

# Healthy Aging using Physical Activity Monitoring

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**Abstract:** The elderly population in the industrialized world is rapidly increasing. In order for them to keep a high quality of life and remain active participants in the community, they need to stay healthy. For this it is important to sustain a high level of physical activity and to be properly rehabilitated in case of a severe disease. This paper describes the concept and first results of the technical assistance system PAMAP, which can monitor the physical activity both in a clinical setting and in the subject's home environment. The goal is to provide physicians with the means to encourage people to a healthy activity level, and also to diagnose problems at an early stage.

**Keywords:** activity monitoring; home-based rehabilitation; electronic health record; body sensor network; inertial sensors; sensor fusion.

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## 1. Introduction

A balanced physical activity level is essential for an active retirement, and represents a fundamental indicator of good health and life quality [1], [2]. It is well-known that physical activity has a positive effect against chronic conditions, and more precisely, stimulates the immune system [3], counteracts depression [4], activates the bone remodeling [5], and reduces the risk of cardiovascular diseases [6]. It is also an important factor in the functional rehabilitation process [7]. Hence, physical activity monitoring is of high interest in the area of *ambient assisted living* (AAL).

This paper presents the concept and first results of the technical assistance system PAMAP. It is designed to improve the physical activity level of elderly. The system can be used to monitor physical activity in a clinical environment, as well as, in daily life, thus providing health professionals with important information to diagnose problems at an early stage.

The overall PAMAP system and its information management infrastructure are described in Section 2. Section 3 then focuses on information acquisition and extraction by means of a mobile sensor network, and Section 4 presents early results. Finally, Section 5 concludes the paper.

## 2. System Overview

The PAMAP system has two separate conceptual parts: the information management (the part most visible to the systems users) and the underlying information acquisition system (the PAMAP sensor network and associated information extraction technology). The former aspect of the PAMAP system is described in this section, and the remainder of this paper is dedicated to the information acquisition.

From the information management point of view, the PAMAP system consists of the infrastructure and the applications used to monitor physical activity, present information, and provide an easy way for the main system users - the monitored subject, her family and friends and the clinicians - to interact. Figure 1 shows the major system parts: The *body area network* (BAN) consists of the PAMAP sensor network and a control unit that links the sensors and several different I/O devices. An *interactive TV* (i-TV) is used for communication between the different system users. The i-TV solution is used to increase the acceptance and ease the learning amongst elderly users, who generally are not very familiar with computers. It is possible to deliver rich content (data and media) to the TV and connect the PAMAP BAN with its back-end infrastructure. With an additional camera, the subject can easily keep contact with the clinician via videoconferences.

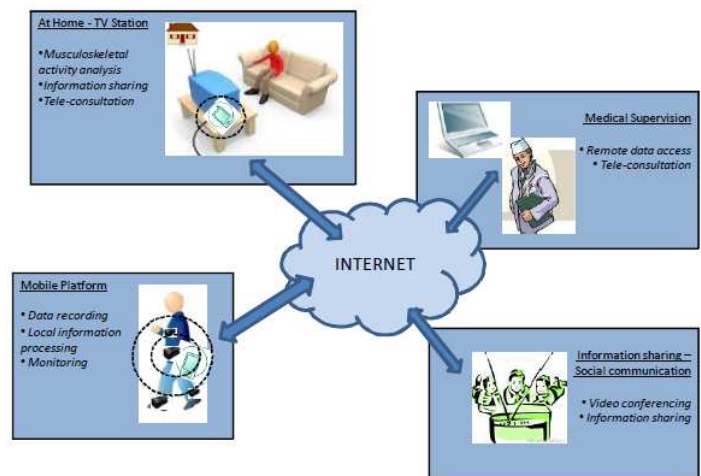


Figure 1: Basic units of the PAMAP concept

Another important part of the PAMAP system is the web application for collection and management of the information in the *electronic health record* (EHR). Apart from the motion and activity information the PAMAP EHR also includes a comprehensive summary of the medical record of the monitored subjects. Although not a full hospital EHR, it is intended to be a broad electronic record of the subject's medical profile and history and also support the possibility of integration and interoperability with legacy systems. The PAMAP system also supplies the means for the communication between the subject and her clinician and friends. The system provides online meeting rooms that enable, in addition to regular web conferencing, presentations, online training, and collaborative whiteboard drawing. It is also possible for the physician to prepare educational material for the subject to view.

## 3. Information Acquisition

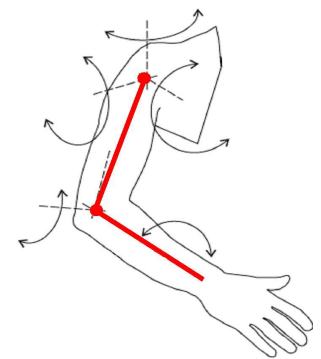
This section describes the PAMAP sensor network and how the wearer's activity is deduced from the sensor measurements using a biomechanical model.

### 3.1. Sensor Platform

The sensor network consists of MEMS<sup>1</sup> based miniature inertial measurement units (IMUs)<sup>2</sup>. Each sensor comprises accelerometers, gyroscopes, and magnetometers capable to measure in three dimensions. This is contained in a 3x3x1.5 cm 18 g casing. The sensor's small size and low weight makes it possible to make the sensor network unobtrusive once the wired sensors are replaced by the next generation wireless IMUs.

### 3.2. Biomechanical Model and Parameter Estimation

Each IMU in the sensor network provides accelerations and angular rates at 100 Hz. These measurements indirectly contain information about the pose and motion of the segment where the sensor is 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. The information is obtained by comparing the measurements with predictions based on a biomechanical model of the body. The model consists of rigid bodies and restricted joints. Figure 2 depicts a simple arm model indicating how rigid bodies (the bones) are connected via joints (sometimes with limited degrees of freedom as in the elbow). This is a simplified but sufficient description of the human body for the purpose. The fusion of the measurements and the model is done in an extended Kalman filter (EKF) [8] which produces joint angles and kinematics to describe the pose and motion of monitored parts of the body.



**Figure 2: Simple biomechanical arm model used for estimating joint angles.**

### 3.3. Extraction of Medical Parameters

Joint angles give the possibility to supervise motion, and compare the performed motion with predefined exercise programs. The PAMAP system can, by comparing the performed and the asked for exercise, derive higher level information such as incorrect motions.

General activity is typically measured in MET<sup>3</sup>, which can be indirectly computed from the oxygen consumed by the body. Today, there are no good tools available for measuring METs in a subject's home environment. Instead pedometers or even questionnaires are used to get an idea of the subject's activity level. This does however just give a limited view. It is for example common that the activity level is exaggerated in questionnaires. The current version of the PAMAP system uses the information about the joint angles and limb kinematics to compute the kinetic energy of the motion. This provides an indicator of the physical activity level. By incorporating more of the individuals physiological pa-

<sup>1</sup> micro-electro-mechanical system

<sup>2</sup> The sensors are Colibris from Trivisio Prototyping GmbH.

<sup>3</sup> metabolic equivalent of task

rameters, future versions of the system will be able to estimate an indicator which is closer to the actual MET.

#### 4. Early Results

The first prototype of PAMAP showcases the possible use of the monitoring system for functional rehabilitation and general activity monitoring, thus addressing both musculoskeletal and cardiovascular pathologies. The two use cases are described in the following.

##### 4.1. Use Case: Home-Based Functional Rehabilitation

The system monitors and promotes repetitive upper limb exercises, typically prescribed to stroke patients to regain or retain mobility. Using a two IMUs sensor network, with an IMU attached just above the elbow and one just above the wrist, an arm exercise can be monitored. The system evaluates the correctness of the movement, frequency, range, and amplitude. Based on this, the subject gets immediate feedback (e.g., by raised alarms or messages) as well as graphical help to perform the correct motion (see Figure 3). Since the collected exercise data is also archived in the EHR (cf. Section 2), it can be reviewed by a rehabilitation specialist, who gets a solid ground for making recommendations for the continued rehabilitation process.



Figure 3 Functional rehabilitation using the PAMAP system.

Figure 4 General activity monitoring using the PAMAP system.

##### 4.2. Use Case: General Activity Monitoring

In the second use-case, the activity level of a subject is monitored. In this case five sensors are used; two for each arm, and additionally one attached to a central point of the torso. This way the activity of the upper body is captured. The user is continuously informed about her activity level through the control unit, and when connected to a display the activity history can be displayed (see Figure 4). This is useful for cardiovascular rehabilitation, where patients are prescribed exercises to excite a certain intensity of physical activity. It is also possible to sound an alarm when the activity level gets too high, or automatically notify the physician if the activity level is below the recommended level. As in the functional rehabilitation case, the captured data is stored in the EHR, keeping the medical personnel informed about the general progress of the subject over longer periods of time.

## 5. Conclusions

The PAMAP system is a technical support system to help care providers to improve the health and quality of life of the elderly population. It can be used both preventive and to make rehabilitation more efficient. Moreover, the system allows for a more independent elderly life style, since it can be managed by the elderly themselves in their homes. This way, PAMAP encourages the elderly to keep an as active, independent, and normal life as possible.

The PAMAP system is still at an early stage of development, and there is on-going work to improve and extend the quality of the information delivered. The design of the PAMAP system is highly extendable, and different methods are evaluated to improve its usefulness. Additional sensors measuring pulse, temperature, breathing, and blood pressure are considered, as well as goniometers, altimeters, GPS and ultrasound. Additional sensors will help improve the overall activity estimate, and the ease of usage.

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