitation partners.

B.2.3.1 Consortium description and contributions

The project has assembled a consortium with the key expertise to achieve the project's objective. The consortium partners have well defined roles, inline with their specific competences. The expertise of partners is distinct, yet each has a multidisciplinary background and understanding of other partners activities. This enables fast and efficient communication. It allows each partner to understand the challenges and methodologies pursued by other partners and ensures that methods and principles developed within the consortium address the project's objective and take into account the specificities of each problem domain brought up by the partners.

The table below summarizes the expertise of the consortium members, and the roles played in the project.

no.	Participant	Country	Expertise	Role
1	ETHZ	CH	Wearable computing and embedded systems, wireless sensor networks, context and activity recognition, signal processing, modelling of context aware systems, bio-inspired systems, adaptive/intelligent systems	Project coordinator Leads WP3 on "Dynamic adaptation and autonomous evolution", contributes to activity recognition validation scenarios. Focus on activity recognition from body-worn and ambient sensors given changing resources by online learning. It leads WP6 (project management) and WP7 (dissemination and exploitation).
2	UP	DE	Context/activity-aware computing, wearable and pervasive/ubiquitous computing (ambient intelligence), sensors and sensor networks, software tools, system modelling, real-world multi-modal activity recognition systems	Leads WP1 on "Sensors and features" and contributes to context/activity recognition validation scenarios. Focus on context and activity recognition from body-worn and ambient sensors given intermediate features and system self-description/self-configuration Leads WP5 on "Case studies".
3	JKU	AT	Pervasive and ubiquitous computing, Embedded Software Systems, Wireless Communication, Parallel and distributed computing, Multiuser Cooperation, Distributed Interaction	Leads WP4 on "Ad-hoc, cooperative sensing" and contributes to context recognition validation scenario. Focus on goal-directed cooperative sensing ensembles, distribution of context-recognition mission in a sensor network.
4	EPFL	CH	Machine learning, Human-machine interaction, EEG-based Brain-Computer interfaces, multimodal interaction, neuroprostheses, neurophysiological correlates of cognition, brain signal for multimodal interaction,	Leads WP2 on "Opportunistic classifiers" and contributes to EEG-based Brain Computer Interface validation scenario. Focus on machine learning algorithms optimized for online signal

			signal processing, adaptive systems, Non-invasive brain controllers..	classification on low-power devices.

The project execution can be roughly seen as first developing novel methods to deal with context and activity recognition in opportunistic networks, and then validating these approaches on a number of scenarios. All partners will participate to the development of the OPPORTUNTIY approaches, and on the validation of these approaches. We outline below how the capabilities of the consortium members complement each other to achieve the project goals.

Leading expertise: maximizing outcomes with a limited consortium size

All the partners have long standing international expertise in designing state of the art, complex multimodal activity and context recognition systems for challenging real-world scenarios (see partner description in section B.2.2).

ETHZ and UP have leading expertise in wearable (on-body sensors) activity recognition systems. UP and JKU have leading expertise in ambient intelligence and pervasive context recognition (ambient sensors). EPFL has leading expertise in the design of EEG-based Brain Computer Interfaces.

This expertise as a whole enables the consortium members to tackle the challenging problems outlined in this proposal despite the limited size of the consortium.

The partners will capitalize on a large number of existing, well studied case studies, hardware and state of the art algorithms. As a consequence, the consortium will be able to tackle the novel scientific objectives of OPPORTUNITY without having to face the prior challenges (already addressed in past research) of investigating statically defined, application specific context and activity recognition systems for complex real-world scenarios.

Contributions to OPPORTUNITY approaches

The four partners will contribute to the development of methods to recognize activities and context given opportunistic sensor configurations. Each partner will have a core contribution in a specific domain, and will contribute to a lesser extend in other domains.

JKU will contribute to the development of goal-oriented cooperative sensing ensembles, including software architecture and programming models (WP4). On the basis of sensed data, UP and JKU will investigate means for the system to self-describe and self-configure itself. UP will specifically investigate sensor aspects and means to abstract from these sensors by using intermediate feature representations (W1). EPFL will develop the machine learning tools: classifiers, classifier fusion methods and online classifier adaptation methods optimized for opportunistic networks (WP2). ETHZ will develop dynamic adaptation principles to cope with changing number of resources (sensor addition/removal) and signal degradation (WP3).

Collaborations

Obviously all partners will closely collaborate during the development of the OPPORTUNITY approaches. The workpackages are interconnected. This requires a close collaborations in all workpackages. Therefore, although the WP leader will be the main contributor and coordinator of the WP, the cumulative PM participation of the other consortium partners to each WP will be close to that of the coordinator. This will emphasize and formalize the need for these tight collaborations between all consortium members.

As an example, the classification chain (sensor, feature, classification) needs to be considered as a whole which requires strong collaborative work between UP and EPFL; dynamic adaptation is strongly linked to the classifications activities, but also to goal-oriented cooperative sensing, thus requiring strong collaboration between ETHZ, UP, EPFL and JKU. These close collaborations will be facilitated by the interdisciplinarity of each partner, and the strong expertise of all partners in the field of activity and context recognition.

Scientific and technical balance

The key objective of this FET project are to achieve scientific advances (see "Beyond state of the art" in section 1.2). This will be the primary effort of OPPORTUNITY. However science needs to be supported by technology. In OPPORTUNITY, technology mostly relates to sensor hardware (wearable and ambient) to be able to infer user context/activities.

We put our research effort on the core scientific and algorithmic issues required to achieve opportunistic context/activity recognition. For technical aspects we will rely wherever possible on standard technologies in order to concentrate on the scientific challenges. Hardware-wise the project will rely on commercial off-the-shelf components and on the large set of devices and systems already available by the consortium members. Concerning networking hardware, we will use standard commercial components and protocols (e.g. Zigbee, ANT, Bluetooth).

However, the consortium partners ETHZ, UP and JKU have a long expertise in developing sensor hardware. If the need arises during the project, the required sensor hardware can be developed in a very efficient way by capitalizing on the existing infrastructure, background material, engineers, and running applied research RTD projects.

Validation in application scenarios

Two categories of validation scenarios are considered: a validation scenario in activity/context recognition, and another validation scenario in EEG-based Brain-Computer Interfaces.

ETHZ, UP and JKU will focus on the activity/context recognition scenario. These partners have a long expertise in that field (see section 2.2). ETHZ and UP are particularly focusing on the detection of user activities from body-worn sensors (although ambient sensors will also be considered), including manipulative gestures, general body motion and posture, interaction with devices and objects and interaction with other humans. JKU is focusing on the use of ambient sensors (instrumented environments) and "software sensors", in addition to information about extended location to infer high-level user activities. As a whole, ETHZ, UP and JKU have the expertise and the required setups (sensors, instrumented environments, smart objects) to validate OPPORTUNITY in activity/context recognition scenarios, and assess performance with respect traditional approaches.

EPFL will assess the generality of the approaches developed within OPPORUNITY by applying them in an EEG-based Brain Computer Interface scenario. EPFL has deep expertise in that field (see section 2.2). It has the required hardware (EEG sensors) and expertise (standardized experimental protocol, algorithms for EEG signal analysis) that will allow it to apply the methods of OPPORTUNITY (in particular dynamic adaptation) in a standardized scenario, and assess performance with respect to traditional approaches.

B.2.3.2 [Sub-contracting]

No subcontracting is foreseen.

B.2.3.3 [Third parties]

Not relevant for this project.

B.2.3.4 [Funding for beneficiaries from third countries]

Not relevant for this project.

B.2.3.5 [Additional beneficiaries / Competitive calls]

Not relevant for this project.

B.2.4 Resources to be committed

With an overall budget of 1.9M€ and a requested contribution of 1.4M€ the project volume is quite small with respect to the project aims and ambitions. Nonetheless the workplan is realistic because it builds on a large body of equipment (several hundred thousand Euro worth of sensors and other equipment will be put at the use of OPPORTUNITY), experience, algorithms, trained personnel, and even existing, ready to use experimental setups. In particular the existing experimental infrastructure for activity recognition with 'classical' means will save very significant amount of time and effort and allow the partners to concentrate on novel scientific contributions.

The core of the budget goes to human resources with each partner planning a full time person for the project plus 12 to 15PMs to be allocated to other specialized staff when specific competences are needed (plus management). There are adequate funds for travel, consumables, management and IPR issues. No major equipment purchases are needed because of the existing equipment of the partners mentioned above.

B.2.4.1 EU Contribution

The project volume of 1.9M€ (with a 1.5M€ requested contribution) accounts for the human resources, travels, material resources, and IPR protection.

Human resources. Human resources (incl. overheads) account for more than 85% of the requested contribution (the remaining being for travel, management, and material resources). The workload of each partner is of similar order and all partners receive about 24% of the total requested contribution for RTD human resources (between 50-53 PM per partner).

Travel. Since the participants are located in different countries, an adequate amount of travel expenses was added to the budget. This accounts for consortium meetings every 6 months, plus appropriate travels as necessary for the participants to fulfil their obligations. Travel RTD budget is 13.2K€, 13.2K€, 9.6K€ and 9.6K€ for partners 1 to 4 respectively.

Material resources. Thanks to the partners' composition, the project will have a majority of the required equipment to reach successfully the goals of the project (see section B.2.4.2). As a consequence, only a small amount of funding is requested for equipment and consumables (less than 3% of requested contribution). Nevertheless the following is allocated in RTD budget for consumables: ETH-10K€; UP-10K€; JKU:5K€; EPFL:5K€. The following is allocated in RTD budget for optional equipment: ETH-10K€; UP-10K€.

IPR. Provisions were made for one 15K€ PTC on ETHZ MGT budget to cover intellectual property of the consortium, shall this be required during project execution.

Dissemination activities: Each participant **will reserve a sum of 2500€ on his RTD budget** to contribute to the dissemination activities. In particular this budget will serve to organize the retreat event (see WP7) by inviting at least one to two participant external to the consortium core competence for a brainstorming event.

The coordinator reserves 2.9K€ of MGT budget (direct cost) for web-site and project flyer production.

B.2.4.2 Partner contribution

Human resources

In addition to the EU requested contribution, each of the participants will allocate appropriate amount of adequate personnel for this project. All organisations involved in the project will assign experienced staff to carry out the project (see Short CVs of key persons involved in the project for each organisation in Section 2.2.). The deep expertise of the staff in charge of the project will ensure that the return on investment of the EU financial contribution is maximized.

Hardware, infrastructure and software resources

All the involved partners have the appropriate communication facilities to foster the collaboration and facilitate the daily work.

In addition partners have already a large amount of material resources to contribute to the project. These resources include ambient intelligence devices, wearable technologies, software tools, librairies, as well as access to specialized equipment.

Hardware: sensors, wearable devices, ambient intelligence devices

- QBic Belt Integrated Computer
- SensorButton [Roggen06]: a custom TinyOS-based wrist-watch wireless sensor mote with acceleration, sound, and light sensors and low-power wireless communication, capable of recognizing the user's activities from sound and motion
- Physiological signal acquisition device (TMSC Mobi) with open source drivers, and Heartbalance HeartMan 301
- Miniature wireless motes (TMote Sky and MICAz) with motion sensor extension board
- Textile integrated pressure sensors, stretch sensors, antennas
- Miniature motion sensor, miniature long-term motion recording devices
- XSens full body-motion tracking inertial sensors
- Silicon-based textile integration technology of electronics
- Two fully portable ActiveTwo EEG/EMG acquisition systems, 32/64 electrodes (Biosemi, NL)
- Vibrotactile piezoelectric actuators with Bluetooth interface (Engineering acoustics, USA)
- Pholemus magnetic tracking system
- Miniature mobile robots: Khepera (K-Team, CH), e-puck (http://www.e-puck.org/)
- Ubisense UWB real-time location system
- See-Through-Display technology
- The Xuuk Eyebox2
- Intersense Wireless InertiaCube3
- Intersense IS-900 Precision Motion Tracker (hybrid technology of inertial and ultrasonic tracking)
- Meshed Systems PicoTag RFID
- Ekahau Real-Time Location System (802.11 RSSI based networking after fingerprinting)

Infrastructure

- Electronic and software development kits

- In-house PCB rapid prototyping facility
- Mechanics workshop, 3D printer rapid prototyping facility
- Electronic engineer
- Parallel processing cluster at EPFL (20x2 dual-core 64 bits CPUs), ETHZ (32x2 dual-core 64 bits CPUs)

Software and libraries

- Statistical classification tools for EEG-based Human-Machine interaction
- Statistical learning library (Torch)
- TITAN middleware: this Tiny Task Network is an architecture for distributing context-recognition task graphs on dynamically changing and heterogeneous sensor networks [Lombriser07].
- CRN Toolbox: open-source Context Recognition Network Toolbox that allows to execute a wide range of context and activity recognition algorithms [Bannach06].

B3. Potential impact

B.3.1 Strategic impact

OPPORTUNITY picks up on the very essential methodological underpinnings of any thinkable Ambient Intelligence (AmI) scenario: recognizing (and understanding) context and activity and proposes a fundamental paradigm shift in the way context and activity recognition can be accomplished. In doing so OPPORTUNITY addresses roadblocks that seriously limit the deployment of AmI system thus creating the foundational basis for wide spread AmI technology development. Thus OPPORTUNITY will contribute to (citing the work program) "…identification and substantiation of new directions that have a high potential for significant breakthrough and that may become the foundations of the information and communication technologies and innovations of tomorrow…"
Research being undertaken by OPPORTUNITY is inherently multi-disciplinary, in that it involves experts from different ICT disciplines and brings them together to explore the innovative idea of "opportunistic cooperative sensing", from both the theoretical, methodological, and technological viewpoint, as a new paradigm for next generation AmI systems and applications The proposed paradigm-shift towards implicit interaction that comes along with the opportunistic cooperative sensing approach will strive –and extend– foundational research in the domains of self- properties (self-description, self-management) of sensors, algorithms and control paradigms for goal oriented behaviour, spontaneous sensor ensemble management, coordination architectures, signal processing and machine learning. OPPORTUNITY targets the fundamentals of these problems: algorithms, models, and methodologies to provide the basis for future context-aware system, by following principles of autonomous operation, self-adaptation and self-improvement. This will also contribute to advances in the field of signal processing and machine learning*

In summary OPPORTUNITY is a visionary, project oriented towards fundamental high risk research with high payoff exactly matches the work program of the FET program in general and the FET/Open instrument in particular. It has parallels with the FET proactive calls on pervasive adaptation and socially intelligent ICT, as well as next-generation autonomous networking systems. It contributes to the i2010 strategy. Thus it has a clear European dimension. OPPORTUNITY benefits from a combination of competences not available in this form in a national consortium. The international nature of the consortium industrial and scientific networks is a key factor in ensuring adequate Europe wide impact of the results. Thus, a European approach is imperative.

B.3.1.1 Relevance for the workprogramme

OPPORTUNITY is in line both with the general goals of FET, and with the specific goals of the FET-Open. Furthermore it will reflect and relate its results wrt. to novel, future oriented research challenges emerging from FET-Proactive initiatives like "Pervasive adaptation" and "Bio-ICT convergence", but also the projects in "Science of Complex Systems for socially intelligent ICT", "Embodied Intelligence" and "ICT forever yours".

Expected FET Impacts

The potential "strategic" impact of OPPORTUNITY is best reflected by quoting from the FET Work-programme:

> *"…identification and substantiation of new directions that have a high potential for significant breakthrough and that may become the foundations of the information and communication technologies and innovations of tomorrow…"*

Here OPPORTUNITY picks up on the very essential methodological underpinnings of any thinkable Ambient Intelligence (AmI) scenario: recognizing (and understanding) *context* and *activity*. The idea of an innovative *coordination architecture* for *spontaneous cooperative sensing* tries to identify a new direction that promises to have high impact for future ICT scenarios. All the models. algorithms and tools studied within the project, there included the implementation of a prototype framework and of use case applications will give notable "substance" to the project, and be of foundational character for future AmI research work. Quoting further:

> "…*Research will consist of radical interdisciplinary explorations of new and alternative approaches towards future and emerging ICT-related technologies, aimed at a fundamental reconsideration of theoretical, methodological, technological and/or applicative paradigms in ICT*..."

Indeed, the research being undertaken by OPPORTUNITY is inherently multi-disciplinary, in that it involves experts from different ICT disciplines and brings them together to explore the innovative idea of "*opportunistic cooperative sensing and opportunistic context recognition*", from both the theoretical, methodological, and technological viewpoint, as a new paradigm for next generation AmI systems and applications. The OPPORTUNITY framework claims to be a fundamental reconsideration of interaction principles, now purely based on *implicit interaction*. At no times before has *implicit interaction* been a serious candidate for solving interactions with and within AmI systems, but nowadays –thanks to the explosive growth and maturing of sensor technologies– this OPPORTUNITY vision is within (easy) reach.

> "…*It will further establish a credible and sufficiently strong science and technology basis in such new and emerging areas, by supporting research for refining visionary concepts, by bringing them to the maturity level where investment from industry can be attracted*…"

Context awareness and activity recognition are key components of the vision of Ambient Intelligence (AmI), which in turn is the core of the FP7 ICT research program, and, notably, a key emerging area of significant industrial investment.

A key limitation of the state of the art, however, is the lack of methodologies to design context-aware systems in a way that: (1) they can be deployed without user-specific training; (2) work over long periods of time (weeks or more) despite sensor failures, changes in sensors placement or availability, (3) provide the freedom to users to change wearable device placement and (4) are capable of capturing the information opportunistically from body-worn and environment sensors. These are roadblocks that seriously limit the deployment of AmI system in real-world applications. The expected OPPORTUNITY contribution hence represents a fertilizer for enhanced industry investment, while at the same time creating the foundational basis for AmI technology development per se.

With the aim for such a fundamental, thus broadly applicable framework for context awareness and activity recognition, OPPORTUNITY by its design avoids the "tunnel vision" project prospect: "*First, by being open to a broad spectrum of needs, opportunities and solutions, it avoids the risk of 'tunnel vision' in ICT research and acts as an early indicator of new directions and opportunities for research in"*, quoted from the FP7 FET-Open call.

Expected FET-Open Impacts

"*FET-Open addresses the widest possible spectrum of research topics that closely relate to Information and Communication Technologies as these arise bottom-up*". Referring to the FET-Open Workprogramme, calling for

> "… *ICT-relevant, visionary, high quality, long-term research of a foundational nature, involving bright new ideas of high-risk – high-pay-off, aiming at a breakthrough, a paradigm shift, or at the proof of a novel scientific principle*,"

we find OPPORTUNITY both visionary and long-term, since it envisions novel AmI scenarios and at the same time pinpoints issues that have not been addressed before: opportunistic context recognition algorithms, opportunistic sensor configurations, goal-oriented sensor assemblies, self-organized cooperative sensing, sensor redundancy and sensing quality-of-service. The proposed paradigm-shift towards implicit interaction that comes along with the opportunistic cooperative sensing approach will strive –and extend– foundational research in the domains of self-* properties (self-description, self-management) of sensors, algorithms and control paradigms for goal oriented behaviour, spontaneous sensor ensemble management, and coordination architectures for cooperative sensing. In addition, truly novel adaptive machine learning approaches capitalizing on an embodied and situated view of context recognition systems emerges. OPPORTUNITY targets the fundamentals of these problems: algorithms, models, and methodologies to provide the basis for future context-aware system, by following principles of autonomous operation, self-adaptation and self-improvement. This will also contribute to advances in the field of signal processing and machine learning. Starting from the concrete problem of activity recognition this research provides grounding to study autonomous- and self-adaptation in a field with quantifiable benefits to users. By tackling a problem where the user is at the centre, this research allows to uncover foundational principles by which user feedback can be included in an autonomous evolving system.

The fundamental nature of the envisioned research combined with high risk and high payoff exactly matches the work program of the FET/Open instrument. It has parallels with the FET proactive calls on pervasive adaptation and socially intelligent ICT, as well as next-generation autonomous networking systems. It contributes to the i2010 strategy.

In detail, the impacts that we expect in this work programme are the results of the concept embedded in the development and implementation carried out in OPPORTUNITY. We highlight below the various impacts of OPPORTUNITY and put them in parallel to the workprogramme where there are significant matches.

Work programme (FET-proactive) expected impact	**OPPORTUNITY co-influence**
Nano-scale ICT devices and systems	• observe technology trends towards increasing computing performance, functionality, miniaturization, communication speed, power consumption, etc. and the respective evolution sensor technology • be influential on the models and systems studied when defining radically new functionalities by the integration of blocks a very small scale
Pervasive adaptation	• introspect the OPPORTUNITY coordination architecture proposal to results coming out of PERADA projects wrt. evolvable and adaptive systems, possibly also coming from projects dealing with “networked societies of artefacts” • be influential on the architectural paradigms of dynamically evolving sensor landscapes (as one instance of adaptive “networked societies of artefacts”), trustworthiness of sensor systems, and models of adaptation of context recognition at many levels
Science of complex systems for socially intelligent ICT	• observe the process of theoretical and algorithmic foundations of scalable techno-social systems • inherit from the methods and algorithms involved in prediction and predictability, transpose and reflect those findings to the mathematical and computational methods for context prediction and activity recognition • be influential in understanding context awareness as a way to support natural interactions, and implicit interaction as an

	interaction design principle • be influential on the algorithms and methods for "scalable" recognition and the notion of "evolvability" in both context and activity recognition
ICT forever yours	• learn from social and socio-technical phenomena studied in projects dealing with the design of very long lasting systems with minimal human intervention • exploit the side effect of pervasive adaptation that comes from very long living system designs towards dependable, long lasting ("eternal") sensor systems • understand the evolvability of opportunistic sensor ensemble configurations as a possible paradigm towards self-sustained sensing • understand mechanism for eternal and reliable access to dispersed knowledge as a possible paradigm towards reliable sensing • with the OPPORTUNITY framework and coordination architecture be influential on the methods and tools for high-level (secure and verifiable) dependable programming of eternal systems • with the methods for self-management and goal-orientedness out of OPPORTUNITY be influential towards the implementation of long living context aware systems
Bio-ICTconvergence	• observe the novel computing paradigms evolving out of investigations on the information representation and processing capabilities in biological systems • possible make use of findings from bio-computational processes in order to address autonomous utility- or goal-orientedness • be influential about e.g. the Bayesian processing in the brain as a higher level of abstraction of bio-inspiration
Embodied Intelligence	• learn from the proposed new design paradigms for emergence, particularly the methods for mind-body co-development and co-evolution in order to address the co-evolution mechanism in opportunistic sensing • understand the "ecological" perspective of the sensors, embodied and situated context aware systems sensing and reacting to its environment, evolving, etc. • be influential on the self-organizing and self-managing system architectures applied to embodied intelligence solutions.

B.3.1.2 Contribution to the General ICT Vision

OPPORTUNITY enables context-aware assistive technologies. These very same technologies are promoted (among others) by the European Treaty that supports a e-health area where the citizen is empowered through e-health tools and services. This is achieved through RTD and policies. In addition to the FP7 research framework, this includes the Lisbon strategy and the objectives of the eEurope 2005 action plan, the i2010 plan, and the Article 169 of the Ambient Assisted Living Initiative.

From an application perspective, the domains that will benefit from OPPORTUNITY include ambient-assisted living (AAL), lifestyle management, smart context-aware assistance, worker's assistants, e-inclusion, etc. These assistive technologies are high priority research goals of the FP7 ICT program. They are sought to address the challenges of an aging or disabled population, but also to reduce risks for healthy citizens (e.g. reduce risks at work)

Well beyond previous ICT FP programs has the Seventh Framework Programme (FP7) clearly identified challenges that societies are increasingly facing wrt. technologies in their socio-economic context, and has defined means and initiatives to reach the goals of growth, competitiveness and employment (according to European Union's Lisbon Strategy to become the "most dynamic competitive knowledge-based economy in the world"). The emerging context at which technology is influential to social systems is phrased as: "*The economic and social transformations triggered by ICT are wide-ranging, complex, and multifaceted. We are no longer at the dawn of the Information Society but witnessing and experiencing its deployment at all levels of economic activity and social interaction. In addition, technological roadmaps are pointing to even more radical socio-economic changes*."

OPPORTUNITY is exactly raising the research challenges and the radical re-thinking in methods and algorithms that address the societal transformation processes, which come form a new role of technical artefacts as not just passive mediators of human interactions but active, context aware subjects of interaction. OPPRTUNITY is addressing modes and styles of interaction, both human to human, as well as human to machine "in the small", but asks for effects and change "in the large". OPPORTUNITY here follows a whole new approach of how "interaction" can be understood in an ever growing, ever emerging, ever overtaking quantity and quality of new ICT technologies. It changes the system perspective in that it not only builds interaction on attentive user input (*explicitly* via conventional means like keyboards), but more radically *from any source of information a system might understand as input* (as *implicit input* via sensors). It changes the Thing-among-Thing interaction perspective in that it not only develops means and protocols for artefacts to communicate with each other, but to be *aware of each other and their activities*, and the *context of their mutual awareness*. It is –by its research hypothesis and approach– interested in giving answers raised by the current ICT work programme, namely the impact that ICT trends and technology deployment have on short and long term adaptation phenomena and behavioural patterns of and in societies. It does so, by researching on "*Activity*" and "*Context*", the grounding pillar of any Ambient Intelligence solution we might think of today. And it is challenged to deliver novel methods, algorithms and coordination architectures for the "recognition" of activity and context, so as to in further let technology rich environments "understand" their situation, and to behave "intelligently".

The OPPORTUNITY framework, the models, the coordination architecture, the means and methods for evaluation, and the empirical evidence delivered by representative case studies (Health-related Lifestyle Management, Intelligent Energy Management in Homes and Offices) will help to better understand the relation of technology and society, and will give recommendation, at least advice to societal authorities for a better way of life in modern societies. The OPPORTUNITY framework, and the mathematical and algorithmic apparatus delivered through it will help to develop and assess policies for the upcoming ICT solutions concerning, e.g. health and medical care, independent living, accessibility for older and disabled people, security and privacy, education and learning, transport and mobility, intelligent vehicles, autonomic products, supportive living environments and intelligent business processes to name a few.

Until now, the real-world deployment of large scale context-aware ambient intelligence environments or unobtrusive context-aware wearables was limited by unrealistic idealistic assumptions about sensor availability, placement and other characteristics. This project alleviates these assumptions. As a result, more robust and adaptive activity and context recognition systems, suitable for challenging real-world use, will become available. This will contribute to bringing Weiser's vision of ubiquitous computing and calm technology [Weiser91,Weiser95] closer to reality.

B.3.1.3 Relation with national, international and European programs/research activities

A comprehensive and topical relation to other existing initiatives with the EU FPs has been elaborated in section **B.1.2.1**. OPPORTUNITY is closely related to projects seeking to infer contextual and activity information from sensor networks. This includes to a wide range of disciplines (e.g. machine learning, signal processing, distributed computation, embodied intelligence, autonomous adaptive systems, wireless sensor networks). The consortium is highly interested and considers the interactions (both drawing from and contributing to) with other European Projects funded in the same or in related initiatives, as well as interactions with related research initiatives outside Europe. With the project partner JKU being responsible for the WP "Research Agenda" of the FET funded project PANORAMA, and associated with the research agenda development in the FET funded project InterLink, there are already well established structures of communication and interaction with the European and non-European research community. OPPORTUNITY by that will have first citizen access to the whole landscape of research initiatives within FET, and to some certain extent also within ICT FP7 - most importantly, however, to the projects running in the PERADA (Pervasive Adaptation) program (ALLOW, Adaptable Pervasive Flows; ATRACO, Adaptive and Trusted Ambient Ecologies; FRONTS, Foundations of Adaptive Networked Societies of Tiny Artefacts; PANORAMA, Pervasive Adaptation Network for the Organization of the Research Agenda and the Management of Activities; REFLECT, Responsive Flexible Collaborating Ambient, SOCIALNETS, Social Networking for Pervasive Adaptation; SYMBRION, Symbiotic Evolutionary Robot Organisms). The related research issues, challenges, efforts and results will thus be influential to the OPPORTUNITY efforts, and findings of other projects will guide the OPPORTUNITY research.

As for the projects proposed for FET open calls, and ICT FP7 in general, OPPORTUNITY will actively network with the other project, particularly the ones that will be funded under the "Science of complex systems for socially intelligent ICT", or even the "ICT Forever Yours" and the "Embodied Intelligence" initiative. Among all of them, OPPORTUNITY addresses foundational questions and develops novel algorithms and approaches to enable next generation context/activity aware systems, thus will link and possibly partner with FET projects aiming at similar research issues, possibly with different research methods.

Concerning other European Projects funded in other initiatives, the OPPORTUNITY project will make its best to exploit the results being made available by other projects, and to leverage them to the specific needs. It will also contribute back to currently running and future projects. In particular, the related initiatives that more directly may be sources of fruitful interactions and cross-fertilization with OPPORTUNITY are in Challenge 1 (Pervasive and trusted network and service infrastructures), Challenge 2 (Cognitive systems, interaction and robotics), Challenge 5 (Towards sustainable and personalised healthcare) and Challenge 7 (Independent living and inclusion).

The consortium has a long expertise of European and International collaboration on which it bases its expertise and that it will use to actively participate and network with related project. Some of the related ongoing/past research initiatives in which consortium partners are active include:

- Allow [UP]: FP7 FET STREP on large scale adaptive context-aware AmI environments that support people in achieving well-defined goals in dynamically changing environments and contexts.
- SENSEI [ETHZ]: FP7 IP aiming at "integrating the physical with the digital world of the network of the future". SENSEI aims to develop large-scale sensor actuator networks and investigates context and information processing and decentralized/distributed control and computation to achieve a desired emergent global behaviour.
- MonAmi [UP]: FP 6 IP on the use of large scale context-aware AmI environments to assist the handicapped and the elderly.
- wearIT@work [ETHZ,UP]: FP6 IP on the use of complex activity-aware wearable computing systems in real life, industrial environments.
- Daphnet [ETHZ]: FP6 FET STREP aiming at uncovering linkage among physiological signals, contextual states, and healthy and pathological cases. Context/activity-aware biofeedback is investigated to support specific user groups.
- PASCAL, PASCAL2 [EPFL]: NoE on Pattern analysis, statistical modelling and computational Learning

- BACS [EPFL]: FP6 IP on Bayesian approaches to cognitive systems, in particular achieving a better understanding of action-perception in living beings (machine learning, embodied intelligence)
- AMIDA [EPFL]: FP6 IP on Augmented Multi-party Interaction with Distance Access (context-aware multimodal interaction support)
- DIRAC [EPFL]: FP6 IP aiming at detecting and identifying rare audio-visual cues (machine learning).
- GALE [EPFL]: US DARPA project on Global Autonomous Language Exploitation (machine learning, natural language processing).
- CARETAKER [EPFL]: FP6 IP focused on the extraction of a structured knowledge from large multimedia collections recorded over networks of camera and microphones deployed in real sites.
- IM2 [EPFL]: Swiss National Centre of Competence on Interactive Multimodal Information Management. IM2 is concerned with the development of natural multimodal interfaces for human-computer interaction.
- CRUISE [JKU]: FP6 NoE aiming at creating ubiquitous intelligent sensing environments (context-awareness, ambient intelligence, sensor networks)
- INTERLINK [JKU]: FP6 FET project whose goal is to support international cooperation activities in future and emerging ICTs. Related topics include ambient computing and communication environments and cognitive systems.
- PANORAMA [JKU]: An FP7 CA aiming at the development of a research agenda for all the FET projects funded under the PERADA (Pervasive Adaptation) program umbrella.

B.3.1.4 A project needing a European approach

The reasons for choosing a European approach rather than a national or international activity are the following:

- Specific key expertise is required to achieve the project's goals. We found it best provided by 4 European partners.
- International collaboration bring the required expertise in the project, however such as an advanced research project requires tight collaboration between the project members. This implies exchange of technical/scientific personnel, possibly extended stay at another partner's group to investigate and integrate algorithms and validate the system in concrete scenarios (available at the partner's location). Proximity makes this more efficiently carried out at the European level.
- The outcomes of the project make a stronger impact in the community by following an European approach. Since the project tackles algorithmic challenges underlying the vision of Ambient Intelligence, which is inline with the European FP7 research roadmap, this enables more efficient transfer of the project's output to applied EU research projects (i.e. non FET projects).
- Overall the project's goals are inline with the European vision of Ambient Intelligence (AmI)/Ambient Assisted living and at the crossroads of socially intelligent ICT (OPPORTUNITY enables large scale AmI), embodied intelligence (context aware systems are embodied, sensing and feedback to the user in a tight loop) and pervasive adaptation (opportunistic sensor configurations). A European approach to OPPORTUNITY offers an excellent platform for discussion and scientific synergies in these complementary fields.

B.3.1.5 Economic Impacts

The technology enabled by OPPORTUNITY will contribute to a number of economic opportunities on a European scale and on an individual and institutional level. It has the potential to strengthen European embedded systems industry as well as the software and services industries. Furthermore, the OPPORTUNITY project help to establish a leading position for Europe in the realization of the next generation of computing systems and applications.

In the past, the European economy was able to establish a very successful and strong electronic and embedded systems industry that contributed significantly to its wealth. At the present time, the worldwide electronics and embedded systems industry alone has an estimated market volume of approximately 250 billion Euros per annum. In addition to its high volume, the overall market is growing extremely fast, with average growth rates of more than 25% over the last years. In order to maintain a leading position in the area of electronics and embedded systems, it is very important for Europe to continuously maintain and improve its innovation capabilities. OPPORTUNITY will help strengthen Europeans industry leading position in the following ways:

- OPPORTUNITY research will contribute to more robust, easier, cheaper and more flexible design of complex networked mobile and embedded systems through the advancement of goal oriented, ad-hoc coordination and cooperation methods.
- Until now, the real-world deployment of large scale context-aware ambient intelligence environments or unobtrusive context-aware wearables was limited by unrealistic idealized assumptions about sensor availability, placement and other characteristics. Thus this technology had little commercial impact. This project alleviates these assumptions opening the way for European Industry to use ambient intelligence technology on a large scale gaining crucial technological advantage.

A similar argument can be made with respect to the software and services industry. In Europe the ICT-related markets account for up to 8% of the gross domestic product (GDP) as well as for up to 6% of employment. With its estimated 20% share on ICT, the European software and services industry is responsible for a relevant part of Europe's economic capacity. However, the software and services market is a fast-paced global market. Thus, in order to maintain Europe's current economic position, it is important to strengthen this industry as well.

The OPPORTUNITY paradigm that frees the user from the burden of configuring systems and having to put up with obtrusive sensor systems will lead to high user acceptance of ambient intelligence systems. It will also lower the deployment cost and barriers of context and activity aware systems by not requiring dedicated sensor deployment. Our cases studies will demonstrate this aspects in such key areas as personal health management and wellness, intelligent, energy aware building management and novel interactive environments. These are all areas where the European software and services industries have crucial interest. Bringing higher user acceptance and lower deployment costs to such crucial, emerging applications will provide the European with a clear competitive advantage.

In summary, in order to maintain and improve Europe's market position with respect to the ICT industry as a whole, it is important to embrace and to control new technologies that bear significant economic potentials. As context sensitive ambient intelligence applications are frequently considered to form the next wave of computing applications, it is necessary to establish a leading position for Europe in this domain. By creating fundamental enabling technologies like goal oriented, cooperative sensing, adaptive signal processing and classifiers, and unsupervised runtime control such a leadership position could be established at the early stages. In the fast moving ICT world, an early technological leadership is usually crucial since the introduction of innovative technology quickly creates de facto industrial standards that are controlled by their inventors. Here the results of OPPORTUNITY will make a clear contribution by doing fundamental, high risk research.

B.3.1.6 Social Impacts

Social impacts stem from better activity recognition systems enabling proactive context-aware assistance and adaptation of the environment. This will produce advances in a number of areas that are in the center of European social policy. Thus, for example, our 3rd generation case studies scenarios were selected from the domains of assistive technologies relevant to personal healthcare and elderly care and energy efficient building management. We outline the impact of OPPORTUNITY enabled technology on these areas below. Similar impacts can be envisioned on other areas such as workplace safety and comfort, access to electronic resources, and safety and security.

Impact on Healthcare

Assistive technologies are promoted (among others) by the European Treaty that supports a e-health area where the citizen is empowered through e-health tools and services. This is of great importance as the growing healthcare cost is a crucial social problem in the European community. At the present time, the expenditures on health care in the member countries of the European community account for an estimated 8.5% of the GDP and 9.3% of employment. Current estimates indicate that the cost of health care could rise up to 11.8% in 2030 even if the current growth rate levels off. This imposes an enormous stress on the European welfare systems in general. In addition to that, some European countries, such as Germany, are already experiencing a shortage of trained personnel in this sector. If this trend cannot be reversed, it will eventually result in a significant loss in quality of the medical care that is available to a majority of European citizens.

The technology and the applications enabled by the OPPORTUNITY project can help to reduce the cost of health care by automating many routine work processes. Such an automation would improve the efficiency of the processes which would in turn allow doctors, for instance, to spend more time with complex medical tasks such as diagnosis and treatment and spend less time doing administrative work. In addition facilitating personal lifestyle and health management will contribute to prevention and early diagnosis which will further reduce the load on the healthcare system and improve the quality of life of European citizens.

Impact on the Elderly and the Demographic Challenge

Dealing with the demographic challenge is at the center of European RTD and policies, in particular in the context of the Lisbon strategy and the objectives of the eEurope 2005 action plan, the i2010 plan, the FP7 research framework, and the Article 169 of the Ambient Assisted Living Initiative. According to current estimations, the average human life expectancy will experience an increase by almost five years between 2000 and 2050. Between 1998 and 2025 the part of the population classified as elderly will increase from 20% to 28%. The fastest growing group of the elderly population is the group of people aged over 80. This, in turn, will not only increase the cost of health care but it will also lead to additional costs for appropriate nursing homes.

The technology explored by the OPPORTUNITY project can mitigate such problems by enabling assistive applications that allow elderly citizens to stay in their own home environments for a longer period of time. If the person’s home is equipped with activity sensitive computing devices (probably common in future home entertainment systems, bathroom and kitchen devices) the automatic adaptation of this environment to the person’s activities could enable many elderly people to lead an independent life much longer than today. This may offer a great relief for them and improve the overall attendance for elderly citizens. The same argument also applies to disabled people who could benefit from a higher degree of independence which could improve their overall quality of life.

Impact on Energy Efficiency

Energy efficiency as means of preventing climate degradation are among key political aims of the Community. The project will foster this goal by bringing energy efficient building management closer to reality. Wide spread activity recognition it will enable buildings to optimally adjust to the current needs of the user with minimal required energy. It will enable energy intensive appliances and standby modes to be activated ‘just in time’ and deactivated immediately when not needed. Thus, the energy savings required to reduce climate damaging emissions could be achieved without reductions in the quality of life and comfort of European citizens.

B.3.2 Plan for the use and dissemination of foreground

***Dissemination and exploitation is an important task within OPPORTUNITY**. **Scientific dissemination will build upon long record of publications in top journals** (e.g. IEEE transactions and Magazines) and conferences (many with acceptance rates well below 20%) by the partners. Beyond publication we will facilitate widespread use of OPPORTUNITY results by providing **open source software**, **publishing experimental data sets**, and **organizing tutorials at key conferences**. We will also work to **build a community to further develop the topic of opportunistic systems** by organizing workshops and possibly special issues of appropriate journals. A big advantage of the consortium with respect to scientific dissemination is the fact that partners are active in many different communities (Ambient Intelligence, Machine Learning and Cognitive Science, Self Organisation, Embedded Systems, Sensing and Signal Processing) ensuring a very broad dissemination.*

*Beyond scientific dissemination a **web site, print materials** plus scores of **multimedia resources** (project movies, ready for use presentation, image libraries) **will ensure the dissemination to a broader public**. We will also exploit rich mass media contacts of the partners (many national TV and newspaper contributions in recent years). Finally we will participate in **European networks** and events such as the annual ICT events and different community publications.*

*Being a FET project, OPPORTUNITY does not directly aim at developing products and commercial services. However the technology being developed in the project has the potential to revolutionized a broad range of emerging applications in areas ranging for personal healthcare, through ambient assisted living, industrial manufacturing, interactive spaces to intelligent energy management. **Based on a long history of industrial collaborations and spin-offs, on huge set of industrial contacts** (e.g. to SIEMENS Corporate Technology, DoCoMo, SAP, Thales, NOKIA, Swisscom, Telekom Austria and dozens of regional SMIs**), we will actively reach to industry**. This will include **two project specific industry oriented technology transfer workshops**, a **special web site section for potential industrial takeups**, **an electronic newsletter, talks at industry oriented events**, **using the case studies as demonstrators at technology workshops** and exploitation of personal contacts.*

Dissemination plans are detailed in section B.3.2.1. The exploitation strategy is described in section B.3.2.2.

B.3.2.1 Dissemination strategy

The key dissemination messages are:

- To convey a message about the primary OPPORTUNITY scientific contributions, i.e. context/activity recognition in opportunistic sensor configurations.
- To convey a message about the derived OPPORTUNITY scientific and technical advances in specific fields, including e.g. advances in machine learning, goal-directed sensing ensembles, wireless sensor network management, autonomous computation, context-aware computing, EEG signal processing for BCI, ambient assisted living.
- To raise awareness in related EU, national and international research projects that relate and/or may benefit from OPPORTUNITY.
- To raise awareness within the communities that benefit on a longer term from the outcomes of OPPORTUNITY (SME, industries), to the general public, and to public authorities (e.g. to ensure subsequent translation of fundamental research into applied research by appropriate funding instruments)

Below are listed the **dissemination target groups** and the corresponding **dissemination instrument**.

Target user group	Dissemination instrument

Scientific and technology community	**Scientific and technological dissemination**. A main action line within the dissemination activities is that of scientific and technological dissemination. All the partners will heavily contribute to the project's dissemination activities by presenting the results of the project in well-known and widely read international scientific journals and also by presentations in international scientific conferences, workshops and exhibitions. Various communities are addressed, including: • Wearable and pervasive/ubiquitous computing communities • Context-Aware Computing communities • Machine learning, artificial intelligence communities • Self-*, autonomous, organic, and bio-inspired computing communities • (Wireless) Sensor Network communities • Application-related communities: Ambient Assisted Living, Context-aware smart assistance, EEG-based Brain Computer Interfaces. Besides publications the consortium will pursue the following additional measures to increase the impact of OPPORTUNITY on the scientific community: • Providing to the community software and tools through GPL licence and distributing them through channels such as source forge (see description later on for specific examples) • Releasing data sets from selected case study experiments to the public, again under a GPL (or equivalent) licence und taking into accounts data protection guidelines • Organisation of tutorials at key conferences in the respective field. Such tutorials will directly enable other scientists to use and further develop OPPORTUNITY methods. They will also promote the use of tools and software that the project will provide through GPL licence • Building a scientific community devoted to opportunistic networks in Ambient Intelligence through organisation of workshops at major conferences (e.g. UBICOMP and PERVASIVE which have a long tradition of workshops in emerging areas).
EU research community	With **public web-site**, **direct contact** to projects and Networks of Excellence in which OPPORTUNITY partners are involved, EU **cordis website**, and ICT/IST news. We will also participate in upcoming ICT events (such as the one taking place this year in Lyon) . Print and multimedia material will be provided through the www site.
General public	Project **web site** with interactive demo applications, **press releases**, general-public **newspapers**, **open-door events**, **interactive demonstrators relevant to real-world application scenarios** (e.g. context-aware Ambient Assisted Living scenarios, EEG-based BCI scenarios). Print and multimedia material will be provided through the www site.
Industries, SMEs	Although the primary outcomes of OPPORTUNITY are not **direct** industrial applications, the consortium will ensure advance dissemination to industries and SMEs as part of normal presence of the partners to events such as **industry fairs, thematic workshops** and **open-door events.** Preferred

	dissemination means includes **demonstrators relevant to real-world application scenarios** (e.g. context-aware Ambient Assisted Living scenarios, EEG-based BCI scenarios) and two technology transfer workshops.

The dissemination effort will provide the means by which to make contact and exchange findings with other research groups.

The dissemination results will be summarised yearly and at the end of the project. All the dissemination activities will take place within WP7. Among the **criteria to evaluate our dissemination success** we can highlight: **conferences and workshops presence, peer reviewed publications, presence in the media, attendance at commercial/scientific/fairs, direct feedback,** etc.

Below are listed a few specific dissemination activities.

Scientific publications and conferences

The project results will be published and presented in peer-reviewed conferences and journals such as the ones listed below.

Conferences

<u>Wearable&pervasive computing and context</u> • Int. conf. on Pervasive Computing (Pervasive) • IEEE int. conf. on Pervasive Computing and Communications (PerCom) • Int. Conf. Ubiquitous Computing (UbiComp), ***also candidate for tutorials and workshops*** • International Symposium on Wearable Computers (ISWC), ***also candidate for tutorials and workshops*** • European Conference on Smart Sensing and Context (EuroSSC) <u>Ambient assisted intelligence</u> • Conf. on Smart Homes and Health Telematics • European Conference on Ambient Intelligence (AmI) <u>(Wireless) Sensor Networks, distributed computing</u> • Networked Sensing Systems (INSS) • BSN (body sensor networks), ***also candidate for tutorials and workshops*** • BodyNets • P2P Intl. Conference on P2P Computing • ARCS (architecture of computing systems) ***also candidate for tutorials and workshops***	<u>Machine learning, information processing, and artificial intelligence</u> • Machine Learning and Data Mining (MLDM) • Int Conf Machine Learning (ICML) • Neural Information Processing Systems Conference NIPS • IPSN (Information Processing in Sensor Networks) • IEEE Int Conf on Acoustics, Speech and Signal Processing (ICASSP) • International Workshop on Self-Organizing Systems • International Joint Conference on Artificial Intelligence (IJCAI) ***also candidate for tutorials and workshops*** • US Conference on Artificial Intelligence (AAAI) <u>Various</u> • Int. Conf. on Multimodal interfaces • Computer/Human Interaction conference (CHI) • Pervasive Health Conference • EMBC (IEEE Engineering in Medicine and Biology Society) • EMBEC (European Medical and Biological Engineering Conference)

Journals

<u>Wearable&pervasive computing and context</u> • Personal and Ubiquitous Computing • Pervasive and Mobile Computing • IEEE Trans. Pervasive Computing • IEEE Trans. on Mobile Computing <u>(Wireless) Sensor Networks, distributed computing</u> • IEEE Sensor Journal • IEEE Wireless Communication	<u>Machine learning, information processing, and artificial intelligence</u> • Machine learning • J Neural Engineering • IEEE Trans. on Pattern Analysis and Machine Intelligence • Journal of Applied Intelligence • Artificial Intelligence Research

• ACM Trans. on Sensor Networks • Sensor and Actuators • Autonomous Agents and Multi-Agent Systems • Computer Networks Journal	• Cognitive Processing Various • IEEE Trans. Syst. Man Cybernetics • IEEE Trans. on Biomedical Engineering • IEEE Trans. on Information Technology in Biomedicine

National science events, or local (university) open days

- Switzerland: Yearly ETHZ Industry Days (audience: local industries)
- Switzerland: Yearly ETHZ Open Days (audience: general public, students)
- Germany: Yearly Open Door Day at the Faculty of Computer Science and Mathematics at the University of Passau

Internet presence

The Consortium will set up a Web site as a dissemination tool. The website will be maintained during the lifetime of the project by the Project Coordinator. It will have the following contents:

- Up-to-date news about the progress of the project
- Information about the presence of the project in conferences, fairs, exhibitions, etc;
- Subscription to an announcement list with news about the project
- Download of public deliverables
- Download of publications related to the project
- Download of multimedia materials

Printed materials

There will be also produced printed materials for the project dissemination within the European Community. These materials include:

- Leaflets with general information about the project objectives, work to be done, etc.
- Leaflets with information about the results (the developed software components and the analysed results)
- Brochures with information about the final system
- Project poster for conferences, exhibitions, etc.
- Project Presentation with the general data of the project

Multimedia material

Multimedia material for the press but also for other researchers and teachers wanting to include OPPORTUNITY concepts and vision in their talks will be disseminated through the web site under the creative commons (or similar) licence. This will include:

- movies from the case studies but also high level (artificial) movies of the OPPORTUNITY vision and applications will be produced
- overview presentations of the project, its visions and results will be publicly available through the www site
- a library of pictures and graphics will be put on the www site

Software and Tools

Selected algorithms and methods implemented in the project as well as tools such as Matlab scripts will be made available to the scientific community under a GPL (or equivalent) licence through forums such as source forge. This will make it easier for other scientists to build their research upon OPPORTUNITY results. GPL software release will focus on algorithms that are useful stand alone, can be used without the need for overwhelming amount of documentation or training, and have a broad applicability. Candidates include (but are not limited to):

- implementation of the variation insensitive signal conditioning methods and abstract features (Tasks T1.2 and T1.3)
- tools and parsers for sensor self description (Tasks T4.2)
- modular classifiers and classifier fusion methods (Tasks T2.2 and T2.3)
- system performance models and modelling tools (Task T3.2)

Datasets

Recording data sets for activity recognition experiments is a difficult, time consuming process that requires a lot of experience and expensive equipment. Thus making the data sets recorded during the project publicly available will be a significant contribution to the research community. It will the projects' experiments better known in the community, and, like the software, make it easier for the community to use, evaluate and further develop the OPPORTUNITY concepts.

Clearly mostly data sets from the Stage 1 case studies will be published to avoid excessive documentation and conversion overhead.

B.3.2.2 Exploitation strategy

Exploitation potential

Being a FET project, OPPORTUNITY does not directly aim at developing products and commercial services or even prototypes of such. However there are aspects of the project that imply a high probability of mid to long term commercial impact.

- There are a number of roadblocks that limit the deployment of current activity/context aware AmI systems in the real world. Among others, the need to do user-specific training, the sensitivity to changes in sensor configurations (e.g. failures, number of sensors), or the static assumptions on device placement. The scientific outcomes of the project will alleviate these limitations. In a longer perspective this will enable the real-world deployment and commercial exploitation of a new range of robust, adaptive, and unobtrusive pervasive and wearable computing technologies (see section 3.2).
- As explained under 3.1 and 3.2, context awareness and activity recognition are key components of the vision of Ambient Intelligence (AmI), which is an important aspect of the FP7 ICT research program. The outcomes of the project and the validation scenarios in particular are highly relevant to European industry and European policy objectives
- The research partners of the project are involved in a range of application oriented and often industrially dominated national and European projects for which the OPPORTUNITY results could be relevant (see section 3.1). Through these projects the partners have contacts to a wide range of companies. They will actively disseminate OPPORTUNITY results to those companies and attempt to initiate joint projects of a more applied, product-oriented, nature.

WP7 will conduct a systematic exploration of commercial exploitation potential of overall results of the projects, as well as subset of the project. It will sum this potential up in the "Dissemination and Exploitation plan" deliverables.

Institutional support for, and experience with, technology transfer and spin-offs

The institutions involved in OPPORTUNITY put strong emphasis on technology transfer and spin off support and have a corresponding infrastructure and experience:

- ETH has an approved strategy for technology transfer either to SMEs or by supporting spin-offs. The Institute for Electronics (of which the participating entity, Wearable Computing Lab, is part) has a long history of establishing successful spin-off companies. These include u-blox AG (a leading ultra compact GPS module manufacturer), Art of Technology (a high density packaging solutions specialist) , Supercomputing Systems SCS (developer of custom high end signal processing and computing solutions), acter (in the area of locking secure access technology) and BS Engineering (computer vision and image processing solutions for automation).
- EPFL: ***Remark****: due to the transfer of the former group IDIAP to EPFL occuring at present time, this description takes mostly from the former expertise at IDIAP and must thus be considered preliminary. EPFL has a dedicated infrastructure for technology transfer via its organization "Parc Scientifique" located on the campus. It has vast experience with technology transfer and spin-off as it is in the Charter of Swiss Federal universities to support such technology transfers..* The group of partner EPFL (formerly IDIAP) has experience with technology transfer and spin-offs. In it's past affiliation at IDIAP, it capitalized on the subsidiary company, IdeArk. IdeArk is part of The Ark, a major project which combines several sites active in the areas of IT and communication sciences, life sciences, tourism and the environment. Moreover, two of IDIAP's spin-offs, Cinetis and Klewel, have received the European Seal of Excellence award at the CeBIT International Trade show on information technology and telecommunications. Researchers, R&D department heads or startup managers may be hosted at IdeArk for a given time period. They will find the expertise and the technological tools they need to complete their training or to evaluate the feasibility of their ideas. In addition, IdeArk proposes to support projects in conjunction with other partners active in different areas that are indispensable to its development: process optimization, coaching, market evaluation, funding, marketing and communication. Currently (year 2006), about 10% of IDIAP activities comes from projects with industrial partners, including: Swisscom (CH), Deutsche Telecom (DE), France Telecom (FR), Qualcomm (USA), Canon (UK), Philips (NL), Spiderphone (CH)
- UP: The Faculty of Computer Science and Mathematics University of Pasau has a special industry liason and technology transfer organisation called IT Research Campus. The IT Research Campus is the central contact point of the University of Passau for cooperation in applied informatics and related fields. It acts as an umbrella organization, which is covering all related research institutes and centers at the University of Passau. It forms a platform for the interchange of ideas and knowledge between science and business fostering cooperative research and development projects of companies and universities. The wide spectrum of services offered by the Research Campus covers consulting, seminars, workshops, recruitment support, internships and student research projects (Bachelor, Master, Ph.D.), as well as funded joint research projects and contract-based research and development activities for industry and commerce. Research Campus is particularly strong in engaging regional SMIs. Industrial partners include: MindMatics AG, Micro-Epsilon Messtechnik GmbH & Co. KG, R&L AG, PENTA GmbH, prevero AG, Fabasoft AG, newCOMer GmbH F&F Computer Anwendungen und Unternehmensberatung GmbH, Integralis AG, Accenture GmbH, ZF Passau GmbH, ANDURAS service solutions AG, CommuniGate Kommunikationsservice GmbH and, msg systems AG
- JKU: The Institute for Pervasive Computing (IPC) (which is the participating entity of JKU in OPPORTUNITY) has established and is successfully operating the Research Studio "Pervasive Computing Applications" (PCA) inside the Research Studios division of the Austrian Research Centers GmbH - ARC since 2005. PCA worked on and is still actively committing to several projects of both applied scientific and industrial type. PCA actively commits to and shapes the change of information and communication technologies (ICT) by a focused research agenda. The availability and fast experimental turn-around time of cutting edge research infrastructure makes the studio a very attractive partner for near-industrial research. PCA supports three research areas: Context and Sensors (e.g. a Wireless Motion Tracking board), Smart Appliances & Environments (e.g. Virtual Machines for Embedded Environments) and Intuitive Interfaces (e.g. Tangible Remote Controls). In 2007, the Telekom Austria presented the Telekom Austria Cube, a design study for the navigation within IPTV portals of the near future - a prominent example for the capabilities of the studio concerning custom electronic design (integration of multiple sensor data

and processing with wireless communication technology) and miniaturization. PCA is currently involved in the FIT-IT research program SPECTACLES developing space constrained electronics for a wearable display and pursues a recommender system for the IPTV portal of Telekom Austria amongst others. With the SPECTACLES project, the internationally operating Linz-based eyewear manufacturer Silhouette was able to impropriate notable know-how in a completely new technology line, which opened a completely new area of application. PCA operates a studio in the 9th district in Vienna, Austria

Specific exploitation and technology transfer activities

Based on the above institutional support, experience and contacts, the following specific activities will be undertaken towards exploitation and technology transfer are:

- Website: The OPPORTUNITY website will contain a specific section dedicated to Innovation & Technology Transfer, including a collection of the case studies described in the proposal and other possible relevant case studies relevant to the industry.
- Publication of articles in industrial journals, magazines with broad industrial audience, such as, IEEE Software, IEEE Pervasive Computing Magazine, Transactions of the ACM, IEEE Computer, IEEE Spectrum and Electronic Times.
- Electronic Newsletter: We will establish an, industry oriented electronic newsletter with the key project results. The recipients of the newsletter will be recruiter from the large body of industrial partners of the OPPORTUNITY participants (see previous section), from related projects and from the participants of the OPPORTUNITY workshop (see below).
- Organization of technology transfer workshops dedicated to bring together researchers and practitioners from academy and industry to stimulate transfer of ideas and results. We plan at least two such workshops during the course of the project. We will invite a selection of companies listed as cooperation partners in the previous section. We will also reach put to partners in other EU funded projects in which OPPORTUNITY participants are involved (see section 3.2). The participants from different backgrounds will receive extended information on the concepts, the technological aspects, and the potential applications enabled by the project in their respective fields. This will take place twice during the project, such that the participants get an early glimpse of the project and may actively get involved. The first workshop takes place in the middle of the project runtime and gives an overview of the prior activities as well as the developed technologies. Especially the demonstrator, which will conclude the first major project phase, will give important insights. It will be shown at the second technology transfer workshop and serve as a way of disseminating the results.
- The case studies carried out in the project will be used as demos for presentation to the industry. Demonstrator will be presented at industrial fairs such as CETBIT, Embedded World where the universities and/or their technology transfer partners have booths that can be used for a small fee.
- The tools developed in OPPORTUNITY will be made available to industry and the research community (see dissemination in the previous section).
- Outreach actions towards specific companies. Partners in the consortium have well established collaborations with companies that are interested in the project results as described in the previous section. This includes the R&D departments of large companies (e.g SIEMENS Corporate Technology, DoCoMo, SAP, Thales, NOKIA, Swisscom, Telekom Austria), national and regional SMI (e.g. FutureShape, Vogt Elelctronic, ElecCon, Phonak, Spiderphone, ublox ,Silhouette).

Management of Intellectual Property

Intellectual property is a critical result of research activities. The prime objective of OPPORTUNITY is scientific dissemination. However, provisions must be made for the case that a piece of IP is deemed worth to protect for later commercial exploitation. It is important to formalize some rules with respect to existing intellectual property and intellectual property arising from the project in order to avoid conflicts during project execution.

All issues regarding confidentiality, IPRs, Pre-Existing Know-How (Background), agreement on exploitation rights, and clarification of each individual's rights and obligations are going to be included in the **Consortium Agreement**, document to be signed by all partners before starting the project. The Project Coordinator is responsible for the use of IPR within the Consortium, according to the terms laid out in the Consortium Agreement.

The Consortium Agreement will detail how knowledge and pre-existing know-how (Background) is accessed. The following lines summarise the basis on which this document will be built:

- All partners will grant royalty-free access to all necessary elements in order to perform the work deemed as necessary for the project.
- Regarding Background, pre-existing know-how, (i.e. any information, software, hardware, etc. that was acquired prior to the project and out of the scope of any EC funded project, and that the partner considers should be explicitly excluded from royalty-free access rights for the project), will be detailed in an appendix of the Consortium Agreement in which every partner is entitled to describe its own Background.
- Regarding access to source code not developed under one of the open source licensing schemas, it will normally be excluded from any access, (especially royalty-free access).
- For those cases in which the only way to achieve a project goal is by giving access to source code, steps will be taken to: Formalise all necessary non-disclosure and confidentiality agreements before any exchange of source code actually starts. Provide access to source code in good faith (provided "as is") and, in principle, royalty free, but only for the duration and purposes of the project. Any use of such source code beyond the scope (in time or in purpose) of the project is, in principle, prohibited. For uses beyond the scope of the project a specific commercial agreement will be signed. This access will normally not be royalty free.
- Each partner will be the only proprietary owner of any "knowledge" element (piece of code, hardware, technical documentation…) developed inside the project by such partner (Foreground). Whenever it is not possible to determine who is the partner owning a specific development (for instance, when a common development of some software system has been carried out), the IPR of such element will be shared among the partners participating in the development pro-rata to the effort (or the associated cost, if so agreed) invested by each partner for such development.

The protection of the knowledge resulting from the OPPORTUNITY project will be managed by the Steering Committee, by reviewing on a yearly basis (or upon request by one of the partners) the following points:

- **Intellectual Property (IP) Identification**: Definition of procedures in order to recognize discoveries that may have potential Commercial value. Review process to identify IP that can be protected and/or exploited.
- **IP Protection**: Definition of policies to clearly manage responsibilities in relation to IP protection including the maintenance of records and the prevention of premature public disclosure of research results prior to obtaining IP protection. Assistance to partners in fulfilling obligations and responsibilities as well as rewarding and encouraging participation in any subsequent commercialisation process.
- **IP Ownership**: Clear policy on whether partners will claim any ownership and/or associated rights for IP generated from their supported research. Policies and relevant procedures for determining the subsequent ownership and/or assignment of IP rights. Clear agreements with employees and grant holders registered through the consortium on ownership and/or associated rights of IP
- **Existing IP Assessment**: Procedures to guide participants in assessing the existing IP in the field that is likely to affect their research in order to determine their freedom to operate

- **IP Management**: Procedures for the regular review of IP and associated commercial activities and outcomes arising from publicly funded research. Procedures to provide advice to the creators of the IP on the options that are available for commercialising IP
- **IP Conflicts**: Policies and procedures that provide guidance in relation to potential conflicts of interest concerning ownership, management, protection and exploitation of IP

B4. Ethical issues

	YES	PAGE
Informed Consent		
• Does the proposal involve children?		
• Does the proposal involve patients or persons not able to give consent?		
• Does the proposal involve adult healthy volunteers?	YES	75
• Does the proposal involve Human Genetic Material?		
• Does the proposal involve Human biological samples?		
• Does the proposal involve Human data collection?	YES	75
Research on Human embryo/foetus		
• Does the proposal involve Human Embryos?		
• Does the proposal involve Human Foetal Tissue / Cells?		
• Does the proposal involve Human Embryonic Stem Cells?		
Privacy		
• Does the proposal involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)		
• Does the proposal involve tracking the location or observation of people?	YES	75
Research on Animals		
• Does the proposal involve research on animals?		
• Are those animals transgenic small laboratory animals?		
• Are those animals transgenic farm animals?		
• Are those animals cloned farm animals?		
• Are those animals non-human primates?		
Research Involving Developing Countries		
• Use of local resources (genetic, animal, plant etc)		
• Benefit to local community (capacity building i.e. access to healthcare, education etc)		
Dual Use		
• Research having direct military application		
• Research having the potential for terrorist abuse		
ICT Implants		
• Does the proposal involve clinical trials of ICT implants?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL		

B.4.1 Ethical issues explanation

The proposal aims at developing algorithms and methods to recognize activities and context from ambient and wearable technologies, thereby enabling more robust and adaptive smart assistants. We will test the system with users to assess the performance of the context and activity recognition principles developed in the project. We believe the project does not contain sensitive ethical issues for a number of reasons:

- User tests are akin to tests of consumer product (e.g. a new domestic robot or cellphone) by focus groups (assessing system functionality, collecting performance data from it), rather than pilot studies or field trial in medical or clinical research.
- Only non-invasive sensors are used.
- The proposal does not aim at collecting data for screening purposes.
- No medical or health oriented experiments are carried out.
- The proposal does not aim (and does not claim to) to provide health-critical assistive technologies.
- Tests are of small scale and duration.
- All data collection (physical activity, physiological signals) will be from healthy, able-bodied, subjects.
- All subjects involved in the research will participate voluntarily after being informed of the objectives and methodologies of the project, following the guidelines of the declaration of Helsinki.
- The risks for the participants are minor—not higher than the ones encountered in their daily life.
- All participants will be clearly informed about the project within the informed consent process that comprises the following elements: the purpose of the research, expected duration, and procedures; the possible risks, discomfort, and side-effects (if any); a description of any benefits to the subject or to others which may reasonably be expected from the research; explanations on confidentiality (and limits) of the data; their right to decline to participate and to withdraw from the research once participation has begun and the foreseeable consequences of declining or withdrawing; whom to contact for questions about the research and research participants rights.

Thus, the main legal and ethical issues involved are **informed consent**, **safety**, and **data protection**. The details of these topics will be agreed before the start of the practical trials with users.

In particular cases, we will check whether it is necessary, or recommended, to get the approval of the ethics committees of the different institutions

B.4.1.1 Does the proposal involve adult healthy volunteers?

The experiments will be performed with healthy individuals (users who are mostly volunteer student and researchers), using devices used according to what the users have been approved to undertake. We will only consider literate and cognitively competent participants. Volunteers will be fully informed of the system to be able to give their informed consent. See section B.4.1.4 for details.

B.4.1.2 Does the proposal involve Human data collection?

No personal data is collected such as e.g. health, sexual lifestyle, and ethnicity, political opinion, religious or philosophical conviction. These data are irrelevant to the project.

The proposal involves data collection from ambient and wearable sensors in order to assess the performance of context and activity recognition systems. Sensors that may be used include e.g. inertial platforms, accelerometers placed in objects, motion detection systems, GPS coordinates, environmental sounds, EEG signals.

Since these sensors are used to measure signals related to user activities or context, they relate to human data collection. Informed consent will be ensured (see section B.4.1.4 for details), and data protection will be handled (see section B.4.1.5) and safety ensured (see section B.4.1.6).

B.4.1.3 Does the proposal involve tracking the location or observation of people?

The proposal aims to infer user activity and context from ambient and wearable sensors. Sensors that may be used include e.g. inertial platforms, accelerometers placed in objects, motion detection systems, GPS coordinates, environmental sounds, EEG signals. Part or combination of these sensors may allow to infer location or observations of people.

However, experiments are carried out in the laboratory. While users participate in the experiment, they will interact with the experimenters and the systems, and they will in no way be given a false sense of privacy. In other words, acting out and behaving in an AmI environment and using wearable devices can be compared to acting out and behaving in a public space, where the subject may also be observed.

In general experiments are of short duration (a few hours at maximum). Shall users be instrumented (e.g. given a wearable device including sensors) for longer periods of time (days or more), they will be fully informed about the data collected by the system, and their consent will be asked. In that case, the system will not store *raw* information from sensors. Information is processed on-the-body and converted in a *summarized* form, that is the user *activity* or *context*. For instance the project would not aim to continuously record sound. Rather signal features would be extracted, and only this last information is stored. Absolute location may be conserved for analyses of path variability and trends over long period of time, however this will not be correlated to geographical places (i.e. no superposition on a map).

For further details on ensuring data privacy see section B.4.1.5.

B.4.1.4 Informed consent

When describing issues relating to informed consent, it will be necessary to illustrate an appropriate level of ethical sensitivity, and consider issues of insurance, incidental findings and the consequences of leaving the study.

There will be documentation of the recruiting and selection process of the Users. All participating Users will have given signed consent, following the EU requirements using a standardised form, which will be printed in the appropriate language.

Prior to the start of the process Partners will agree the method of approach to the individual, the handling of the completion of forms, confidentiality of the process, ability of the User to decline, and the handling, access and the storage of data will all follow a predetermined design at all sites.

All Users will also be informed of the due process of withdrawal from the project.

Each User will be given a User Identity number and only this will appear on all other documentation during the project. This will assist in the anonymity of all the Users.

B.4.1.5 Data protection issues

The project does not aim to collect large scale personal and/or medical data of individuals, since the project emphasizes algorithm development rather than large-scale user instrumentation. Nevertheless, a limited set of users will be behave within AmI systems or use wearable devices (to monitor e.g. motion and behaviour). The strategy that we will pursue to deal with privacy and data protection include:

- Minimizing the number of potentially private data the system encounters; and avoid the unnecessary collection and use of personal data.
- Establishing an Identity coding system which is used throughout the project. Anonymizing these data as soon as possible (immediately prior to any data collection.,)
- Defining rules for data collection, data handling, data transfer, data access, data storage during and after the project.
- Using identity coding agreed between partners to identify of the source of the data. If data was collected as part of previous research, the data is transformed into the new identity coding format.
- Establishing a system of informed consent for any data being used. Where possible, we will avoid data collection which is specific to one person. Where this is collected use ID codes and ensure safe storage and transfer of such data. We will describe how all data, and especially personal identify of the data is protected, and how this data will be used.

For all these aspects we will refer to ethical best-practices and informed consent of participant to experimental aspects of the project. The informed consent form will include: (i) Information on the research study, including expected outcomes and expected risks, payment, health-insurance coverage explanation, etc; (ii) a participant identity reference number assignment, (iii) a participant consent form, (iv) an investigator confirming statement, that the information provided to the participant is in all possible respects accurate and true.

Regulations that will be followed include among others, as applicable: EU Privacy Directives and Recommendations on the Protection of Medical Data (EU Data Protection Directive 95/46/EC and the Electronic Communications Data Protection Directive 2002/58/EC, Convention for the Protection of Individuals with regard to Automatic Processing of Personal Data of the Council of Europe of 1 January 1981, Declaration of Principles of the World Summit on the Information Society of 12 December 2003), and national laws.

B.4.1.6 Safety

The safety of wearable devices and ambient intelligence environments needs to be ensured. The consortium will ensure that the risks for the participants are minor—not higher than the ones encountered in their daily life.

Any equipment connected to a participant will be evaluated for personal safety. The Consortium shall take all measures to assure that appropriate environmental safety provisions are fulfilled in the course of the project by all contractors. The only burdens for users involved in the tests will be the time spent and the requirement to perform a set of activities in AmI environments, within normal limits of an average person. All recordings, including physiological measures will involve non-intrusive sensors or systems. Due to outstanding expertise of all partners in their field and their thorough acceptance of high ethical standards, accidental risks will be minimal.

In particular, safety issues are addressed as follows:

- The systems that will be used are not meant to be health-support devices - this will be made clear to the participants (informed consent).
- Systems are non-invasive: no implanted sensors or actuators will be used. Only body-worn and ambient sensors and and feedback devices will be used.
- Systems will not be dangerous: safety rules of electric design will be followed (as an example: no direct skin contact with connection to mains). Before human testing, the necessary system analysis will be carried out. Feedback systems (e.g. for haptic interfaces) will not be able to exert dangerous forces. No implanted actuators will be used.
- Some devices may measure physiological signals (e.g. to measure EEG, heart rate). These will be certified medical devices and/or will be devices satisfying the standards listed below.

The following standards issues will be considered to ensure these points:

- 93/42/EEC Medical Devices Directive
- IEC60601-1/1988 Medical Electrical Equipment Part1: General requirements for safety compatibility
- IEC60601-1-4/2000 Medical Electrical Equipment Part 4: Programmable Medical Electrical Systems
- IEC60601-2-30 Medical Electrical Equipment part 2-39: Essential Performance, of automatic cycling for non-invasive blood pressure monitoring equipment
- IEC60601-2-25/1994 Medical Electrical Equipment part 2-25: Particular requirements for safety of electrocardiographs
- IEC/TR60930/1998 Guidelines for administrative, medical, and nursing staff concerned with the safe use of medical electrical equipment
- IEC/TR61258/1994 Guidelines for the development and use of medical electrical equipment educational materials.

Simple checklists which show that the technology used complies with EU legal and regulatory requirements will ensure we meet Commission good practice guidelines.

B5. Consideration of Gender Aspects

Following the European policy of equal opportunities between women and men, the Commission has adopted a gender mainstreaming strategy by which each policy area, including that of research, must contribute to promoting gender equality. The consortium is highly concerned by this issue and all the partners are engaged to promote Women scientists' participation in FP7. The project consortium is engaged to take actions to increase the involvement of women in order to reach the 40% minimum target for the participation of women.

The main actions will be articulated around three ideas:

- women's participation in research must be encouraged both as scientists/technologists and within the evaluation, consultation and implementation processes,
- the study must address women's needs as much as men's needs,
- research must be carried out to contribute to an enhanced understanding of gender issues

How the project contributes to the achievement of European objectives?

- There should be a gender balance between men and women in laboratories, in senior management, which reflects their roles in society, as decision-makers and as consumers.
- More women will need to be recruited, retained and promoted. Good practices will need to be fostered in order to develop democratic, inclusive and innovative work cultures in industrial research to release the spark of creativity. That is why exchange of best practices on this issue will also be part of the project deliverables.
- For promoting gender equality, the participants will take a hard look at themselves to identify customs and practices that have the unintended consequence of structurally disadvantaging women or indeed excluding them from the organisation.

Suggestions: what can partners do to increase diversity and the number of women in research?

- an attractive work environment, which encourages and provides opportunities for innovation, offers career development opportunities in a life-cycle perspective;

- a commitment from the top to gender equality, diversity policies and dignity at work values;
- a high degree of transparency and two-way communication systems, merit-based open recruitment and staff review systems;
- sound work/life balance policies (maternity and paternity leave, child-care facilities)
- flexible work schedules, opportunities for some distance work

While the gender diversity is a global objective, the consortium will pay particular attention to ensure women to be really involved in the European Research:

- Participation in project activities: the project participants will be asked to pay attention to the level of women in project activities as co-ordinators and as members of project teams.
- Participation in expert evaluation panels: there is a need to increase women participation.
- Participation to international conferences such as "Women in Industrial Research" events- to promote the involvement of Women in the innovation process.

A. Appendix

A.1. Detailed BCI case study description

The third scenario has been chosen to test the generality of OPPORTUNITY methods in fields different than activity recognition. This scenario comes from the field of EEG-based Brain-Computer interfaces where electrical activity of the human brain is decoded to infer the user intentions or to recognize underlying cognitive processes (e.g. error detection, anticipation or alert). We will build up from EPFL's expertise on developing these type of interfaces to generalize the OPPORTUNITY approach aiming at the development of fully adaptive and robust BCI applications

In a typical non-invasive BCI setup, brain activity is acquired through a rather large number of sensors –typically 32 or 64 electrodes- located on the user scalp (i.e. electroencephalograph, EEG). These signals go through a pre-processing stage that usually consists of temporal and spatial filtering. Then, relevant features are extracted in either the time or frequency domain and feed into a classifier in order to recognize the user's mental state. Development of these systems imposes a particular challenge since EEG signals are characterized by a very low signal-to-noise ratio (SNR), are variant in time and may be affected by contextual situations (e.g. user's fatigue, lack of attention, etc). In addition, the electrical signal captured by the electrodes can be contaminated by noise generated by muscular activity [Goncharova03,Whitham07] or loose contact between the sensor and the skin.

Successful BCI systems rely on a mutual training phase where classifiers are updated in order to achieve better recognition of EEG patterns of activity while, simultaneously, the user learns how to modulate his/her brainwaves in order to improve the overall recognition performance. During the training phase, a feature selection process is performed to identify which electrodes are the most discriminant, and which are the features that better describe relevant mental tasks. Finally, classification is performed based on these features using methods that range from simple thresholds [Wolpaw02] to statistical methods [Millan04b], support vector machines, linear discriminant methods [Gerson06] or Bayesian networks [Shenoy05]. Furthermore, as is the case in several activity recognition systems. some approaches combine multiple classifiers at the *decision* level following voting schemes [Scherer04,Bourdaud08] or probabilistic combination of classifiers [Lemm07].

In most of these cases feature selection and classifier training is performed off-line. Only a few attempts have been done to implement on-line adaptation to BCI systems [Millan04, Buttfield06, Shenoy06]. These approaches are mainly based on a permanent update of the BCI classifier using supervised techniques where the labelling of the data is provided (i.e. ground truth). These approaches are intended to allow BCI systems to adapt to changes in the EEG patterns of activity (e.g. due to changes in the user mental strategy or fatigue of the user).

A first adaptation mechanism that has been used in BCI systems is the adjustment of the classifier's output using a bias or scaling factor. In this approach, the classifier remains unchanged and its output is shifted in order to minimize the error on the labelled data. Alternatively, adaptation may be based on the online estimation of the input data distribution. For example, in a simulated online scenario of a four-class BCI, the iterative estimation of the means and covariance matrices of the data classes led to a significant improvement in the classification performance [Buttfield06]. Similarly, [Vidaurre04] update the parameters of a quadratic classifier (QDA) after each trial in a cursor-control task. In these approaches, the features used for classification are selected during an off-line calibration process and remain the same during on-line adaptation. Finally, adaptation can also be achieved by performing online *both* feature selection and the updating of the classifier parameters. [Shenoy06] compared the three approaches for BCI adaptation in motor imagery tasks using common spatial patterns (CSP) features and linear classifiers (LDA). They found that recomputing the CSP features using on-line data yields no improvement with respect to a static classifier. Presumably as a result of the small number of data samples available for computing the new features. In contrast, retraining of the LDA classifier, as well as bias adaptation outperform the original static classifier. However, this approach requires a short calibration period at the beginning of each new session, instead of a continuous adaptation of the BCI system.

Despite these efforts to build adaptive BCIs, these interfaces remain highly sensitive to sensor failures or noise. Moreover, up to our knowledge, no current system is endowed with the capability of dynamically change the channels or features used for mental state recognition. We hypothesize that OPPORTUNITY methods are suitable for the development of robust BCI systems able to dynamically select the appropriate set of electrodes required to achieve successful operation and, upon detection of failure, recruit additional channels in order to minimize the performance degradation. Moreover, these systems will also be able to adapt to inherent changes in the EEG signal. Dynamic adaptation mechanisms (c.f. WP3) can be used to assess the system performance and prompt an appropriate corrective action (e.g. removal of noisy channels and the adaptation of the classification process).

Sensor self-description and runtime signal monitoring can be used to detect failures or signal contamination (e.g. loose contact changes the electrode impedance, EMG contamination is reflected in spectral changes in the EEG signal). Upon detection of these changes, opportunistic BCI systems will adapt either by applying on-line de-noising mechanisms or by removing that channel from the classification process (and possibly adding new channels) to achieve graceful performance-degradation.

Moreover, in line with previous studies at EPFL [Millan04,Buttfield06], OPPORTUNITY dynamic adaptation mechanisms will be applied to estimate the statistical properties of the input data, and if required update the classifier parameters. After a first evaluation of existing classifiers (i.e. Gaussian classifiers, linear classifiers) with respect to the opportunistic requirements—robustness, fast online learning—we will propose improved BCI classifiers. Furthermore, characterization of the changes in the input data space will be used to select the appropriate adaptation mechanism to be applied (i.e. either to adjust the classifier bias, or re-train the classifier).

Opportunistic BCI systems will be tested on experimental protocols ranging from the detection of evoked and event-related potentials linked to the user cognitive state, to the recognition of user modulated brain rhythms. These protocols were chosen taking into account the previous development of BCI systems for these signals by several groups (including EPFL). This studies give us baseline performance measures to compare the benefits of applying the OPPORTUNITY principles. In addition, these protocols provide labelled feedback data that allow us to reliably measure the system performance and its adaptation capabilities.

A first experimental paradigm we will use is the detection of Error-related EEG correlates. These signals are generated when the user perceives an erroneous action or feedback. This signals will be studied in speed-response protocols or human-computer interaction to assess recognition of brain activity related by errors committed by the person himself [Parra03], or generated during the interpretation of the user’s decisions [Ferrez08]. This activity is typically localized in frontocentral areas and appears 100 to 300 ms after the error. Previous classification attempts have achieved classification performances above 75% [Chavarriaga07,Ferrez08,Parra03], based on temporal features. In a similar way, we will also apply the OPPORTUNITY principles to the recognition of EEG signals related to anticipatory processes, where the user awaits the appearance of relevant events based on predictive stimuli. Previous studies at EPFL achieve classification performance of these signals above 70% [Garipelli07].

For the design of Opportunistic BCI system we will adopt the experimental protocol previously developed at EPFL [Ferrez08, Chavarriaga07, Garipelli07]. For error-related signals, we use a protocol where the user tries to control the movement of a cursor on the screen. Errors in the interpretation of the user commands are artificially added to the interface so as to allows us to measure brain signals elicited by erroneous movements of the cursor. Anticipatory processes are studied using a classical paradigm where predictive stimulus predicts the appearance of a second stimulus after a specific period of time (i.e. Contingent negative Variation paradigm, CNV). Anticipation-related EEG activity has been observed to develop after the onset of the first stimulus. For both phenomena, we have been able to achieve good classification levels using a few electrodes, which makes them extremely sensitive to sensor failure. In the Opportunity project we will start by quantitatively assessing the classifier's sensitivity to changes in the sensor configuration for both protocols,. (e.g. recordings using 32 or 64 electrodes). Moreover, using off-line studies, we will emulate sensor failures (e.g. loose contacts or electrode breakdown) by adding noise to a subset of electrodes. This study will allow us to characterize performance degradation of traditional BCI classifiers. Then, we will propose Opportunistic adaptive classifiers and fusion mechanisms that ensure robust recognition of changes in the sensor configuration in dynamic situations. This requires on-line monitoring of the signal characteristics of the electrode signal to detect changes due to sensor failures or configuration changes; as well as a classifier able to cope with those changes

An exploratory study of the opportunistic approach to BCI systems decoding motor imagery and other mental tasks will be performed. This study will be particularly focused on the assessment of the opportunistic techniques to track variations in the incoming EEG signal both *within* and *across* recording sessions. For comparison purposes we will adopt an experimental paradigm similar to the one used in [Buttfield06] where three different mental tasks (left and right hand movement imagination and vocabulary search) were identified using as a features the power spectral density of eight centro-parietal electrodes and Gaussian classifiers.

In a first stage, offline experiments will be performed with no online adaptation during several sessions. This recordings will allow us to evaluate the capabilities of an opportunistic system to track changes in the EEG signal by comparing the performance of the online classification to the performance of a static classifier (i.e. a classifier trained using only the data of the first session). Similarly, the system's performance will also be compared to the accuracy obtained using a temporal k-fold cross-validation[17]. This measure provides an estimation of the variability of the system by comparing classifiers that are trained using information from the overall system operation (including past and future samples), with classifier's that only take into account previous samples as is the case in real-time operation of a BCI. The off-line analysis, give us the opportunity to fully characterize the system performance and fairly compare several adaptation mechanisms using the same datasets. Taking into account that the goal of this scenario is to assess the genericity of the OPPORTUNITY methods, and the time constraints of the project, rather than developing a full operative BCI applications we will perform the study of BCI systems based on motor imagery in a simulated scenario using off-line acquired data.

In the case of event-related potentials related to cognitive states, after the validation in off-line simulated scenarios, we will implement on-line opportunistic BCIs, where the user receives feedback corresponding to BCI decisions. As done in the off-line case we will compare classification performance of both static and adaptive classifiers.

Similarly, we will systematically assess the robustness of the developed BCI systems w.r.t. to channel signal quality by offline addition of noise to previously recorded data. This will allow us to thoroughly characterize performance degradation. Online analysis will performed by physical manipulation of the electrodes (e.g. electrode removal, displacement) during the system's operation.

[17] In this case each fold is constructed by taking separate recording blocks respecting the original sample time order.

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