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PAMAP Activity Monitoring Software Report and Documentation

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EXECUTIVE SUMMARY

PAMAP project aims at developing a system that enables the accurate monitoring of the physical activity of ageing people in order to support rehabilitation programs or, generally speaking, well-being. This deliverable provides the reader with information about the software components that process the data measured by means of the PAMAP sensor network, derive relevant and meaningful parameters of physical activity, and send the extracted parameters to the PAMAP server, where they can be accessed through the overall PAMAP system software. The software components described here are developed within WP4 (Bio-mechanical model and parameterization) and are referred to as "Measurements (Advanced) Processing Applications" in D2.3 (System Specification).

Section 1 gives a general introduction to WP4 and puts this in the context of the overall PAMAP system. Sections 2 through 4 describe the different software components and Section 5 (Appendix) lists documents that are appended to the deliverable in order to provide additional information about algorithms, methods, as well as technical details.

1. INTRODUCTION

The goal of the overall PAMAP system is to provide a platform for monitoring and aiding the physical activity of ageing people focusing on hypertensive, cardiac, and stroke patients' rehabilitation. These populations represent a high percentage of cases in elderly people. The basis for the system is a network of miniature inertial sensors and complementary sensors - such as heart rate monitor and GPS - that are worn by the patients in order to measure their motions and vital signs. The relevant parameters of physical activity are then stored in an Electronic Health Record, from where they can be accessed by the different PAMAP system users through the services defined in D2.3.

In this context, WP4 connects the sensor network to the overall PAMAP system. It is dedicated to acquiring the raw sensor measurements and extracting higher-level information that can be used to accurately control the patients' rehabilitation. Hence, the major goal of WP4 is to investigate, develop and implement algorithms to extract the required information from the raw sensor measurements.

As described in D2.1 (User Requirements), a typical rehabilitation program to be supported by the PAMAP system consists of both resistance/stretching exercises and aerobic exercises, whereas rehabilitation support includes both a tutorial and an assessment aspect. This results in two different sets of algorithms to be developed in WP4. Section 2 focuses on monitoring and aiding resistance/stretching exercises. Section 3 is dedicated to monitoring aerobic training.

Apart from the measurement processing algorithms, another aspect of WP4 is related to the issue of communicating with the PAMAP server in order to store the extracted information and make it available to the overall PAMAP system and to access demographic data of the monitored patient for being able to personalize the processing algorithms (see Section 4).

2. RESISTANCE EXERCISE MONITORING AND AIDING

In order to accurately control the execution of specific stretching or resistance exercises, both the assessment and the tutorial aspect are important. Assessment corresponds to monitoring the time and duration of the training and – on exercise level - more specific parameters such as the number of repetitions. The tutorial mode corresponds to helping the patient when performing the rehabilitation program, in particular when performing unusual exercises, by means of comparison with a reference movement and proper visualization and feedback. This is especially important for ageing people, since incorrect execution of exercises, e.g. due to loss of suppleness, arthrosis but also lack of training, could occasion more damages than benefits.

In order to provide these functionalities, the first challenge is to be able to precisely estimate the body motion in terms of rotations and positions (see Section 2.1). Based on this, the second challenge consists in extracting relevant quantitative and qualitative parameters from the captured movement (see Section 2.2) in order to evaluate the movement execution. The first activity monitoring software prototype brings particular attention to upper-extremity movements. Indeed, upper-extremity movements are particularly complex and not as easy to monitor as lower-extremity movements due to the complexity of the upper-extremity joints (trunk, shoulders) and the large number of movement possibilities. An early version of the software prototype is described in the publication AALIANCE.pdf (see Appendix).

2.1. Upper-body pose estimation

The accelerations and angular rates provided by the inertial sensors can be used to compute the pose and motion of the segments on which the sensors are attached. Hence, by placing the sensors at strategic positions on the body, it is possible to gain information about the pose and motion of the limbs. At least one inertial sensor is required at each segment that should be monitored in order to obtain the complete orientation of the segment. For an accurate monitoring of the upper-extremity pose and movements, at least five sensors are then needed. A sixth sensor might be added in the next prototype in order to distinguish the upper-torso movements from those of the pelvis. This number of sensors is acceptable for resistance training, which is usually performed during a short period of time (< 1 hour during cardiac rehabilitation).

The sensors' placement is chosen with respect to several constraints: it should be unobtrusive, limit the skin motion artefact, and insure an easy positioning and accurate data. The recommendations for the sensors' placement of the upper-extremity are given in the document TR2.pdf (see Appendix).

The first software prototype is built in a modular way. It automatically identifies the connected sensors and tracks the respective parts of the upper body.

In order to estimate body motion, a biomechanical model of the human body and a precise calibration of where the sensors are attached to the body are required.

Given this, the data are then obtained by combining the actual measurements obtained through the integration of the accelerations and angular rates with predictions based on the biomechanical model.

The model consists of rigid bodies (the bones) and restricted joints. It is parameterized by the segment lengths, so that it can be personalized for the monitored subject.

The fusion of the measurements and the model is done in an extended Kalman filter (EKF), which produces joint angles and kinematics. Together with the segment lengths this describes the motion of the monitored parts of the body.

A more detailed description of the upper body pose estimation is given in section 4 in the publication EuroSSC2010.pdf (see Appendix).

The first biomechanical model is a simplified description of the human body. One aspect of future work will be to improve the model of the shoulder griddle, which currently represents only the gleno-humeral joint as a ball-and-socket joint. Other degrees of freedom will be added in order to better represent the other joints of the shoulder griddle. Moreover, adding redundant sensors to the upper arms is considered as one possibility to correct for drift and estimation errors. In addition, different tests should be performed to consider the calibration method that provides the best compromise between simplicity and accuracy.

2.2. *Exercise monitoring and aiding*

With the first prototype of the upper body pose estimation as described above, it is possible to record a reference movement – i.e. together with a clinician that sets up the rehabilitation plan – in terms of a sequence of time stamped joint configurations. This can later be used for both, demonstration as part of the tutorial mode, or as good reference movement to compare with.

The relevant parameters to be extracted and controlled are the posture, the number of repetitions, the movement amplitude, smoothness and speed. Moreover, the challenge is to develop an algorithm for estimating the diversion between the performed movement and the movement of reference.

The current prototype includes a proof-of-concept implementation of a biceps curl, where the system automatically counts the number of repetitions and controls the movement amplitude and the posture of the shoulder. A required number of repetitions can be defined by the clinician, the system tells the patient when this is reached to finish the exercise. It is also possible to define more than one set of repetitions, with an appropriate pause between two sets. The system also recognizes unwanted movements, i.e. if the shoulder has moved too much, or the elbow is not entirely flexed or extended, and sets an appropriate warning flag, which can be used by the visualization to output a micro-alarm or an error message.

Work is also currently done to define a more generic way of evaluating the movement performed by the subject. As aforementioned, different parameters have to be checked according to the movement performed: the body posture, the movement, the number of repetitions, the movement amplitude, the movement smoothness and speed. As many combinations exist, a general algorithm is to be proposed. The clinician could then define which parameters are meaningful according to the exercise to be done and only these ones will be used to provide feedback to the patient. For instance, during push-up exercise, the distance between wrists should not exceed a certain distance, the back has to be straight, and the shoulder movement has to be performed around a specific rotation axis. The movement of reference recorded in presence of the clinician can be used to define what the expected values for each one of these parameters are and only a certain deviation will be tolerated between the actual and the expected values, otherwise an appropriate warning flag will be activated.

In its present form, the algorithm takes as inputs the orientation for each joint as well as the joint position for the actual and the movement of reference. Therefore, it currently works offline and should be adapted to work in real time. The algorithm also takes as inputs a structure that lists the name of the body parts that have to be considered and finally a structure that gathers the parameters that should be checked. The definition of body parts is used to limit the data to load, which will be especially meaningful when the lower body is also integrated to the measurement.

The first step of this algorithm consists in identifying the different movement cycles. It is performed by applying cross-correlation of the most moving joint, which can be different from one exercise to the other. Once each movement cycle is identified, the quantitative parameters such as the number of repetitions, and the movement speed are computed and compared to those expected.

The second step consists in computing the almost constant values corresponding to the posture that the body should respect, namely, distance between joints or joint angles. The mean and the standard deviation of these values are computed and compared to the reference values.

The next step consists in evaluating the movement amplitude and rotation axis. The rotation axis is compared to that of the reference movement in an anatomical reference frame. It is then easier to specify, how the patient should correct the movement, which is not always easy for movements around joints such as the shoulder (e.g. the shoulder should be more abducted/flexed).

The last parameter to be checked is the movement smoothness, which detects jerks in the movement. Here again, the most moving position is used. This parameter is not implemented yet.

The robustness of this method has to be tested through many movements and subjects and the validity of the parameters chosen has to be validated with the help of physiotherapists. Modifications have to be expected.

3. GLOBAL ACTIVITY AND AEROBIC EXERCISE MONITORING

In order to control aerobic training, assessment is the most important aspect. The three most important global parameters to be assessed are frequency, intensity, and duration of physical activity. While frequency and duration are rather easy to obtain, the challenge remains to develop a methodology to estimate – based on the available sensor measurements - the intensity, i.e. the energy expenditure, in a more automatic, more precise, and more reliable way than current methods allow for. One important constraint is, however, a limited number of sensors and relaxed requirements for calibration and fixation, since global activity should be monitored over a long period of time.

Sections 3.1 and 3.2 describe the different approaches investigated during the first project cycle. The most promising and advanced approach is based on signal-oriented activity classification and is described in Section 3.2.

As a general comment, all approaches mentioned here can be personalized by including demographic data of the monitored subject, such as her weight, height, and age.

3.1. *Mechanical energy*

Energy expenditure can be indirectly measured by estimating mechanical energy. This can be extracted from the upper body motion by approximating the body segments as cylinders with a certain weight. However, this first approach, which is implemented in the first prototype, shares the requirements of the body motion estimation described in Section 2.1 with respect to the number of sensors, their fixation and their calibration, and is therefore not well suited for a long-term global activity monitoring.

3.2. *Global activity monitoring*

3.2.1. *General approach*

The aim of the global activity monitoring is to identify the aerobic activities traditionally recommended with a high reliability, and to classify other, miscellaneous activities according to their intensity level. The recommended aerobic activities to identify are walking, running, cycling and Nordic walking. In addition, the aim is also to identify the postures lying and sitting/standing. As for all other activities, the system should classify them as activities of light, moderate or vigorous effort. This activity intensity classes are defined by the energy expenditure while performing an activity: light intensity (< 3 METs – MET: Metabolic Equivalent of Task), moderate intensity (3-6 METs) and vigorous intensity (> 6 METs). To determine the intensity level of a certain activity, the Compendium of physical activities is used (see [1] of DataCollection.pdf). This compendium contains MET intensities for more than 600 specific activities, thus can be used as reference to determine the intensity class of certain activities.

3.2.2. *Data collection and offline processing*

To construct and train the activity classifier and validate the first prototype, data from performing activities have to be collected. The protocol of the data collection is given in the Appendix (DataCollection.pdf). An indoor and an outdoor scenario is defined within the protocol, containing the above mentioned recommended activities, and some other, everyday activities to be classified in one of the activity intensity classes. The protocol also contains the 5-digit codes and MET intensities of each activity from the compendium, which will be used as reference data.

During data collection, the test subject is wearing inertial sensors on foot, chest and wrist, a heart rate monitor, all connected to a data recording unit. The sensors are synchronized by the data collection software. While performing the activities from the data collection protocol, the test subject or a supervisor inputs on the data recording unit the activity ID of the next activity, to assure labeled data.

From the collected data, signal-oriented (in time- and frequency-domain) features are extracted and selected, mainly from acceleration and heart rate data. These features are used to construct and train a decision tree: the decision nodes contain selected features, and the leaf nodes represent the activity and intensity classes. The methods used for feature extraction, selection and decision tree based activity classification are described in Section 3 in the publication EuroSSC2010.pdf (see Appendix).

3.2.3. Online activity classification

The above described decision tree is implemented on a portable device. When wearing the sensors, the activities performed by a patient are monitored and stored over time.

4. PAMAP SERVER COMMUNICATION

In order to store the information extracted by means of the physical activity monitoring software and make it available to the overall PAMAP system and – on the other hand - to access patient-related and demographic data that is required for being able to personalize the processing algorithms, the software components of WP4 need to communicate with the PAMAP server. The communication is based on messages, which are sent when available over an HTTPS connection using a set of web services provided by ICOM. The specification of the binary message format and the API for the communication with the PAMAP server are detailed in MTBF.pdf and icomapi.h (see Appendix).

5. APPENDIX

The following documents provide additional information as well as technical details:

- Publication on activity classification and upper body pose estimation (EuroSSC2010.pdf)
- Technical Report on IMUs' placement and calibration (TR2.pdf)
- Publication on early PAMAP system (AALIANCE.pdf)
- Protocol of data collection for general activity monitoring (DataCollection.pdf)
- Specification of Motion Tracker Binary Format (MTBF.pdf)
- Specification of API for communication with PAMAP server (icomapi.h)