# A Wearable Accelerometer Based Platform to Encourage Physical Activity for the Elderly

Wagner O. de Morais, Anita Sant'Anna, and Nicholas Wickström

*Abstract*— **The growth in the elderly population will pose great pressure on the healthcare system to treat common geriatric problem. Preventive approaches like encouraging elderly people to perform physical exercises can decrease the risk of developing chronic diseases. In cases when diseases already have developed, further developments could possibly be retarded. In this work a wearable platform to recognize user's movements presented. The platform provides interactions with simple computer games designed to promote physical activity.**

## I. Introduction

OVER the last years, the evolution in miniaturization of electronic components has led to smaller computers, sensors and other devices. This evolution in combination to the progresses in the communication industry makes it possible to integrate computing devices into the environment [1]. These new technologies also have important implications in how they can be used to improve quality of life, e.g., dealing with problems like effective healthcare systems for elderly people.

Projections in population show, as depicted in Fig. 1, that in the next 40 years the largest part of population growth will be among people aged 65 and older, especially in Europe. It even happens that the senior population will be twice as large as the population of the youth [2].

This growth in the elderly population will pose great pressure on the healthcare system to treat age-related problems which includes different aspects of physical, social, and cognitive wellness as well as assistance from professional and informal caretakers [3]. Thus, the development of cost-efficient methods to treat common geriatric problems has become an emergent problem in healthcare.

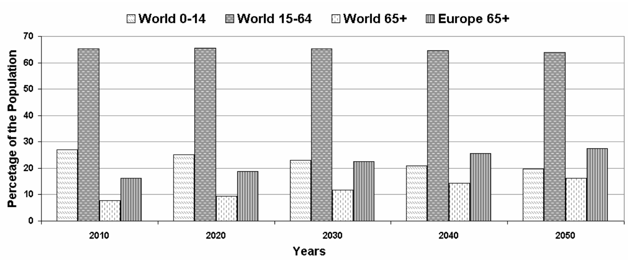


Fig. 1. Predicted population by age groups for the next 40 years in the world and in Europe [2]

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W. O. de Morais, A. Sant'Anna and N. Wickstrom are with the School of Information Science, Computer and Electrical Engineering, Halmstad University, Halmstad, Box 823 Sweden ({wagner.demorais, anita.santanna, nicholas.wickstrom}@hh.se).

In order to reduce the risk of chronic disease development, existing approaches highly recommend that preventive programmes are adopted e.g., by encouragement of physical exercises [4]. Most of the health problems caused by physical inactivity demand long-term treatments and are more costly when compared with prevention programs [3], [5].

Over the past years, several reports [3], [6]-[8] discuss the benefits of being physically active in life from a health and socioeconomic aspects. One big portion of the elderly population live alone and, in particular, falls is one of the major problems that hinder them to carry out the activities encountered in daily living routines [9]. Physical exercises programmes designed to improve strength and balance may result in a reduction in falls [5], [10]. Physical exercises help also to improve cognitive functioning, to reduce the symptoms of depression, and the chances to develop dementia, including Alzheimer's disease [11]. Furthermore, an exercise agenda may offer an excellent opportunity to the elders to have social interaction, meeting new people, and developing new skills [6].

Although efforts have been made to promote physical exercise programmes to the elderly population, they have not succeeded in giving the desired effect. Challenges in this encouragement range from elderly acceptance and engagement to infrastructure requirements, such as transport, facilities, instructors and similar obstacles. Thus, there is a need for systems that are user centred and home based [12], i.e., systems that allow users to exercise in their homes. These systems can enable constant monitoring of the users' information, such as position and orientation, while performing their daily activities, regardless if they are inside or outside the home.

Mobile and wearable sensors are the enabling technologies of this vision. Recently, these technologies have been combined in different architectures and applications in healthcare, especially for remote real-time patient monitoring [13]-[15].

In this paper, a new approach to encourage physical activities is presented. This work proposes a platform, based on a wireless wearable accelerometer sensor, to be used as an input device to simple computer games in order to promote physical exercises for elders and in addiction, can serve as a permanent measurement platform.

Several wearable accelerometer based platforms have previously been proposed for different applications in healthcare due to their small size, low-power consumption and low-cost. These platforms have been used to classify daily activities [16], [17], detect falls [18], [19], abnormal events [20], and to analyze energy expenditure [21], [22].

The requirements for such a wearable platform are present in Section II. In Section III the hardware components of the platform is presented. The model for motion detection is explained in Section IV. Section V and Section VI presents the software architecture and application examples of the platform, respectively. Finally, some conclusions are drawn in Section VII.

## II. Functional and non-Function Requirements

Specification of requirements is the most important task during any system design because it describes what the system will realize and how it will be implemented. In general, requirements can be classified in two groups: functional and non-functional requirements. The former reflect what the system must do, like behaviour or functionalities. The latter describe how it needs to be implemented in terms of performance, robustness, reliability, usability, and so forth.

### A. *Functional Requirements*

An ideal wearable platform to promote physical interaction with computers must gather user's motion information regardless of his or her location and activity. The data can be stored locally on the platform and/or transmitted using a wireless link to a host computer for analysis and posterior feedback to the user. These statements (collect, store, analyze and transmit) describe our general functional requirement.

In order to better understand the fundamental differences between different tasks, they were separated them in two views: an application oriented top-down view and a data oriented bottom-up view.

In the application oriented top-down view, two types of behaviours are clearly observed:

- Dynamic behaviours – here as time sequence of data is analyzed to understand the interaction with the system. Examples of such behaviours are tracking of e.g. a limb in 3D space. Other examples are gait analysis or gesture recognition.
- Static behaviours – here a posture or fixed configuration of the sensor is captured and analyzed.

In the data oriented bottom-up view, two different categories can be seen:

- Continuous – here data is analyzed continuously and the results are transmitted. Examples are calculations of energy expenditure and tracking of a movement in a game situation.
- Event driven – here data is analyzed continuously and when some action that is monitored is identified the result is transmitted. Examples are fall detection and gesture recognition.

Most posture and gesture recognition systems rely on computer vision using motion capture systems [23], [24]. However, this method requires a more refined environment, with cameras and good lighting conditions, which is not suitable for our application.

More sophisticated methods combine accelerometers and gyroscopes to create inertial navigation systems [25].

### B. *Non-functional requirements*

Aiming to provide a wearable motion detection platform, which can be strapped around some part of the body, the main challenges are balancing portability, unobtrusiveness, and usability. To meet these requirements, size, weight, and power constraints must be addressed.

The restrictions on size and weight of the form factor are extremely relevant to a wearable device. Portability can be achieved by using light weight and small components.

As the user is encouraged to wear platform, the provided device must be as unobtrusive as possible. Ideally, this wearable platform should be imperceptible, i.e., mounted in the sole of the shoe or inside of a wrist watch. However, with small and portable devices, the volume of the power source represents a significant portion of the total size. Just as the size of keys in a keyboard can not be dramatically reduced without compromising usability, the size of the power supply can not be reduced compromising the energization of the platform.

There is a need also for system architecture in order to enable the development of tools necessary to acquire sensor data, to process it and to display the resulting information. One desired feature is to provide sensor node abstraction to the developer through components that encapsulate the low-level programming related to communication, configuration, and so on.

## III. Platform Components

To fulfill the requirements mentioned before, the selection of required components was mainly made in terms of size and energy efficiency. The platform (Fig. 2) integrates one motion sensor, one master microcontroller, one electrically erasable programmable memory, one wireless communication module, and the power source to form a wearable sensor node.

The motion sensor selected for this platform is a VTI SCA3000-E04 [26] three axis accelerometer with a measuring range of ±6g. This accelerometer is characterized by its small size and low-power consumption (120µA at 3.3V) if compared with other similar products.

The accelerometer sensor has low-power operation modes like movement detection that is a useful feature towards system level power management. If the user undresses the platform, some components in the platform could be switched off or turned to operate in low-power mode, such as the microcontroller. If the user turns to wear the platform again, accelerometer will sense the movement and will interrupt the microcontroller that will turn on all others components.

The main microcontroller is a PIC16F690 [27] model from Microchip that is well suitable for low power applications (power saving modes) and easy to program (only 35 instructions). A 256Kbit serial SPI bus EEPROM is provides as an off-line storage resource.

The communication component is a Free2move Bluetooth module model F2M03GLA [28]. This module is characterized by its low power consumption and an integrated high output antenna. While active, the communication module consumes more than 90% of the total platform energy. However, Bluetooth is a standard wireless technology currently present in mobile phones, PDAs, and laptop computers which simplifies the communication with surrounding systems.

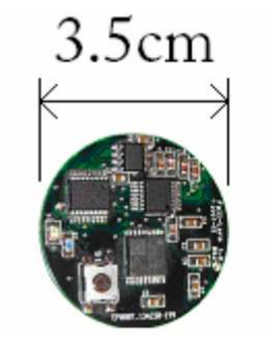


Fig. 2. A small and light measurement system based on a 3 axis accelerometer integrated with an energy efficient microprocessor. A serial memory allows storage of data and a Bluetooth module permits wireless transmissions.

## IV. Motion Models

Current motion tracking systems applies computer vision techniques, electromagnetic or microelectromechanical system (MEMS) sensor like accelerometers and gyroscopes as input devices [29].

Traditional gesture recognition is performed with e.g. Hidden Markov Models (HMM) [30] or other machine learning algorithms [31]. However, in wearable applications with limitations as outlined in previous chapters a more light weight approach is required.

Thus an analysis methodology based on finite state machines (FSM) is proposed. The idea is to model the phases of a gesture with states and to use thresholds for filtered acceleration signals and its standard deviation as criterions for transitions. To exemplify the applicability of the methodology a set of hand movements are used (Fig. 3):

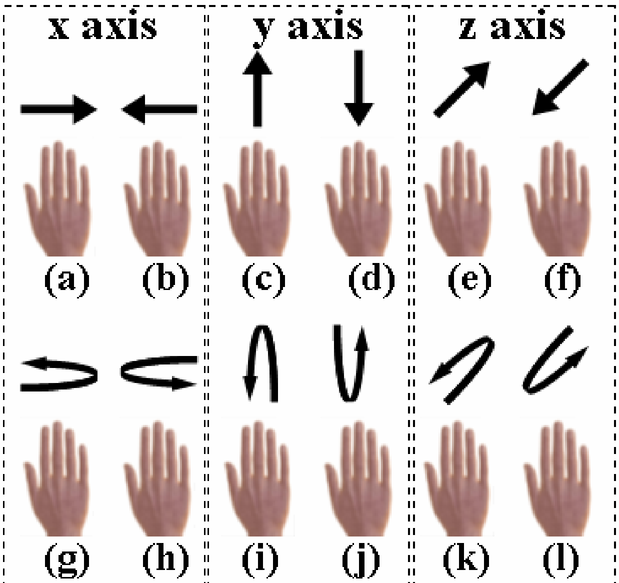


Fig. 3. Right hand movement directions as (a) “Right”, (b) “Left”, (c) “Forward”, (d) “Backward”, (e) “Up”, (f) “Down”, and (g, h, i, j, k, l) represent the same movements but returning to the origin.

For each movement, a running average and the standard deviation for the x, y and z axis acceleration is calculated, using two window's sizes, 5 and 20 samples respectively, at a sampling rate of 150 samples/s, as illustrated in Fig. 4.

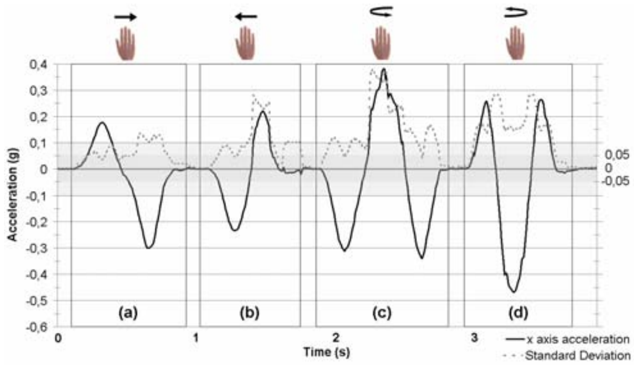


Fig. 4. X axis acceleration waveform and standard deviation for right hand movements. (a) “Right”, (b) “Left”, (c) "Left returning to the origin", and (d) "Right returning to the origin"

Therefore, three finite state machines for each acceleration axis were developed. Each state machine is composed by 4 states and two different events and each state describes one motion phase.

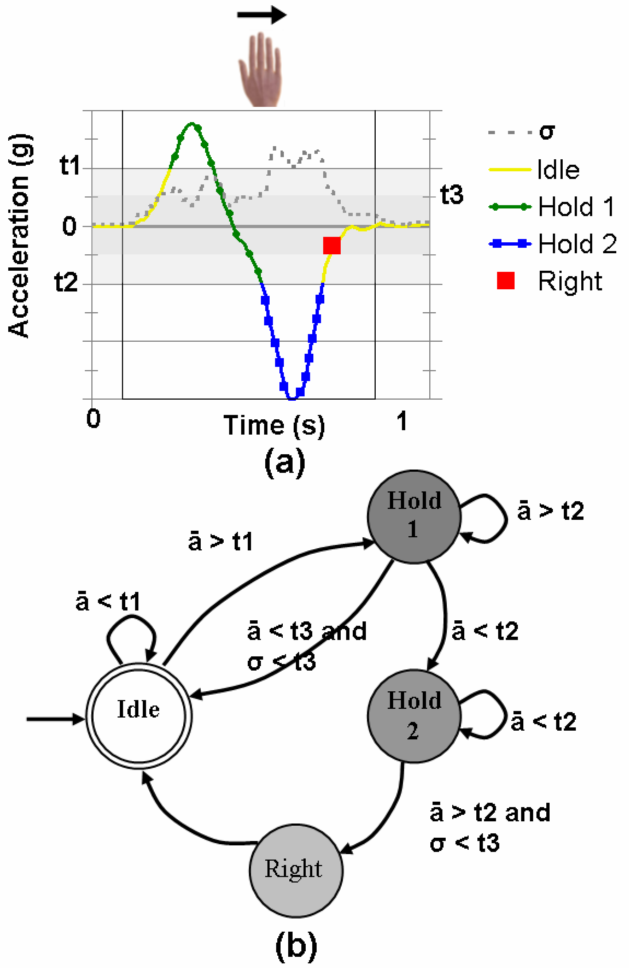


Fig. 5. (a) X axis acceleration waveform generated by a movement to the right. (b) State diagram to detect the movement. “ā” is the acceleration in the x-axis and “σ” is its standard deviation.

Considering that acceleration data presented in Fig. 5 (a), the state machine Fig. 5 (b) performs the transitions described in Table I.

Table I. State Transition Table. "ā", "σ", "**Right**" stand for "Current acceleration value", "Standard deviation", and "Raise event "Right"", respectively..

| Condition \ Current State | Idle | Hold1 | Hold2 |
|---|---|---|---|
| ā < t1 | Idle | - | - |
| ā > t1 | Hold1 | - | - |
| ā > t2 | - | Hold1 | - |
| ā < t3 and σ < t3 | - | Idle | - |
| ā < t2 | - | Hold2 | Hold2 |
| ā > t2 and σ < t3 | - | - | Idle/**Right** |

## V. Software Architecture

In this work, a layered architecture (Fig. 6) is used proposed similarly as proposed in [32].

Each layer is responsible for well defined tasks that range from data acquisition to user interaction. The first layer is the physical layer and it includes the wireless sensor network. This layer is responsible for sensing the user and its environment. It also provides power management at the sensor node level, enabling the sensor node to decide how to efficiently use its energy.

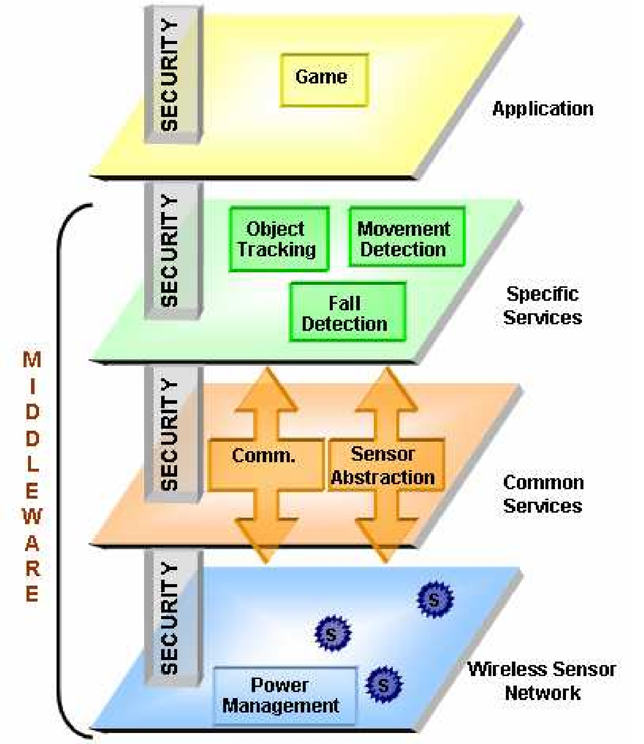


Fig. 6. The proposed Layered System Architecture. Each layer hides unnecessary information from the layer above.

Considering that heterogeneous sensor nodes can be used, another layer is required to provide common services like abstraction and communication, thus hiding irrelevant information from the layers above. Since distinct applications use sensor information differently, one more layer is need to specific services such as movement or fall detection, and object tracking. These three layers compose the middleware which will provide well defined services to different environment interaction applications.

At the top of the architecture is the application interface layer. This layer makes use of the specific services to interact with the user through an application, for instance, a game.

## VI. Application Examples

Computer and video game interaction is sometimes considered a lazy activity. However, the concept brought forth by new video games, mostly by the Nintendo Wii [33], is that movements can be used as input to the game. In some games, for example, the user performs almost the same movements as when dancing, playing a guitar, golfing, bowling, boxing, playing baseball, and recently, skiing and others.

In contrast to the old entertainment devices, these new video games can improve the players' health by involving them in physical activities.

Two game applications were built to demonstrate how the platform can be used as input device. The first application was built to verify that the requirements for dynamic recognition were fulfilled; the second application addresses the static pose recognition based on events. Both applications use a custom component that provides motion detection. This component was build following our software architecture, and provides specific functions, in this case, motion detection. It interacts with another component, called SCA_3000, that abstract the sensor node, i.e., the component provides common services, such as communication and sensor abstraction.

### A. *Continuous movement detection application*

To verify the platform in a continuous movement detection application, a game application was built using the GATetrisControl [34], a C# control to build Tetris game, and the SCA_3000. In this application, instead of using directional keys, the player easily moves the falling-blocks (Fig. 7) through arms' movements (gestures).

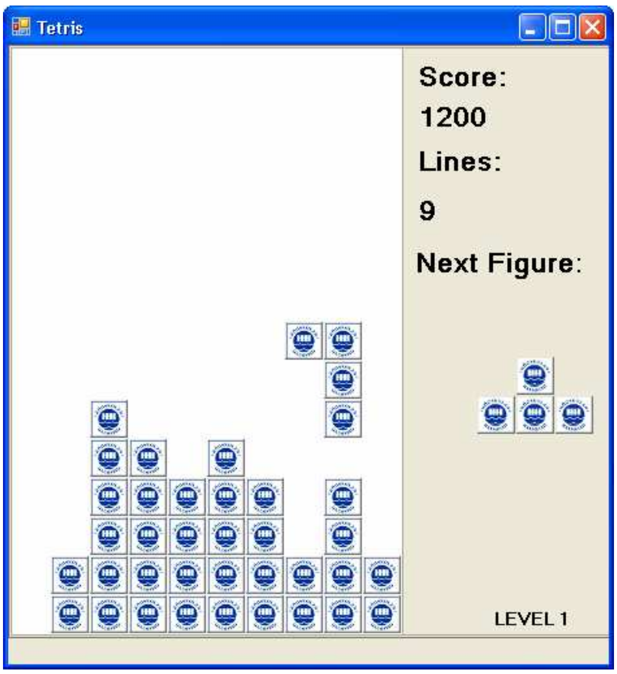


Fig. 7. The Tetris game application where the user controls the falling blocks with gestures.

### B. Event-driven movement detection application

Another application was built using the motion detection feature present in the acceleration sensor. When the user's movement is detected, the platform sends a data stream containing the acceleration data to the host computer. These data is feed through the state machine which recognizes the movement. This application uses the same SCA_3000 component present in the Tetris game. An illustration of the application is in Fig. 8.

The application is inspired by Tai Chi which has proven an effective method to train balance, which can aid in the prevention of falls [35]. However, a full implementation of a Tai Chi game would require more then accelerometers. The drift in accelerometers would generate inaccurate positioning; this can be solved with a combination of sensors, such as accelerometer and a gyroscope combined with a Kalman filter [36]. However, the proposed application does not require accurate position because it makes use of the direction of the movement.

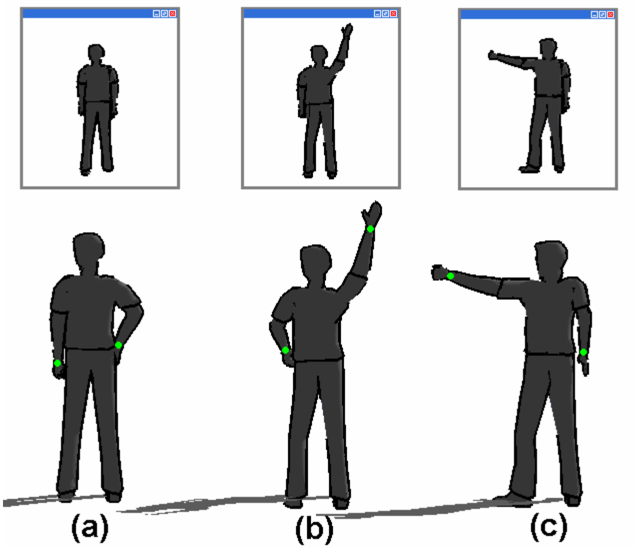

Fig. 8. The movement detection application demonstrates how postures can be used to control a game.

## VII. Conclusion

This paper presents a wireless wearable platform to detect users' movements for game interaction.

The proposed hardware platform has a three axis acceleration sensor and provides wireless communication via Bluetooth, a standard wireless technology present in mobile and stationary computers. The driving forces during the platform design were to meet the requirements especially in terms of size and energy efficiency.

A light weight methodology, useful in particular for wearable applications, is proposed to detect the motion phases of simple gestures using a finite state machine. The layered software architecture is versatile and scalable which permits the use of other sensors and applications.

Finally, two example applications are used to demonstrate how the platform can promote physical activity.

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