Intelligent Device for Sensing Physical Activity

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Abstract
Health and physical activity are intimately connected and the concern for health keeps on increasing. These make the measurement of physical activity an important issue. The purpose of this project was to develop a prototype of a physical activity monitor. The device can transmit the acquired data making a detailed study possible. The prototype based on a tri-axial accelerometer was successfully produced. It can be personalized by setting up the time and the recommended daily activity. The registered data can be uploaded via Bluetooth to mobile phones. The memory can store more than 18 hours with a sample rate of 1 Hz.

Key Words- health, physical activity, activity monitor, Bluetooth

1. Introduction
Today health is handled as one of the most important issues in the world. In several country members of the European Union half of the population is overweighted and one third of the adults are clinically obese[1]. The costs with this “obese people epidemic” have been estimated to be over 118 million euros.[2]

Physical activity is strongly related to health status, and has a pervasive effect on preventing several diseases and premature death and also has a positive impact at the psychological level[3].

Physical activity (PA) is commonly defined by “the voluntary movement produced by contraction of skeletal muscles resulting in energy expense.”[4] It is characterized by the duration of session, frequency, intensity (rate of energy expenditure), surrounding environment and social conditions[5]. With such definition it is very difficult to measure the PA under free living conditions. There are several measurement techniques with or without human observation, but each one has its flaws and strengths. Only with reliable measurement techniques, can researches go further in improving or creating theoretical models for physical activity. At the present there is no universally accepted gold standard[6], and problems will arise when comparing studies based in different measurement techniques.

Due to the advancements in micromechanics and microelectronics the measurement of PA based in accelerometers seems promising. They transduce acceleration into an analog electrical signal with low power consumption. The footprint of the circuit is very small enabling the production of small and light-weighted devices.

2. Objectives

Project and make a working prototype of a physical activity monitor. The monitor should be able to capture and record the physical activity of daily routine. Extreme situations (i.e. extreme sports, accidents, etc.) should not be considered.

Stored information should be able to be uploaded to a computer for data storage, processing and analysis. Available transmission technologies should be considered for implementation.

The interface to the device should be simple, allowing the storage of several sessions and uploading all data on demand. Once uploaded, all the registered sessions should be deleted.

The monitor should be personalized by setting up a recommended daily physical activity.

3. Methods

The system is composed by the monitor, the mobile phone, the server (computer) and some clients (computers).

The monitor is divided into an analog part (accelerometer, filtering, and analog calculation) and a digital part (analog to digital conversion, data storage, telecommunication and interface).

The mobile phone collects data from the monitor trough Bluetooth. It can represent the data graphically on the screen and send the data of any recorded session to the server.

The server acts as an information repository with login/password clearance. The clients can access the server to consult previous stored data.

1. Signal Characterization

In the everyday situations people are not exposed to accelerations of 3g (9.8 ms$^{-1}$)[7]. After comparing several accelerometers, the iMEMS$^\circledR$ AXDL330 from Analog Devices was chosen. The device has a range of ±3 g in 3 axes, with a bandwidth of 0.5-550Hz and senses static acceleration.

A list of common physical activities (sleeping, walking, running, jumping and cycling) was elaborated. The sensor was firmly strapped to the waist while
performing all activities mentioned in the list above. The raw data from the sensor showed that the highest frequencies were observed while jumping. While jumping, components with frequencies higher than 10 Hz become irrelevant (figure 1). In order to have a security margin, only frequencies below 15 Hz are considered relevant. Also during jumping, the Z component presented spikes of 4.2g, outside the range of the accelerometer.

2. Proposed Algorithm to calculate physical activity

As effort is developed both while jumping and in reception, it is important to have in account positive and negative accelerations which causes energy expenditure. To calculation the physical activity for a specific period of time the equation 1 is used.

\[ PA_{\text{Index}} = \sum_{i=1}^{3} \left[ \int_{t=0}^{t=\Delta} |\langle \vec{a}, \vec{e} \rangle(t) \rangle dt \right] \]  \hspace{1cm} (1)

- \( PA_{\text{Index}} \) – index of physical activity
- \( \vec{a} \) - dynamic acceleration
- \( \vec{e} \) - unity vector
- \( \Delta \) - duration of activity

3. Analog Block

A second order Butterworth band pass filter was designed with a band-pass of 0.5 to 15 Hz.

The algorithm was used in a simulation in Matlab with real data from the sensor. The analog block was implemented and simulated in LTSpice before drawn in EAGLE for production of the printed circuit board. After manually soldering the components, the board was tested with a signal generator and one oscilloscope. Signals between 0 Hz and 15 Hz presented output amplitudes proportional to the source signal.

<table>
<thead>
<tr>
<th>Tabel 1 Power consumption of the analog module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption [W]</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>0.066</td>
</tr>
</tbody>
</table>

4. Digital Block

This block is composed by the power supply, the memory, the display, the microprocessor, and the telecommunication module. The diagram of the connections is on figure 2.

4.1. Memory

The non-volatile memory adopted was one EEPROM (25LC1024) from Microchip. It has a fast access (20 MHz), SPI interface and the power supply can be 2.5 – 5 V. The ID of the device, the Bluetooth host address, the password, the daily activity, the version of the software, the size of the memory, the URL of the server, the data from each session and the recommended daily activity are stored in the memory.

4.2. Telecommunication module

Several technologies were compared: ZigBee, Bluetooth, GPRS, RFID and USB.

The USB is the only one with the inconvenience of being wired. It has a very fast output (<480Mbps) and can extract power from the cable to charge batteries. For a USB communication there must be only one host; all the others must act like clients. Most smart phones in the market can only act as a client, which prevents the developing of the physical activity monitor to act as a client.

The RFID is an emerging technology with reasonable speed (<26.48Kbps) using two transponders. Unfortunately during the development of this project there was no mobile phone with RFID.

GPRS operates over the GSM network and it is widely available. Many devices operate in quadric-band enabling them to operate in 80% of the world’s cellular market. This technology makes possible to communicate up to 35 Km. The information transport has a moderate level of security with shared-secret cryptography. The GPRS service allows transmissions of 80K bps for downloading and 40 Kbps for uploading. To provide independence from other devices and enhance the mobility, this technology was adopted. The
drawback of this technology is the high power requirements which are far more demanding than all the other technologies compared. The adopted GPRS module was the GM862-GPS (Telit, Italy). Having the module, it is also necessary to subscribe the GPRS service with a mobile phone operator. Therefore a contract was celebrated with T-Mobile.

The Bluetooth provides short ranged transmission (up to 100 meters) with the maximum speed of 720 Kbps (version 1). It operates in the 2.4 GHz band and each device is identifiable by one 48-bit unique address. Among several profiles of available services, the serial port profile is the most suitable for the physical activity monitor. It can be configured to provide the physical activity of the RS232 (a common interface standard). The Ezurio BISM2 was the selected module. It can transmit up to 100 m with the maximum transmission rate of 300 Kbps. It has a serial interface; it’s controlled by AT commands and has a low power consumption of 22 mA during transmissions.

The ZigBee protocol is aimed for embedded applications with low data rates and low power consumption. It uses a mesh network, automatic retries and high interference tolerance. It can transmit up to 75 meters at 250Kbps. It has a very low power consumption of 300 μA during transmission, making it a strong candidate. The drawback of this technology is the lack of compatible mobile phones, making its exclusion compulsory.

4.3. Microprocessor

The 18F2860 from Microchip was selected due to its versatility and high level language of programmmation with resource to extensive C libraries.

The μP runs in two modes: normal (20 MHz) and slow (32.768 MHz). The last one is used while waiting for a key to be pressed or for the next acquisition. Using a slower mode enables to save power and also to implement a real time clock via software.

The flowchart of the microprocessor can be seen on figure 3.

4.4. Power Supply

The power supply is composed by two Li/Ion accumulators connected in serial providing 3.7V and 7.4V. Li/Ion batteries had to be used to satisfy the requirements of the GPRS module:

- Nominal supply voltage: 3.8 V
- Max. supply voltage: 4.2 V
- Supply voltage range: 3.4 V - 4.2 V
- Max. peak current consumption (impulsive): 1.9 A
- Max. average current consumption during GPRS transmission: 400 mA
- Average current consumption during power saving: ≈ 4 mA
- Average current consumption during idle (power saving disabled) ≈ 17 mA

To regulate the voltage two LDO (LT®1528) were used to provide 3.3V and 7.2V. They are able to deal with loads up to 3A, voltages input of 1-15V and have voltage controlled shutdown. This configuration has the disadvantage of discharging one of the accumulators faster than the other.

<table>
<thead>
<tr>
<th></th>
<th>Theoretical [W]</th>
<th>Measured (Average) [W]</th>
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<tbody>
<tr>
<td>Transmitting</td>
<td>0.223</td>
<td>0.867</td>
</tr>
<tr>
<td>Idle</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td>Recording</td>
<td>0.08</td>
<td>0.127</td>
</tr>
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</table>

5. Mobile Phone

The mobile phone can be used both as a server and a client. It can receive incoming connections, via Bluetooth, from the physical activity monitor to acquire new data. The phone can connect to the server to upload the previously acquired data from the monitor.

To cover the biggest possible market, two mobile phones were chosen: Nokia N70 and Nokia N73 Music edition, both powered with Symbian OS™ 8.1 and Symbian OS™ 9.1, respectively. They were programmed by Python 2.2.2 which is supported by the phone manufacturer that provides the package PyS60.

The communication is done through a client/server architecture and the information is exchanged through messages with a rigid format.

When a connection is established, the client must provide a login/password otherwise the connection will be dropped by the server. Each device has a number with 16 bits that identifies it in the network (ID), which allows keeping track of the source of each session’s log.

The implementation of the communication protocol was made independently of the technology (Bluetooth, GPRS, Ethernet) by creating an abstract layer with the package communication object. The communication hierarchy can be seen on the figure 4.
The program was split up into several modules so that each one deals with a particular task:

- **Config** – configuration parameters
- **Communication** – bluetooth and TCP/IP interface
- **Record_to_file** – file handling
- **Take_care_request** – used by the server to handle client’s requests
- **Phone** – main script
- **Show_graph_app** – record’s graphical visualization
- **Bluetooth_server** – script to implement bluetooth implementation

### 6. Server

The server accepts incoming connections from mobile phones, monitors equipped with GPRS and the clients. It’s used to store and to access to previously recorded data.

The server was also programmed in Python allowing the reutilization of the code. The GUI had to be changed to work on the computer. Two modules were developed for the server:

- **Users** – deals with login management
- **Userman** – GUI to manage the logins

The program provides an interface where it is possible to track the requests and answers from every client. A configuration menu allows to register/modify/remove a login to the server.

### 7. Client Program

The program allows to connect to the server, to retrieve a previously stored session, to display it graphically and to provide some statistics about the chosen session (maximum, minimum, average, integration).

### Results

After the production of the PCB, some corrections had to be done to the analog block. The device, with the corrections, was placed inside a card box measuring 19cm x 13.5cm.

The physical activity monitor was attached to a belt fastened to the waist. Although the light weight of the apparatus didn’t disturb the performed activity, the size of the box restricted the natural swing of the arm.

Three subjects equipped with the monitor performed different kinds of activities: walking, running, jumping, climbing and descending stairs. The statistical treatment of the collected data can be observed on table 2.

### Discussion

A working prototype, with Bluetooth, was able to sense and register different values of physical activity achieved in the above mentioned situations. The most demanding activity was performed in the following order: jumping, running, descending stairs, climbing stairs, and walking. As expected, the results were very similar regardless of the subject.

Any alteration in the batteries’ output voltage reflects in the value of the physical activity index. This is caused by the generation of a constant voltage through a resistive voltage divisor directly connected to the accumulators. A good alternative would be to use either the µP or an LDO to generate the necessary value of the constant.

The size of the device must be reduced in order not to interfere with the different activities.

Sometimes the accelerometer registers values outside its normal range. In those cases there is no guarantee that the real acceleration is not even higher. However and despite the high amplitude, they have a very short duration. Therefore, their effects over the physical activity index are not significant.

Even though the algorithm to calculate the physical activity works, it can still be improved.

The results should be compared with similar devices available in the market.


7. NASA. *ASTRONAUTICS AND ITS APPLICATIONS.* 1959: GOVERNMENT PRINTING OFFICE.