# Remote Patient Monitoring in Home Environments

Paulo Gonçalves, José Torres, Pedro Sobral and Rui Moreira

Faculdade de Ciência e Tecnologia, Universidade Fernando Pessoa
Praça 9 de Abril, 349, Porto, Portugal

**Abstract.** The humanity is currently facing the difficulties of an aged society with an ever-growing predominance of chronic diseases and associated problems (e.g., mobility issues, possibility of falls, etc.). Traditional hospital or clinical internment is not an efficient answer both in terms of human, therapeutic or economical aspects. Alternatively, ambulatory and home healthcare are becoming preferred and predominant solutions. However, the typical home environment is not suited nor prepared for monitoring and helping to take care of elderly and/or disabled people. To overcome some of these issues, this paper proposes a wireless low cost hardware solution based on a microcontroller with several sensors (cf. temperature, oxymeter, 3-axis accelerometer) which allows monitoring several physiological parameters (e.g., temperature, heart bit, etc.) and infer human activities (e.g., standing, walking, falling, etc.) of home confined people. A similar platform with ambient temperature and light sensors was also created for monitoring the home environment. The collected data is pre-processed on the sensor nodes and then transmitted to a wireless gateway allowing the backend system to log the patient activity, his health condition as well as the living surroundings. Finally, a web application is provided to healthcare professionals for viewing, analyzing and statistically operating this information, thus empowering homecare.

## 1 Introduction

As the average span of life increases, people at the age of 65 or older are the fastest growing population in the world. According to the projections of an EUROSTAT report [4], the median age of the European population will rise from 40.4 years in 2008 to 47.9 years in 2060. The share of people aged 65 years or over in the total population is projected to increase from 17.1% to 30.0% and the number is projected to rise from 84.6 million in 2008 to 151.5 million in 2060. The healthcare system in the developed countries is growing under pressure and will not be efficient enough to provide a reliable service on the health treatment for this aging population [9].

Even though wireless sensor networks research was initially driven by military applications, more recently, the medical community is the one showing more interest in the applicability of this technology to the development of telemedicine health care systems. These systems use modern telecommunication and information technologies to provide clinical care to remote located individuals. With more research progresses in this field it will be possible to provide a better quality of life to patients while reducing healthcare costs [11].

There are several issues that will lead to the use of telemedicine systems, e.g.,

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critical shortages of medical staff, an increase in chronic illnesses or medical conditions requiring continuous monitoring, a complex medical environment in which diagnostic errors can contribute to raise hospital admissions, increased healthcare costs and decreased access to healthcare providers, etc.

The requirements for reliability, flexibility and portability make wireless sensor technologies particularly attractive for telemedicine applications [7]. Venkatasubramanian et al identified the following challenges for developing a health monitoring system using wireless sensor networks [9]:

- Dependability (the ability of a system to be able to avoid service failures);
- Long-term Data Collection (the capability to provide continuous data collection facilities);
- Energy Efficiency;
- Real-time information Gathering;
- Information Completeness (collected data has to be complete, allowing medical staff to accurately diagnose the patient's condition);
- Security (Integrity and confidentiality of the data must be preserved).

A smart homecare system can hold the essential elements of diagnostic used in medical facilities. It extends healthcare from traditional clinic or hospital settings to the patient's home. A smart homecare system benefits the healthcare providers and their patients, allowing 24/7 physical monitoring, reducing labour costs and increasing efficiency. Wearable sensors can notice even small changes in vital signs that humans might overlook [8].

There are some projects for remote medical monitoring [5]. In comparison to this work, the following are the most relevant ones:

- Code-Blue: is a wireless sensor network developed at Harvard University and intended to assist the triage process for monitoring victims in emergencies and disaster scenarios. The caregivers, using a query interface, can access data obtained from the sensors [6].
- AMON: encapsulates many sensors (blood pressure, pulse oximetry, ECG, accelerometer and skin temperature) into one wrist-worn device that is connected directly to a telemedicine center via a GSM network, allowing direct contact with the patient[2].
- AlarmNet: continuously monitors assisted-living and independent-living residents. The system integrates information from sensors in the living areas as well as body sensors. It features a query protocol for streaming online sensor data to user interfaces [1]

## 2 Home Healthcare

The main goal of this project was to create a homecare framework with the following requirements: design simplicity, reliability, low cost and with the less possible user interaction as possible. Our system has four elements: a corporal device, an environment monitoring appliance, a wireless gateway and a server. The corporal device detects the patient vital signs (temperature and heart rate) as well as its activity. The environment appliance senses the patient environment temperature and light conditions. All the data gathered from the sensors is sent over a wireless Zigbee link to the Gateway. The data is then recorded on a MySQL database located on the server.

### 2.1 Devices and Sensed Data

All system components were built using low cost hardware. Size and shape of the corporal device were considered to improve the device usability. Sensors raw data is processed in the device and then transmitted to the gateway.

#### 2.1.1 Hardware Devices

For the device data processing and control we used a Sparkfun (www.sparkfun.com) WEE based on the Arduino platform. This is a prototyping platform based on flexible, easy to use hardware and software. The WEE has an ATmega168V micro controller running at 8 MHz and 8Kbytes of in-system programmable flash. For power supply we used two AA batteries with 5V DC-to-DC step up. For data transmission we used the WEE serial communication capabilities. This hardware is programmed using the Arduino development environment.

The wireless link between the devices and the gateway is established using the ZigBee Technology (IEEE 802.15.4). The ZigBee defines a set of communication protocols developed for small and low power digital radios. It is also a low cost technology compared with other WPAN solutions like Bluetooth (e.g. a simple ZigBee device uses only 2% of the software design needed for the same Bluetooth application). We have choosen the MaxStream XBee pro radio for the ZigBee communication.

Data collection was done with several kinds of sensors. For temperature sensing we have used a DALLAS DS18B20-PAR 1-wire Parasite-Power digital thermometer. The digital thermometer has a unique 64-bit identification code, it provides 9 to 12-bit centigrade temperature measurements, communicates over a 1-wire bus and it has an operating temperature range from -55º C to +100º C and is accurate to ±0,5ºC over a range of -10ºC to +85ºC. For patient activity monitoring we have used a Freescale Semiconductor MMA7260QT ±1.5g-6g Three Axis Low-g Micromachined Accelerometer. The accelerometer measures acceleration and gravity induced reaction forces. The MMA7260QT has temperature compensation and a g-Select which allows selecting among four sensitivities. This accelerometer includes a Sleep mode that makes it ideal for handheld battery powered electronics.

The pulse oximeter uses an ultra bright red LED (Light Emitting Sensor) and a LDR (Light Dependent Resistor). The LDR is facing the LED through a fingertip, and measures the absorption of the red light. From the ratio of absorption it is possible to determine the patient oxygenation percentage. The monitored signal bounces in time with the heart beat because the arterial blood vessels expand and contract with each heartbeat. However due to the lack of reliability of this particular oximeter setup, we will not use it in this project. We are now looking for alternatives for the heart rate and blood oxygenation monitoring.

### 2.1.2 Corporal and Environment Devices

The corporal device was assembled using a prototype board and some wiring to connect the components. It is composed by a WEE microcontroller, a three-axis accelerometer, a digital temperature sensor, a XBee pro radio and the power supply. With 10x6x2.5 cm and weighing 150g the device can accommodate all the components and be wearable without causing too much discomfort to the patient. Using different materials it is possible to reduce the size and weight of this prototype, allowing a better user experience. The corporal device should be placed above the patient right hip, pointing up, because this is the location in the human body with less position changes during activity. The accelerometer measures the acceleration on a 3D axis of that given point. The digital temperature sensor measures skin temperature, so for a more reliable body temperature, the sensor must be placed in the patient armpit. The corporal device transmits the current patient activity and body temperature.

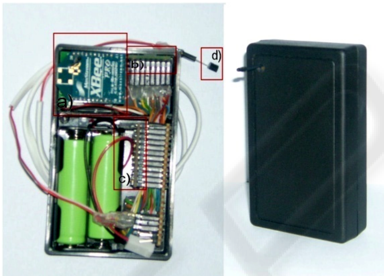


**Fig. 1.** Corporal device - a) XBee pro radio, b) accelerometer, c) microcontroller, d) digital temperature sensor.

**Fig. 2.** Position of the corporal unit in the body of the subject.

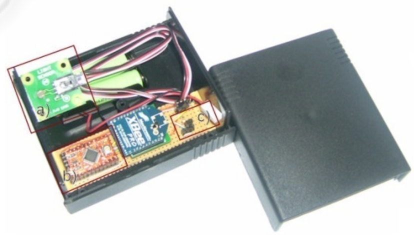


**Fig. 3.** Ambient device setup a) LDR sensor, b) microcontroller WEE, c) Temperature sensor.

The environment device is composed by a microcontroller, a XBee pro radio, a digital temperature sensor and a LDR – Light Dependent Resistor to detect light conditions. By gathering the patient environment sensor data, it's possible to frame the received patient vital signs and activity within its surroundings. For instance, we may statistically link the patient activity or some physiological changes to the environment light conditions.

#### 2.1.3 Gateway Device

The gateway is a XBee pro radio with a USB interface connected to a server which receives the data sent by the sensor devices and stores it in a MySQL database. The gateway has a wireless coverage area of 300 meters indoor and 1500 meters outdoor; this makes it suitable for in home monitoring.

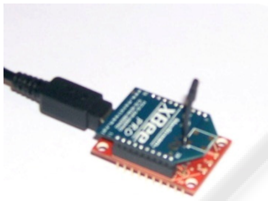

**Fig. 4.** Xbee pro USB gateway.

### 2.2 Sensed Data Processing and Analysis

Digital sensors output a formatted value; however, analogue sensors output a value from 0 to 1023. Raw data read from the analogue sensors must be pre-processed in order for the readings to make sense to the application.

#### 2.2.1 Accelerometer Data

The accelerometer is an analogue sensor which outputs its data value as an integer from 0 to 1023. It outputs a value for every axis (X, Y, Z), which corresponds to the measured acceleration. In rest position the accelerometer outputs the average values of 500 for the X and Y axis, and 750 for the Z axis. The Z axis shows a different value because it's affected by gravity.

After a series of tests, where the volunteered subjects performed their daily routine activities, we were able to select the following main activities identified by the accelerometer:

- Standing
- Sitting
- Walking
- Running
- Laying down (Sleeping)
- Falling

It is possible to determine if the patient is sleeping in the back position, side position or stomach position. Although this is not a particular important distinction for monitoring elderly patients, it can be important for monitoring infant's sleeping position. For example, an infant sleeping on his stomach has up to 12.9 times more probability to die from SIDS (Sudden Infant Death Syndrome), hence, forcing children to sleep on their backs reduces the incidence of SIDS by 40% [3].

Detecting a fall is a two class decision problem; we can have positive samples for a fall and negative data for non-fall. While the positive samples have a lot of commonness, negative samples are extremely diversified. So, for training a classifier correctly, we would need a lot of negative samples, and even so a real fall could be classified into a doubtful data set [12]. Processing all this data takes a lot of processing power, and being ours a low cost approach, less processing power is available. So, the objective was to find a way of classifying activity without a lot o processing.

For determining the activity pattern values, the volunteered subjects performed their activities and we recorded the raw accelerometer data into the database. One value for each axis was reported by the accelerometer every 100 milliseconds. After several runs, 200 values for each activity were selected. The analysis of the graphics generated by the stored data, allowed us to understand that single values have no meaning; sets of values, however, could be used to determine pattern activities. Nevertheless, different activities may sometimes produce similar sets of values, so it was important to find another characteristic that, combined with the set of values could identify, without any doubt, a given activity. Further graphical analysis allowed us to recognise that the value of each axis could also determine an activity. So, the set of values and the correspondent axis can determine accurately the current activity.

The next challenge was to decide how large should be the set of values; if it is too small it will not allow to identify a pattern, but if it is to large the risk of overlapping different activity patterns increased. So a set of values cannot be longer than the fastest occurrence of an activity. In fact, the activity that takes less time to occur is a fall (about one second). Based on this, we selected a set of 10 values. Figure 5 and 6 show a sample of the graphics for walking and falling; the fall occurs only between readings 33 and 43; after that the volunteer subject lies down on his stomach.

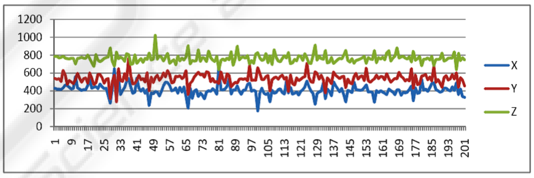


**Fig. 5.** Walking accelerometer raw data.

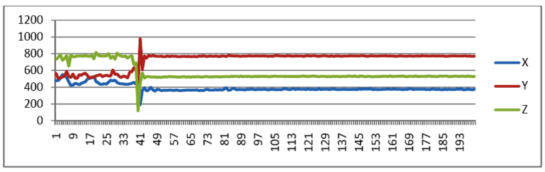


**Fig. 6.** Fall accelerometer raw data.

Having the sets of values we required a formula for transforming each set of values into a single value without losing it's meaning. The statistical variance was the best way to do it, but calculating the variance for the set of values of each axis, would give us three distinct values. Hence, the average between these values would give us a single value that could be used to identify an activity. We have called this value VAI which stands for Value for Activity Indicator. The variance and VAI formula are shown below:

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \tag{1}$$

$$VAI = \frac{(Sx^2 + Sy^2 + Sz^2)}{3} \tag{2}$$

The accelerometer values vary from subject to subject, and it is impossible, for example, to walk exactly the same way all the time, so we needed to identify a list of range values for each activity. Therefore using the VAI formula and the raw data previously acquired we built with the following table.

**Table 1.** Max and Min VAI values for each activity.

| | Stand, Sit, Laying Down | walk | Run | Fall |
|---|---|---|---|---|
| Min | 0 | 450 | 50000 | 15000 |
| Max | 120 | 5000 | - | 48000 |

From table 1 we realize that stand, sit and laying down activities have the same VAI range. So we use the axis values, for instance, for lying down back the x and z-axis must return almost the same value, x must be lower than 420 and y-axis value must be lower than the x-axis value. With this definition most activities can be well identified by a simple algorithm. However, the identification of a fall poses some problems. Sometimes running is miss-identified as fall and a fall may be misidentified as running. To solve this problem we added to the algorithm an activity matrix that incorporates known situations in which a fall occurs, e.g, if someone is running and in the next second is laying in his stomach it is feasible to say he suffered a fall. So we filled the matrix with several of these scenarios. The matrix is composed by: two past activities, the activity to analyse, two future activities and the activity we wish to identify. In real time an array is filled with the activities identified by the accelerometer readings. This array has two past activities, the "present" activity to analyze and two "future" activities. The array is then compared with the matrix. If we have a match with a sequence of events in the matrix then the algorithm outputs the corresponding activity. If we do not have a match, the algorithm decides, based on the single window of data for the "present" activity. In reality, the detection has a delay of 3 seconds, because we need to wait for two more future readings before making a decision. After the use of the known scenarios matrix the fall detection improved from 30% to 60%, adding more know cases to the matrix will improve even more the detection. However, it can cause some false positive detection. Running activity detection has a rate of 70% accuracy, this numbers can be improved by adding known case for running to the matrix. All the other activities have 95% detection accuracy. However, when tested on an elderly subject, and being that our main objective, due to their degraded motor skills, the activity detection improves for near 100%.

#### 2.2.2 Temperature and Light Sensor Data

A digital sensor monitors body and environment temperature. The output is in centigrade degrees, so no pre-processing is needed.

The light sensor LDR is an analogue sensor so its output needs to be transformed in meaningful values. We considered three categories: bright light (values from 0 to 250), medium light (from 250 to 600) and dark (above 600).

### 2.3 Gateway and Transmission

The gateway connects to the server via a serial port, allowing it to receive the information transmitted wirelessly from de sensor devices. The messages exchanged by the devices and the gateway have a specific format. The gateway receives a string with the following format; "M001S00136.23", the first four characters address the sensor device. This way we can have from M001 to M999 devices or if needed even more using an alpha numeric sequence. The second four characters represent a specific sensor, for example "S001" is the code for the temperature sensor, the number of sensor can also be 999 in case we use a numeric sequence. The remaining characters represent the sensed value, in this case 36.23º C. For activity monitoring the following message could be received in case of a fall: "M001S002FALL". Using a python script we disassemble the received string into meaningful data and insert it in the database. The corporal sensor device reads a temperature value every second and the accelerometer every 100 milliseconds, but for power saving reasons a sensor device only transmits the sensed data if it is different from the previously transmitted one.

## 3 Data Visualisation

The monitoring system is composed by the sensor devices, the gateway, server and graphical user interface for visualisation and data managing.

After deploying the sensor devices (corporal and environmental), we need to plug to the server the USB ZigBee gateway, and then run the connection python script. After this, all the data received by the gateway is treated and stored in the database. The application has three main users, healthcare professional, patient and family member. The healthcare professional can create a new patient, link a given corporal device and environment device to a patient during a certain period of time, insert diagnostic or process notes for a patient, view patient data and create patient and family member login.

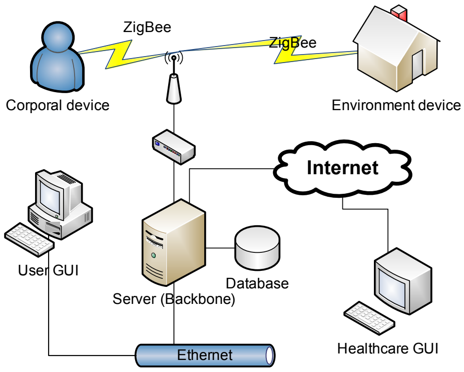


**Fig. 7.** System components diagram.

The patient can insert the symptoms that he is feeling at the time and view his log in real time. The family member can view the patient real time data.

The connection python script has an alert system that sends a SMS, using a GSM modem, to the patient family member contact phone if some disturbing values are received, such as if the patient fall or if the body temperature rises rapidly.

The health care professional can view, in one page, all the received data related to one patient during a certain period of time. In this way they can relate the patient symptoms with the activity and environmental conditions.

**Fig. 8.** Example of the healthcare professional GUI for listing patients.

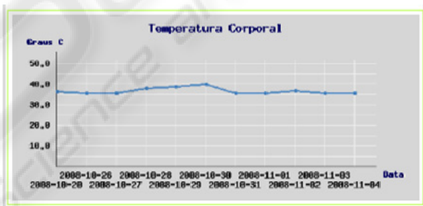


**Fig. 9.** Example of the healthcare professional GUI for corporal temperature data visualisation.

## 4 Conclusions

To design an ambulatory monitoring system, several aspects must be taken into account, reliability, cost, security and user friendliness. By acquiring some ECG, heart rate and other medical sensor equipment we can cover all vital signs, increase the number of applications maintaining the low cost approach. Fall detection can be improved increasing the number of known position in the matrix. A trial and error approach can be used to achieve the maximum detection reliability without too much false positives. This way the system can be reliable and remain low cost.

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