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Final Activity Monitoring Sensor Platform and Software Report and Documentation

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EXECUTIVE SUMMARY

The aim of the PAMAP project is to promote physical activity especially in the elderly population by developing a platform that can accurately monitor, supervise, motivate and help the practice of physical activity in clinical environments or specific structures, but also in daily life at home.

This deliverable focuses on the activity monitoring methodology developed in WP4 based on the sensor platform provided by WP3. Since the work of WP3 and WP4 is tightly coupled, it was decided to fuse the presentation of the final prototypes in one document. Respectively, this deliverable provides the reader with information about both the final hardware platform, in D2.5 (Revised System Specification) referred to as "Personal area network", and the final software components for data collection, processing/monitoring and online feedback as specified in D2.5, Section 3.4-6. It has to be noted that the different online user interfaces were formerly presented as part of D5.2 (PAMAP System Software Report and Documentation). Again, due to their tight coupling with the activity monitoring system, these interfaces are now covered in the present deliverable. Further, this deliverable covers the communication of the activity monitoring components with the PAMAP server, which provides the connection to the PAMAP system software for data management and medical supervision by means of the Electronic Health Record application and communication tools. The latter is specified in D2.5, Section 4.

Section 1 gives a general introduction to the work performed in WP3, WP4, and WP5 (for the online user interfaces) and the further organization of the deliverable.

1. INTRODUCTION

The aim of the PAMAP project is to promote physical activity especially in the elderly population by developing a platform that can accurately monitor, supervise and help the practice of physical activity in clinical environments or specific structures, but also in daily life at home. For that purpose the supervision of physical activity has to be achieved whilst teaching the user the good principles of physical activity practice, by helping the user to follow his program, and by providing him instant feedback and motivational elements in order to preserve or increase motivation and program adherence.

As described in D2.4 (Revised User Requirements), the PAMAP system follows a holistic approach for physical activity monitoring by supporting both types, **aerobic activities** that are performed to promote the health of the cardio-vascular system and prevent obesity and **strength exercises** that promote muscular strength of the musculo-skeletal system. Both of them are needed, since they cover different but complementary aspects of the physical health.

Now, the practice of these two different physical activity types also implies different aspects for their monitoring and support. Monitoring aerobic activities (such as walking, running or cycling) that are performed over a relatively long period of time and at a specific intensity implies to determine global parameters, such as frequency, intensity, type, and time (FITT principle) based on a reduced sensor setup. Strength training implies the repetition of short and specific exercises and requires an accurate realisation and body positioning. Monitoring these strength training exercises implies then to help the individual to perform the exercises correctly, which requires accurate tracking of the body segments with an extended sensor setup, evaluation of more specific movement parameters (such as number of repetitions performed, movement speed, amplitude, and smoothness) and an elaborated tutorial mode and online feedback mechanism.

Moreover, since PAMAP targets the elderly population, which is in general frailer with a higher percentage of limiting pathologies (functional or cardiovascular) and less used to physical activity practice, an important aspect in the design of the different activity monitoring methodologies is the possibility for **personalization**.

The final WP3 and WP4 hardware and software prototypes provide the above mentioned functionalities and have been developed according to D2.4 (Revised User Requirements) and D2.5 (Revised System Specification). Both use cases, the supervision of aerobic activities and the supervision of strength training, are based on one common system architecture with two adapted configurations and monitoring methodologies. Section 2 describes the general system architecture and the common denominator of both applications, which is a network of wireless inertial sensors, on which the monitoring is based. Section 3 provides details on the final prototype for strength exercise monitoring, while Section 4 details the final prototype for aerobic or global activity monitoring.

2. SYSTEM ARCHITECTURE AND INERTIAL MOTION SENSORS

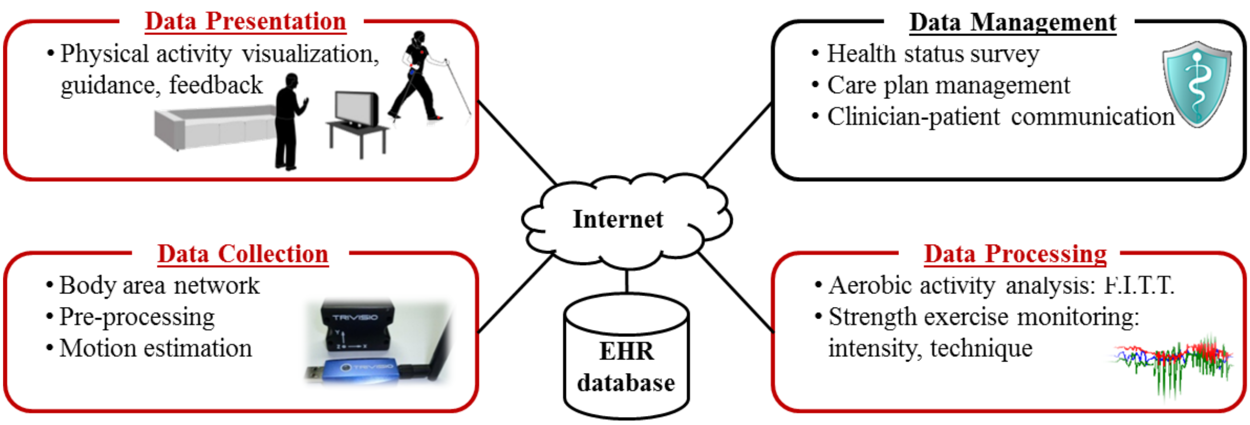

Figure 1 Overall system architecture. This deliverable focuses on the components outlined in red.

Figure 1 outlines the architecture of the overall PAMAP system from an activity monitoring point of view. The upper components represent the part of the system that the user interacts with. The lower components encapsulate the underlying activity monitoring technology. The components outlined in red are focused on in this deliverable.

The data collection component includes the hardware platform, in D2.5 referred to as “Personal area network”, and the software to acquire synchronized data, pre-process it, and extract higher-level information such as posture. The core of the hardware platform is a wireless inertial sensor network that is worn by the user and that has been developed within WP3 as specified in D2.5, Section 2.1.2. With this, up to ten wireless inertial measurement units (ColibriW) can be operated in a synchronized way via one USB receiver dongle. The application programming interface developed to operate the sensor network is documented in Sensor_software_API.pdf (see Annex). Respective fixations for conveniently attaching the sensors to the body have also been developed. For the final prototype, a special suit with predefined fixation points, different types of velcro straps (with clippers for fixation above normal clothes and with velcro and silicon for stable fixation on the suit), as well as, special fixations for the chest and the pelvis have been developed and produced in different sizes for the clinical trials.

The data processing component encapsulates the actual activity monitoring algorithms. Both together are in D2.5 referred to as "Strength Exercise/General Activity Measurement application".

The data presentation component encapsulates the different online user interfaces that visualize the respective physical activity parameters and provide guidance and feedback, while the training is performed. This component is in D2.5 referred to as "Online Strength Exercise/General Activity User Interface application". The data management component refers to the PAMAP system software as developed in WP5 and detailed in D5.4.

As indicated in Figure 1, the different components communicate with each other over network. As specified in D2.5, Section 4, the communication is based on messages, which are sent over an HTTPS connection using a set of web services provided by WP5. The communication channels, the protocols and the binary message format used are specified in Communication.pdf, while the API for the communication with the PAMAP server is given in icomapi.h (see Appendix).

The complete activity monitoring system for both applications, strength exercise monitoring and aerobic activity monitoring, is described in AALForum2011.pdf and in JAPA2012.pdf, whereas the latter also provides an evaluation of both systems (see Appendix).

3. Final Hardware and Software System for Strength Exercise Monitoring

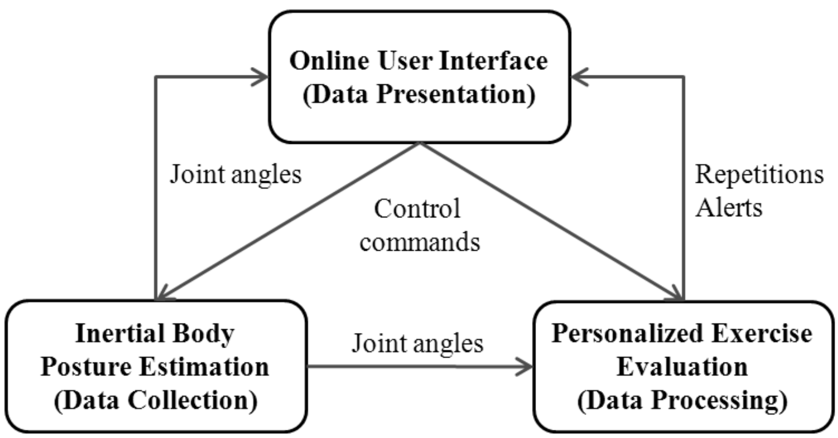

Figure 2 The different system components and how they interact in the strength exercise monitoring use case.

This section describes in more details the instantiation of the above described system architecture for the strength exercise monitoring use case as outlined in Figure 2. As required in D2.4, special focus was put on supporting an elaborated tutorial mode in order to support elderly also when exercising alone at home. As aforementioned the detail of the algorithm used for strength training monitoring is described in PervasiveHealth2011.pdf. To summarize, in order to prevent injuries but also in order to insure that the strength training program was correctly performed, the load of the exercises through the number of series and repetitions, the movement speed, range of motion but also smoothness was verified, the muscles to work were controlled by analysing the rotation axes whereas the injury prevention was ensured by analysing the posture.

The data presentation component, which was in D5.1 (PAMAP System Software Report and Documentation) coupled with the PAMAP system software and introduced as a "Measurement Visualization application", has during the second development cycle been developed to a complete and stand-alone digital "Personalized Strength Exercise Trainer". Since the development process was tightly coupled with the activity monitoring components and has been performed at DFKI, it has been decided to present the final prototype in this deliverable, rather than in D5.4 (Final PAMAP System Software Report and Documentation), which is dedicated to the EHR and i-TV applications.

The functionality provided by the final prototype is according to D2.4 and can be summarized as follows: The digital exercise trainer supports a panel of exercises as suggested by the end user CIT-INSERM (see ExercisePanel.pdf in the Appendix). It allows freely selecting single exercises or preconfigured exercise sessions (four adapted exercise sessions have been configured together with CIT-INSERM for the clinical trials) and loading individual exercise programs that have been configured and exported by means of the EHR application thanks to the common xml format as specified in RevisedRehabilitationPlanSpecification.pdf (the revision was done based on D2.5) and rehabilitation-plan.xsd (see Appendix). The interaction is done via a remote control and the output device is a TV in accordance with the i-TV interfaces developed within WP5. Once, an exercise session has been selected, the digital trainer guides the user through the different phases of the program including preparation, warm-up, work, and cool-down phase; it controls the exercise load by suggesting the weights, number of sets and repetitions, and breaks according to the training plan; it functions as a virtual memory by counting the number of sets and repetitions; and it controls the exercise technique by providing valuable feedback on the way the exercises are performed. Moreover, the motions of the user are visualized through a virtual avatar (see the videos in the Appendix).

Of course, the described user feedback is based on the ability to sense and evaluate the motions of the user, whereat this functionality is provided by the lower components in Figure 2, which contain the core technologies developed in WP3 and WP4. The major elements of this methodology are, an accurate full-body motion tracking system based on 10 wireless inertial sensors attached to the body, a method for segmenting a continuous stream of motion data for extracting single repetitions of a given exercise motion, and a method for comparing a segmented repetition to a reference motion and evaluating the execution in terms of specific parameters, such as movement amplitude, velocity and smoothness. Moreover, the basic idea in PAMAP is to allow for personalized exercise evaluation by comparing the motions performed by the user not to a pre-defined deterministic exercise model, but to a reference motion that has been recorded within a supervised training session in order to respect the individual limitations of the user. This idea is illustrated in Figure 3. In order to support this, another key technology developed within WP4 is the automated learning of reference motions from few examples and the generation of a probabilistic model using machine learning techniques.

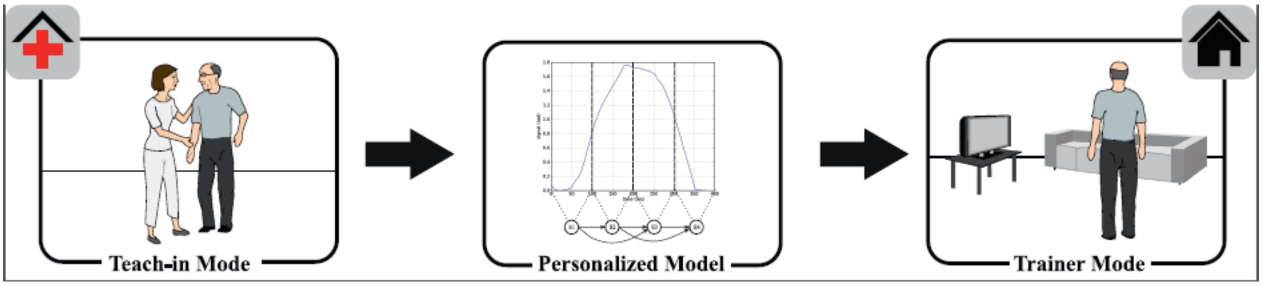

Figure 3 Overview of the personalized exercise trainer use case. Reference motions for each exercise are recorded during a supervised training session. From this personalized models are generated and then used as reference motions for exercise evaluation.

The complete system for strength exercise monitoring as outlined above is described in more detail in PervasiveHealth2011.pdf. A journal article is currently under preparation and will be extended with results of the clinical trials. The learning and modeling of reference motions is further detailed in SMC2011a.pdf, whereat an addition article has been submitted with extensive evaluations of the methods. The online user interface is also described in EHealth2012.pdf. Moreover, a complete video documentation presenting the features and usage of the Personalized Strength Exercise Trainer User Interface and a tutorial are provided in UI_Features.mp4 and UI_Tutorial_en.mp4, respectively. All of these files are attached in the Appendix.

As an addition to Section 2 it has to be noted that the final prototype does not support an online bidirectional communication link between the strength exercise monitoring system and the PAMAP server in terms of real-time data upload and download. Respective interfaces have been specified, tested and integrated into the aerobic activity monitoring system as detailed below. The communication between the strength exercise monitoring system and the PAMAP server is in this use case offline and is based on the common rehabilitation plan xml format as mentioned above.

4. Final Hardware and Software System for Global activity and aerobic exercise monitoring

This section describes in more detail the instantiation of the above described overall system architecture for the aerobic activity monitoring use case. As described in D2.4, the goal was to develop a mobile and unobtrusive system that enables the accurate monitoring and assessment of the user's aerobic activities in daily life, and to support and motivate the user by providing real-time feedback about the performed activities. The following paragraphs of this section describe the mobile hardware system, the software system including the data processing methods and their evaluation, the user interface and finally the integration of the mobile system into the overall PAMAP system for aerobic activity monitoring.

Opposed to the hardware system for strength exercise monitoring (described in Section 3), since aerobic activities are monitored over a long period in daily life, the hardware system for aerobic activity monitoring has some important constraints to follow: only a limited number of sensors can be used, and only relaxed requirements can be defined for calibration and fixation of the sensors. Therefore, the mobile system for aerobic activity monitoring consists of the following components: three wireless inertial sensors, a wireless heart rate monitor, and a control unit for data collection, processing and online feedback. These hardware components are specified in D2.5, Section 2, and further described in AUCN2012.pdf and in ABRA2012.pdf. An analysis of the necessity of the different sensors can be found in EMBC2011.pdf, concluding that the proposed sensor setup (three inertial sensors and a heart rate monitor) is the minimum required to achieve the goals in aerobic activity monitoring defined for the system.

As specified in D2.5, Section 3.9.1, the goal of the aerobic activity monitoring mobile application is to deduce general parameters of aerobic physical activity: to identify the aerobic activities traditionally recommended with a high reliability, and to estimate the intensity of all performed activities. To achieve these goals, a data processing chain has been developed, consisting of preprocessing, segmentation, feature extraction and classification steps. The main focus here was on developing new algorithmic methods for activity classification. Compared to the results achieved with the first prototype – reported in D4.2, Section 3.2 – significant improvement can be observed in this component. The data processing chain is described in more detail in ABRA2012.pdf. Moreover, SMC2011b.pdf reflects on some algorithmic aspects related to this component.

The data processing chain is implemented on the control unit, providing the main functionality of an online aerobic activity monitoring application. As defined in D2.5, Section 3.9.2, this application provides a summary of the already performed activities, and also includes additional functionality related to the user’s heart rate. These functions are accessible via a simple user interface, developed specifically for the control unit. A more detailed description of the mobile application's functionality, and the user interface on the control unit, can be found in AUCN2012.pdf.

In order to test the practicability of the developed mobile hardware system, to test the developed online aerobic activity monitoring application and user interface, and to evaluate the proposed data processing methods, 9 subjects were wearing and testing the mobile system during a new, extended data collection (D4.2, Section 3.2 reported on the first data collection, for testing and evaluating the first prototype of the mobile system). This data collection, and the creation of a new dataset of aerobic physical activities, is further described in ABRA2012.pdf. Moreover, both datasets of aerobic physical activities created during the PAMAP project have been made publicly available for academic research, thus making valuable contribution for the research community. As presented in ABRA2012.pdf, the second published dataset also includes a benchmark on various defined classification problems, establishing a basis for future research work.

In the final prototype of the aerobic activity monitoring use case, the mobile system has been integrated with the EHR, providing online bidirectional communication between the mobile aerobic activity monitoring application and the PAMAP server, by using the defined communication protocols and the binary message format, specified in Communication.pdf. On the one side, this allows the download of basic personal information (age, resting heart rate, etc.) of a monitored subject from the EHR into the mobile application, making personalized aerobic activity monitoring possible. On the other side, the subject can upload the result of the aerobic activity monitoring e.g. at the end of each day. With this, the clinician can look at the subject's daily progress using the visualization provided in the web interface of the EHR (WP5), thus supervising her aerobic activity sessions. The entire final system of the aerobic activity monitoring use case is described in AUCN2012.pdf, presenting also a typical scenario where the clinician and the monitored subject interact with the system over various steps.

5. APPENDIX

The following documents (as referenced above) provide additional information and technical details. Please note that some of these documents have been submitted for publication and are therefore confidential:

- Application programming interface documentation for operating the wireless ColibriW sensor network (UserManual_Colibri_API.pdf)
- Publication and manuscript describing and evaluating the complete activity monitoring system (AALForum2011.pdf, JAPA2012.pdf – this paper is submitted and thus confidential)
- Technical Report on IMUs' placement and calibration (PAMAP_TD02.pdf)
- Specification of the communication channels and protocols between the different software components and the PAMAP server and specification of the Motion Tracker Binary Format (Communication.pdf)
- Specification of the API for communication (data upload/download) with the PAMAP server (icomapi.h, API FUNCTIONS.pdf)
- Revised (based on D2.5) specification of the rehabilitation plan format shared by the PAMAP system software (WP5) and the Online Strength Exercise User Interface application (RevisedRehabilitationPlanSpecification.pdf, rehabilitation-plan.xsd)
- Specification of the exercise panel supported in the final prototype of the Online Strength Exercise User Interface application (ExercisePanel.pdf)
- Publication describing the strength exercise monitoring system (PervasiveHealth2011.pdf)
- Publication describing the body tracking, segmentation and evaluation for strength exercise monitoring (SMC2011a.pdf)
- Publication describing different user interfaces of the PAMAP system (EHEALTH.pdf)
- Video tutorials explaining the Online Strength Exercise User Interface, or also referred to as Personalized Strength Exercise Trainer (UI_Tutorial_en.mp4, UI_Features.mp4)
- Publication presenting an early prototype of the aerobic activity monitoring system, and analyzing the necessity of different sensors (EMBC2011.pdf)
- Publication reflecting on algorithmic aspects related to aerobic activity monitoring (SMC2011b.pdf)
- Publication presenting the hardware setup and describing the data processing chain of the aerobic activity monitoring application, and describing the creation and

benchmarking of a new dataset for aerobic physical activity monitoring (ABRA2012.pdf – this paper is to appear and thus confidential)

- Publication describing the final prototype of the aerobic activity monitoring system, presenting the user interface and visualization of the results, and the communication between the mobile application and the PAMAP server (AUCN2012.pdf – this paper is to appear and thus confidential)