

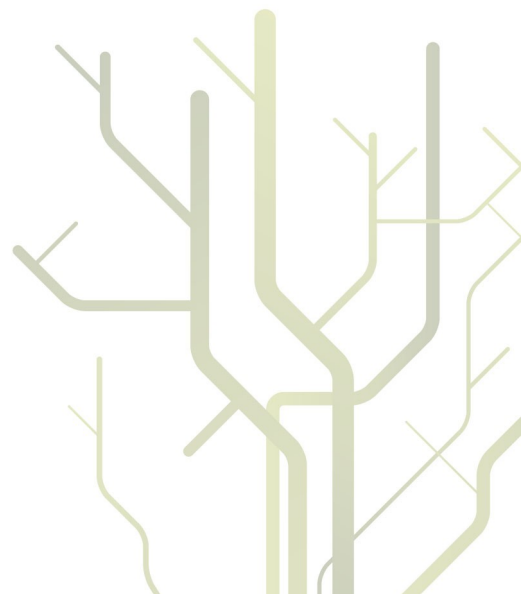
Breathing as user interface for pulmonary rehabilitation

Respiration tracking using the Wii remote controller



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Breathing as user interface for pulmonary rehabilitation: Respiration tracking using the Wii remote controller

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Abstract

INTRODUCTION

Respiration exercises are an important part of the pulmonary rehabilitation in COPD (chronic obstructive pulmonary disease) patients. Furthermore, there is evidence that showing feedback about their respiration pattern helps them to improve their breathing skills. This study tests the feasibility of monitoring respiration using the Wiimote's infrared camera and showing BPM (breaths per minute) as feedback. A summary of the challenges addressed to achieve such a solution can also be found here.

METHODS

A prototype was developed in order to study the viability of using the Wiimote to capture the breathing rate for creating applications to provide guidance to patients.

RESULTS

The system implemented was able to acquire breathing data and provide feedback to the patient consisting in its breaths per minute. It is a non-invasive, low cost system, composed of a normal computer, a Wiimote, some markers and an infrared illuminator. It is also a comfortable solution without wires, batteries or any kind of electronics, the patients only wear passive markers.

DISCUSSION

Despite the system was able to acquire breathing, it has some important limitations. The user has to be as immobile as it can, otherwise the system will fail. Some other issues found are discussed for future work. Although there exist these problems, the prototype had good outcomes when the subjects were resting of their exercise. They presented less than 15% of maximum error and the RMSE was lower than 6% in all the tests. This study establishes the basis to develop a Wiimote-based system to acquire respiration signals and present feedback or game-based rehabilitation.

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1 Introduction

This chapter will introduce you to this 30 ECTS (European Credit Transfer and Accumulation System) thesis carried out for five months. First, it is described the actual situation, followed by the explanation of the motivations of the study. The proposed solution is, then, briefly explained, including scope, goals, limitations and methodology. Finally, a short overview of the results is presented.

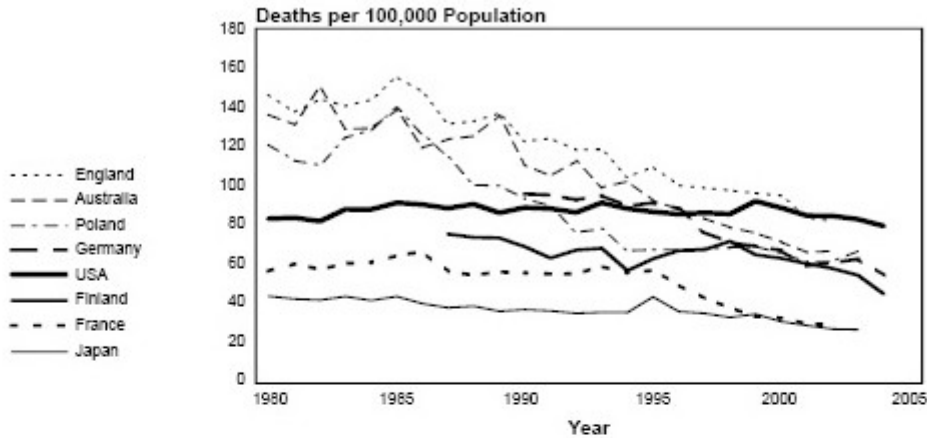
1.1 The burden of chronic diseases

Quality of life of the entire population has been increasing in the last decades. Health care spending has also been rising at the same time. Nowadays, most of it is focused on care for elderly and chronic disease treatments, reaching 70% of it in the USA (Bendixen et al. 2009). In addition, chronic diseases such as diabetes or Chronic Obstructive Pulmonary Disease (COPD) are the cause of the 50% of the deaths worldwide (Yach et al. 2005). Therefore, it is very straightforward to conclude the importance of this health and economic problem related to chronic illnesses.

Specifying a bit more, COPD, a significant part of the whole issue, is the focus of this master thesis. COPD is defined as a chronic airflow obstruction which is usually progressive and irreversible (Anto et al. 2001; Viegi et al. 2001). Its main causal factor is smoking. It is known as a heterogeneous disease related to asthma, bronchitis, emphysema, etc. (Mannino 2002).

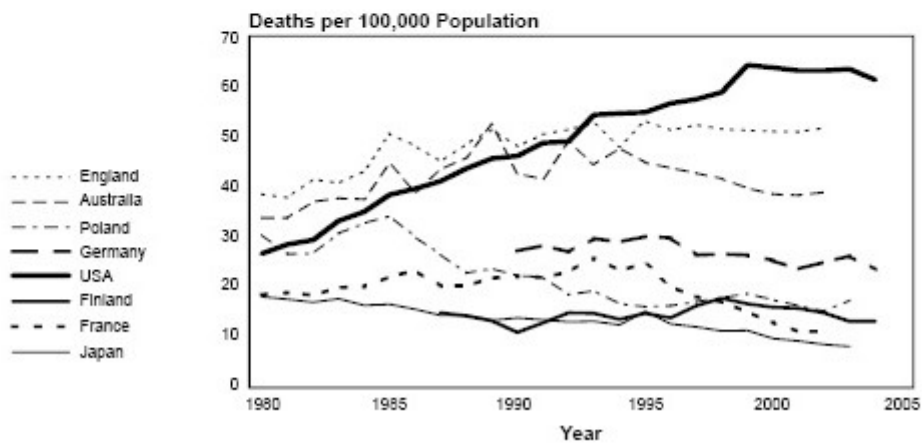
COPD is a common cause of death. According to the WHO (World Health Organization), there are actually 210 millions people with COPD and it accounts for the 5% of all world deaths in 2005 (WHO n.d.). It is expected to be the forth leading cause of death by 2030, raising up to 8% or nearly 6 million deaths worldwide (Mathers and Loncar 2005). From 1963 to 2004, deaths from COPD increased by 153% in the USA, although more recently its growth was lower, 24% from 1984 to 2004. This change is partly related to the population increase, but also to a bigger impact among women (NHLBI 2006) as shown in Figure 1.1. Furthermore, several studies have shown that deaths due to COPD are underestimated (Mannino 2002; Hughes, Muldoon, and Tollerud 2006; Jensen et al. 2006) so therefore the data above may be taken as the lower bound of the real situation.

Death Rates* for Chronic Obstructive Pulmonary Disease in Men Ages 35+ Years, Selected Countries, 1980–2004



* Age-adjusted to the European Standard Population.
Source: World Health Statistics Annual, WHO.

Death Rates* for Chronic Obstructive Pulmonary Disease in Women Ages 35+ Years, Selected Countries, 1980–2004



* Age-adjusted to the European Standard Population.
Source: World Health Statistics Annual, WHO.

Figure 1.1. Age-adjusted death rates for COPD by country and sex during the period 1980-2004 (NHLBI 2006).

Although COPD is not fully reversible, it is a treatable disease. The standard therapy is often enhanced by a pulmonary rehabilitation program in which exercise training is an essential aspect, patients should stay active in order to not aggravate their illness due to misuse of lungs (Ries et al. 2007). Most of these programs include lower extremity training that may be cycling or walking or both (Gosselink, Troosters, and Decramer 1997). In addition, they usually follow respiratory exercises to improve their breathing skills, avoiding symptoms such as exercise limitation or dyspnea (Gosselink 2004). Therefore, patients following pulmonary rehabilitation programs get significant improvements in aspects as exercise capacity, symptoms and quality of life, so they can deal better with their daily living activities

and be more independent. As a conclusion, it is fair to say that the better the results within pulmonary rehabilitation, the healthier the patients (Ries et al. 2007).

1.2 Problem definition: pulmonary rehabilitation and breathing exercises

To remain as healthy as possible is, of course, the best motivation that a patient can have to attend a rehabilitation program. But sometimes it is not enough. Lack of motivation is often a situation they have to fight against. For instance, pulmonary rehabilitation is usually associated with gyms and sports. There is evidence that this association may appear threatening to patients who had poor self-confidence related to exercise (Smith and M R Partridge 2009). Other barriers include problems with transportation to the rehabilitation center, disruption of normal routine, being tired after training, limited privacy and previous negative experience of the hospital (Fischer et al. 2007).

Rehabilitation, in the traditional way, is likely to be misinterpreted or to reinforce negative connotations because it is also something a person has to undergo after illicit or bad behavior (Smith and M R Partridge 2009). It sometimes contributes to create a kind of aversion to the therapy itself. Furthermore, if the patient has insufficient information about it, such as uncertainty about the improvements achieved through them, it might lead him or her to quit, becoming a failure (Fischer et al. 2007).

On the other hand, recent studies have shown that telerehabilitation programs can be more successful than traditional ones within chronic ill and elderly care (Vieira, Maltais, and Bourbeau 2010). The barriers previously mentioned can be avoided staying at home while recovering from illness, achieving better results in exercise capacity and increasing quality of life (Hernández et al. 2000; Wijkstra et al. 1994). Furthermore, Lange et al (2009) suggests that game-based telerehabilitation has an important potential when it comes to motivation. In Figure 1.2, these two aspects are represented as arrows a and b respectively. But the fact of being far from the guidance and support of the healthcare professionals may end in more lack of knowledge and motivation.

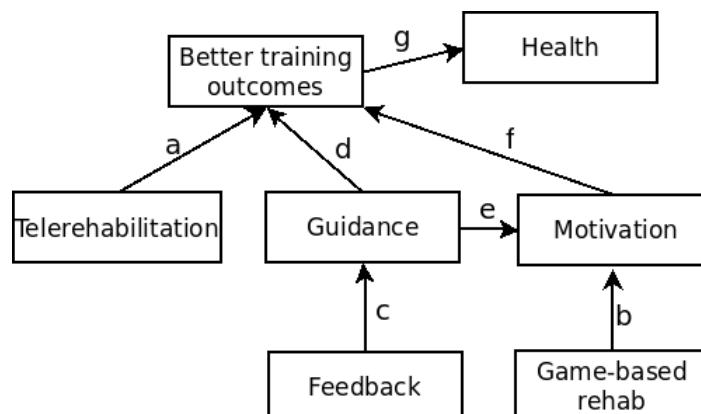


Figure 1.2. Assumptions of the thesis

Studies by Collins et al (2003; 2008) showed that giving feedback to the patients about how they are breathing has positive effects. They instantly knew whether they were breathing correctly or not, and this guidance ended up with better training outcomes. Relationships c and d in Figure 1.2 resume the conclusions achieved in these studies.

In this thesis, it was also assumed that motivation of the patient improves its training outcomes and, therefore, its health. Motivation may also be enhanced if the patient receives guidance to perform better the exercises. Arrows e, f and g in Figure 1.2 establish these relationships.

Evidence suggests us that rehabilitation can still be enhanced by avoiding the existent barriers. Mixing both ideas, feedback and game-based rehabilitation, could end in an even better approach. But they are only possible through technology. It is necessary to research and develop new affordable and effective systems to enable the patients to reach their goals.

1.3 Proposed solution: feedback to enhance rehab

The importance of breathing techniques in pulmonary rehabilitation is a fact (Gosselink 2004). While previous projects have been focused mainly in the physical exercises, breathing techniques are the main area of this project. Low-cost systems to track breathing rate in order to provide feedback to patients can play a major role in future pulmonary telerehabilitation systems. These systems do not need to be used for diagnostic purposes but to remind and help the patients to perform the exercises.

Patients with COPD need to perform physical exercises in rehabilitation centers or at home as part of their rehabilitation. For example, the need to exercise in the stationary bike for 4 minutes. Then they need to rest for several minutes before continuing exercising. During these periods of resting it is recommended that they use breathing techniques to recover faster.

Both, motivation and guidance, are key aspects in rehabilitation. The aim is to enhance mentioned issues in combination with telerehabilitation. As shown in Figure 1.2, it can be done providing feedback and game-based rehab to the patient. The goal is to create a system that will present feedback and guidance about breathing techniques during the resting periods. It can include a game-like application that will encourage patients to do the breathing exercises. One of the main challenges of such system is to capture information about the breathing rate, with a low-cost and minimally invasive system.

In order to involve game-based feedback with rehabilitation, the simplest solution may be to adapt existing game systems. In this study, potential of the Wii remote controller (Wiimote from now on) to implement such solutions is researched.

As part of the popular Nintendo Wii game console, the Wiimote is a very common device in millions of homes worldwide. It is also a cheap and powerful device. It is able to measure movements with its three accelerometers and detect up to four infrared light emitters with its camera. Inspired in Johnny Lee's finger tracking project¹, this research will test the possibility of developing respiration tracking applications using the Wiimote's camera.

Acquiring breathing signals with an infrared camera has already been tested with success (Orimoto et al. 2009). Just attaching some reflective markers in the patient's abdomen and using a infrared light source, it is possible to track their movement because of the respiration. Received data can be easily processed in a computer to estimate the breathing pattern.

Developing a prototype based on the Wiimote able to reproduce the results achieved with a camera was the aim of this project. It will provide feedback to the patient, guiding him or her through the rehabilitation exercises. It will also be possible to monitor breathing, enabling respiration telehabilitation programs and helping the health-care professionals to correct bad behaviors. Further improvements in the application could easily implement game-based solutions to enhance motivation.

Despite the fact that there are a lot of commercial devices to acquire respiration signals, there are several reasons to think that the Wiimote could be a better choice. The advantages of this approach may be its comfortableness, because the user does not wear any electronic device on its body, furthermore its low price and popularity (it is already present in many homes). In addition, such a gaming device may be a good option to cope with game-based applications for breathing techniques (Tanner 2008).

1.4 Research goals

The aim of this project is to implement a prototype to know the potential of the Wiimote's camera in tracking tiny movements such as breathing chest movements and, therefore, to test the possibility of using the Wiimote within respiration rehabilitation. Due to lack of time, it is not addressed a game-based solution, but only a program showing some breathing signals as feedback. The goal is to find answers to this research question:

1 Johnny Lee's Wiimote tracking example: <http://johnnylee.net/projects/wii/>

- Is it possible to use the Wiimote's camera to acquire useful data about the breathing for rehabilitation and feedback purposes?

If the answer to the previous question is affirmative, then a second goal would be addressed:

- What are the challenges that need to be solved to develop a system based on the wiimote that uses breathing as user interface?

Based on the outcomes, feasibility of developing game-based applications providing motivation and fun to support COPD patients in their daily rehabilitation exercises will be discussed.

1.5 Methodology

A prototype was developed in order to study the viability of using the Wiimote to capture the breathing rate for creating applications to provide guidance to patients. As explained below, the system is comprised of hardware elements to capture the breathing rate and software to process the data and provide feedback to the users.

In the beginning, two infrared light led arrays were designed and built to act as light sources. A Velcro belt was made to attach some markers to the user's body.

Once the hardware was ready, the software part was developed. First, a research on existing software and libraries managing the Wiimote was carried out. Some examples of code for different purposes were also taken into account. Finally, a small application that acquires breathing data from the Wiimotes and presents it through a graphical user interface (GUI) was written. At this point, a proof of concept was already finished. It shows the infrared sources seen by the Wiimote's camera, so we are able to know what the Wiimote can do. At the same time, the user watches some breathing signals and data acting as feedback.

In order to evaluate this proof-of-concept prototype, several tests were performed with healthy volunteers. During the tests, different markers were tested to achieve the best performance.

1.6 Main results

The prototype was finally able to track the user's respiration and present some feedback data with surprising precision. The tests performed showed very promising results. Therefore we can conclude that it is possible to use the Wiimote to acquire respiration signals.

There were some issues that could not be solved, they are presented and discussed in the corresponding section.

The challenges within respiration tracking with visual devices were gathered in this study. The most important are low cost, minimally invasive and comfortable, accurate enough for rehab purposes and real-time feedback.

The tests were done by healthy users only. To try with COPD diseased people it would be needed to carry out some future work in advance. Some proposals are commented in the last part of this document.

1.7 Summary

This thesis will show the possibility of using the Wii remote controller within respiration rehabilitation to provide feedback to the patient. There have been briefly explained in this chapter the problem definition, methodology and goals of the solution addressed, and a short comment on the results achieved.

2 Background

This chapter will present some background information. The information conforming the basis for this research and the state of the art in respiration sensors is shown. Game-based rehabilitation is also briefly commented.

2.1 Importance of breathing rehabilitation

The chronic lung diseases situation has been presented in the previous chapter. Its burden is huge, even ignoring that the impact may be underestimated. Pulmonary rehabilitation has become a recommended treatment for patients with COPD, and also other respiratory disorders, that can provide important benefits (Ries et al. 2007). There is evidence that exercise in pulmonary rehabilitation has a lot of benefits. It reduces depression and symptoms of dyspnea and anxiety (Paz-Díaz et al. 2007). In addition, it increases exercise capacity, enabling the patients to be more independent in their activities of daily living and, therefore, augmenting quality of life.

However, there still exist some barriers for them to participate in such programs. The word "rehabilitation" is likely to be misinterpreted or to reinforce negative connotations because it is also something a person has to undergo after illicit or bad behavior (Smith and M R Partridge 2009). Patients' beliefs about pulmonary rehabilitation comprise several reasons or negative aspects that usually lead them to drop out, as mentioned in the introduction.

Fischer et al (2007) divide these negative aspects into four categories. The main reason to quit is the association of pulmonary rehabilitation with gyms and sports, particularly threatening for some COPD patients (Taylor et al. 2007). They may feel that the training intensity would exceed their capabilities, especially to patients with poor self confidence related to exercise.

The second category is related to problems with transportation to the rehabilitation center. Patients without car or those who live alone and sometimes are unable to drive due to their illness are the most likely to have difficulties to attend regularly the rehabilitation course. The rate of adherence within the patients living near to where the course is taking place was higher compared to the ones living far (Fan et al. 2008). Related to transportation, disruption of normal routine is another common concern.

The third cause is uncertainty about the outcomes. It is difficult for them to measure objectively the improvements achieved, leading them to lose motivation and stop the treatment.

The forth, and the last one, consists in a collection of psychosocial factors. Limited privacy, previous negative experience of the hospital, contact with severe COPD ill or conflict with other patients are examples of these factors.

Home-based rehabilitation has been shown to be as a more successful alternative than the traditional one (Vieira, Maltais, and Bourbeau 2010; Wijkstra et al. 1994; Hernández et al. 2000). Some of the situations mentioned above, such as transportation problems or psychological factors, may be avoided addressing telerehabilitation solutions.

Feedback may be also a key aspect to improve pulmonary rehabilitation. A research carried out by Collins et al (2003; 2008) demonstrated that giving feedback to the patients about how they are breathing has positive effects. They developed a computerized system which showed the user's breathing pattern. Some bars were displayed on a screen representing duration of inspiration and exhalation cycles (Figure 2.1). Green targets were also shown to indicate the expiratory time goal. Reaching these green points, patients were able to modify their respiration, reducing impact of hyperinflation and dyspnea and improving exercise capacity. They learned to breathe better.

Previous studies have been mainly focused in the physical exercises to enhance rehabilitation programs. But the feedback system proved that breathing techniques are also important within pulmonary rehabilitation. Furthermore, it can fight against the uncertainty about achieving better outcomes, showing personalized goals and congratulating the patients every time one of them is reached.

In Collins et al research (2008), they acquired respiration data by a system based on a pneumotachometer. This is a medical sensor placed in the mouth that measures airflow directly. Despite of being very accurate diagnosis device, it is neither user-friendly nor affordable. Therefore it is far from being a good choice for rehabilitation purposes. The discussion of the different alternatives in breathing sensors is to be found in the following subsection.

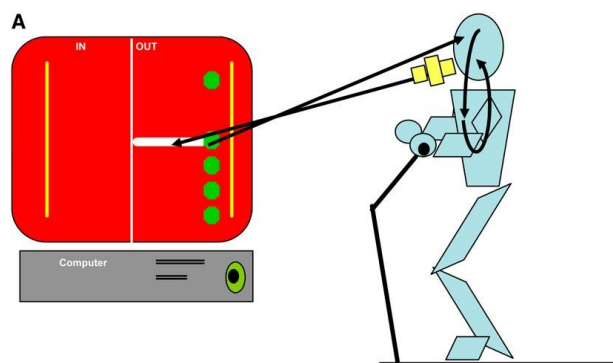


Figure 2.1. Feedback system for COPD patients (Collins et al, 2008)

2.2 Breathing sensors

As part of the study, a review on existing technology within the field of COPD and breathing rehab was carried out. It was mainly focused on respiration sensors, alongside a short introduction to feedback. Due to the non-systematic method used to find out the information, it may not be an exhaustive study of the state of the art. Several search engines (PubMed, ISI, ACM Portal, Google and Google Scholar) were used to find out diverse device types and technologies. The objective was to point out the most relevant alternatives to measure breathing. In order to detect them, it was established some criteria to be met. Sorted by importance, the criteria are:

- Systems or sensors selected must be already implemented and tested so we can evaluate their feasibility, strengths and weaknesses.
- Rehabilitation sensors must be non-invasive and wearable. Complex medical sensors for diagnosis or treatment were discarded.
- Framework of the systems selected is either set for non-clinical conditions or capable of being reproduced for outpatients and home conditions.

Several approaches involving different technologies were found, these are discussed below.

Belts

Most common breathing detection devices are sensing belts. Usually, the easiest, non-invasive way to obtain breathing signals consist in placing a kind of belt around the chest or abdomen. Through changes in chest wall circumference it is possible to estimate a person's respiration. But technology involved in the sensors can be quite different.

They often include mechanical transducers, such as inductive, capacitive or piezoelectric transducers, measuring stress in the belt induced by chest movements during respiration. One example of them is respiratory inductive plethysmograph (RIP) (Brüllmann et al. 2009; Clarenbach et al. 2005). It consist in one or more inductive sensors, wires in a sinusoidal shape, surrounding the body of the subject providing a voltage proportional to the stress suffered by the belt. Piezoelectric films (Pennock 1990) or capacitive elastic strain gauges (Gramse, De Groote, and Paiva 2003) were also valid solutions.

Some other approaches were found. For example, using light attenuation in a bended optical fibre or ultrasounds in a rubber tube placed around the body (Augousti, Maletras, and Mason 2005; D'Angelo et al. 2008; Lafortuna and Passerini 1995).

Belts are a good solution, they are very accurate and relatively comfortable, specially the wireless ones.

Accelerometers

Accelerometers are also feasible to be used in this purpose. These devices are able to measure accelerations, and some studies show that attached on the chest or the neck they can measure breathing movements (Hung et al. 2008; Phan et al. 2008; Morillo et al. 2007). It may be necessary to place more than one in order to be more accurate and differentiate respiration among other movements, so they may be less comfortable than belts. System costs is not specified in any of the studies. High accuracy values were achieve under restricting conditions (user immobile). On the other hand, they can acquire data for several purposes at the same time like, for instance, detecting heart rate or acting as pedometers.

Visual devices

The last suitable alternative was visual devices. A camera, which can be a webcam or an infrared camera, is able to track some markers on the body of the subject and estimate breathing pattern (Wiesner and Yaniv 2007; Orimoto et al. 2009). It is not fully developed but it looks very promising according to the information reviewed. Even involving little user movements, high correlation values were achieved (Wiesner and Yaniv 2007). Although depending on user movements, accuracy of the system may be more or less affected. Webcams presented the issue of ensuring privacy of the patient, but it was not a problem when it comes to infrared cameras. They may be the most comfortable approach since there is no sensor at all placed on the user.

Other

Finally, other techniques were pointed out. But due to lack of wearability, they are not considered as an option in this document. As an example of them it can be mentioned a prototype capturing breathing audio through a special microphone to be placed on the skin,



Figure 2.2. Belt-based breathing monitoring system (Zephyr BioHarness)

preferably on the neck (Corbishley and Rodriguez-Villegas 2007). Analyzing the sounds recorded, it was possible to calculate valid data.

All the solutions described above were tested with success by researchers and physicians, and the results were published in various prestigious journals. But only a few of the different technologies have already been applied into commercial sensors. As part of this study, it was intended to find out what kind of commercial sensors can be bought out in the market to know better the field. All of the devices that were found belong to the category of "belts". Their prices varies from US\$260 the cheapest one, called Pasport Respiration Rate Sensor², up to more than US\$1000 the most expensive device, the Zephyr BioHarness System³ (Figure 2.2).

Table 2.1. Breathing sensors classification.

	Advantages	Disadvantages
Belts	Accurate , some of the solutions (RIP) showed high precision values. Comfortable , specially the wireless ones.	Expensive , commercial sensors cost between US\$260 and more that US\$1000
Accelerometers	Can be used in several purposes at the same time like, for instance, respiratory waveform and heart rate	Expensive , there is no low cost commercial sensor available. Uncomfortable , one or more devices placed on the body. Accurate under restricting conditions (low user motion)
Visual devices	Comfortable , there is no sensor placed on the body. Cheap , webcam prices from US\$10	Accurate under restricting conditions (low user motion).

Therefore, the conclusion extracted from this review of the state of the art is that visual devices have some advantages that may not have been fully exploited (Table 2.1). They are cheaper since, as it is explained further on, a simple inexpensive webcam or Wiimote can be used for the same thing. They can be more wearable and comfortable than the other options. And, although their accuracy is not their strong point and they are definitely not the best solution for diagnostic purposes, they should be accurate enough to enable new rehabilitation applications based on this technology.

2 Available in : <http://sciencekit.com/product.asp?pn=IG0029706&mr:referralID=352ca0ed-1570-11df-b5f3-000423bb4e95>

3 Available in: http://www.habdirect.co.uk/products/Zephyr_BioHarness_System-p11543-r873



Figure 2.3. Wiimote

2.3 Wiimote

As a result of the study of the state of the art, it was decided to focus the thesis on the visual devices, and more specifically, on the Wiimote. Part of the previous work was a short review on this device. The Wiimote is a remote controller for the video games console Nintendo Wii released in 2006 (Figure 2.3). It integrates all the following features⁴:

- Eleven regular buttons plus a power button to turn the Wiimote off.
- Three accelerometers for measuring acceleration up to +/- 3g (including gravity).
- An infrared camera with a field of view of 33° horizontally and 23° vertically. Image seen by the camera is not available to the host, it is processed in a built-in image processor capable of detecting up to 4 spots.
- Bluetooth communication.
- Feedback features: four leds, a speaker and a rumble motor.
- A expansion port that augments its capabilities through connecting any of the addons, such as the Nunchuck, the Guitar Hero guitar or the Wii Motion Plus.

Despite all this features, it is very affordable, costing approximately 40 US dollars.

2.3.1 Wiimote tracking movement applications

This sophisticated and low cost device has become very popular and it has been integrated in other systems and platforms by the open source community. It had been completely disassembled and studied through reverse engineering processes. Once the hardware architecture and the communication protocols were public, many programmers

4 Further information to be found in <http://www.wiibrew.org/wiki/Wiimote>

started to develop their own applications and libraries to connect the Wiimote to computers for playing games, control the mouse, etc.

Nevertheless, not only gamers were seduced by this new way of interact with computers, but also the research community noticed its potential. One of the first who pointed it out was the researcher Johnny Chung Lee⁵. He carried out some prototypes to show the feasibility of using the Wiimote creatively to develop new human-machine interactions. The base of his Wiimote projects is the infrared camera, used to track infrared light sources. One of them, "Tracking your fingers with the Wiimote", was the inspiration for this thesis.



Figure 2.4. LED array and Wiimote

Johnny Lee's finger tracking project (Lee n.d.) consists in a very simple prototype and the software to manage data received. The prototype is an infrared light source, a LED array in this case, and the Wiimote itself (Figure 2.4). Reflective tape stuck on the fingers reflects LED's emitted light so they can be seen by the Wiimote's camera. It provides 2D position of the spots detected, up to four. This data is sent via Bluetooth to the computer where the demo application is running.

Creative usage of the Wiimote has already been applied by engineers and researchers in many ways. But also within the field of rehabilitation, providing to this project a very good starting point with some useful information. Attygale et al (2008) built an at-home assessment system for upper extremity rehabilitation with Wiimote based motion capture. They made a prototype very similar to Johnny's and tracked a marker situated on the wrist with quite accuracy, about 10% of error. With such a simple system, they developed an interactive rehabilitation program that used audio and visual feedback to train stroke patients to improve their arm movements. Another successful example of the use of the Wiimote is the one implemented by Murgia et al (2008). They presented a system able to detect some markers on the patients' hand in a 3D space, intended to allow them to interact with a virtual environment. Two Wiimotes were used in both studies in order to calculate 3D positions from the 2D data

5 Johnny Chung Lee curriculum and projects can be visited on <http://johnnylee.net/>

given by each Wiimote. This stereo vision technique with Wiimotes to detect points in space has demonstrated to be very accurate (Cuypers et al. 2009; Scherfgen and Herpers 2009). Other example of Wiimote-based system for rehabilitation is the prototype designed and implemented by Decker et al. (2009). It will be illustrated later in this chapter.

It is important to remark that, although this thesis is based on the Wiimote, we are not tied to this piece of hardware since a inexpensive normal webcam can be converted into an infrared camera. The procedure consists in removing the infrared filter they usually have and replacing it with fogged photographic film. In this case, it would be necessary to preprocess the image to identify the infrared sources in it and calculate the coordinates for each source.

2.3.2 Existing libraries

Thanks to its wide popularity, there are a large number of libraries and applications already done to connect a Wiimote to the computer and use it in different purposes. There is also available a lot of information on how it works and its characteristics. The best site to get it may be wiibrew.org, where it is possible to find data related to Wii hardware, software and related projects.

In the beginning of this study, a review on existing software was addressed⁶. It was focused in existing libraries which could be helpful when writing the application to manage the Wiimote for respiration tracking. Due to the computer used in this research was running on Linux, Windows and Mac native libraries were automatically discarded. The next list contains only some Linux and multiplatform libraries:

- **Wiiuse:** lightweight library written in C for Linux, although it is also compatible with Windows systems. It allows fully communication with several Wiimotes and the usage example provided is very easy to understand.
- **WiiuseJ:** Java API built on top of Wiiuse, exploiting its efficiency and lightweight. It is a very simple and easy way to control the Wiimote. It works with both Linux and Windows Wiiuse libraries.
- **MoteJ:** multiplatform Java library with lots of features and the most extensive documentation. It depends only on a Java Bluetooth implementation.
- **WiiremoteJ:** another multiplatform Java library also sitting on top of the same Java Bluetooth implementation as the previous one. It is one of the most popular despite it is not an open source library.

6 Most of the information was found in <http://wiibrew.org/wiki/Wiimote/Library>

These are the libraries with most potential. There are some other alternatives but not with so many features than the ones above.

2.4 Markers

Choosing the right marker is very important when it comes to tracking applications through cameras. A camera acquires just images, which have to be processed to extract the only information needed and avoid the rest. A marker is meant to make easier this image processing. It could be something with a special color, shape, a light emitter, etc. so it is very straightforward to differentiate them into the image or video.

As it was mentioned before, the Wiimote has a built-in image processor. It detects dots of infrared light and provides the coordinates corresponding to them into the image seen by the camera. In this case, infrared light emitters are going to be the markers.

An infrared marker can be either active, generating light, or passive, just reflecting light. Active markers are easier to track, but they need energy to produce light. For instance, a LED needs a battery, making the whole marker, intended to be attached to the body, bigger and less wearable. On the other hand, passive markers such as reflective tape are much more wearable but less visible because of light dispersion. Despite passive markers present lower performance than active markers, it could be enough for most of the applications. An evaluation about the level of performance needed must be addressed before discarding this solution. Improved wearability is a very important advantage to take into account passive markers.



Figure 2.5. Reflective tape in the user's arm (Decker et al 2009)

However, passive markers may present an additional issue that active markers don't, and this is noise. When the camera is seen a marker, if all the reflexion is not concentrated in one point the algorithm detecting the sources may infer that there are several sources. A good marker design avoids this problem. For instance, a marker with sphere shape disperses all the light except a small fraction that returns to the camera as a single point. Another way to solve the noise problem is to develop additional software routines to ignore noise. A prototype by Decker et al (2009) implemented this solution. They were using reflective tape that presented noise problems due to irregular shape (Figure 2.5). A computer algorithm was employed to isolate the strongest points, which represented the markers, from the noise.

About the position where the markers should be placed in a respiration tracking application, Orimoto et al (2009) documented that the best place may be over the abdomen area. Markers that showed up higher deviations due to breathing were located in this area. This information was taken into account during the testing phase.

2.5 Game-based telerehabilitation

Although game-based rehabilitation is not part of the solution presented in this master thesis, its feasibility of being implemented will be discussed and proposed as future work. The prototype could be easily integrated into a game to remain the patient about the breathing exercises. Game-based telerehabilitation has demonstrated to be a very good approach when it comes to motivation (Lange, Flynn, and Rizzo 2009). Virtual reality games can change the patient's adverse feelings about rehabilitation. If the game is fun enough, the user focuses on it instead of its impairment. Exercise becomes more enjoyable, distracting and likely to be maintained over time.

Until the introduction of new gaming technology in the form of video game consoles, the use of virtual reality was expensive and required technical expertise (Halton 2008). But since the release of Nintendo Wii game console in 2006, and some others more recently such as Playstation Eye, the field has turned into a more promising one. These devices enable user-friendly and low-cost rehabilitation oriented solutions, stimulating a large amount of research on this idea. A lot of literature about gaming and rehabilitation can be easily found.

Some examples about Wiimote-based systems implementing games for rehabilitation were collected as related work. A study by Decker et al. (2009) showed the design and implementation of a system for rehabilitation of wrist flexion and extension. They used the Wiimote's camera to track some markers placed on the patient's arm (Figure 2.5). The arm became the user interface to interact with the computer. Acquired data was the input for a small game to encourage the patients to do the exercises in a more enjoyable way. In Figure 2.6 the interface of the game is shown. It is a game similar to the old Pong. There is a bar in



Figure 2.6. Game-based rehab example (Decker et al. 2009)

the bottom part of the screen controlled through the degree of flexion or extension of the wrist. The goal is to move the bar horizontally in order to keep the ball in the screen without “falling to the floor”. On the background it can be seen the relative position of the arm, wrist and hand. In other studies, virtual reality was the way to motivate the patients. Murgia et al. (2008) also used a Wiimote-based tracking application to allow the patient to interact with a virtual world, making the rehabilitation exercises more distracting and fun.

2.6 Summary

In this chapter, breathing sensor alternatives have been explored. Usage of visual devices for respiration tracking has been tested with success. As shown in Table 2.1, they may be the best approach. They are cheap, very comfortable and accurate enough to be used in rehabilitation programs. Moreover, infrared cameras presented less issues than webcams when it comes to privacy because images of the user are never recorded. But there is also an important lack of information indicating that this field is not yet fully developed.

On the other hand, popularity of the Wiimote has been rising. It has been introduced by the researchers into telemedicine and telerehabilitation applications, achieving great results in some fields. The Wiimote studies reviewed were the seed of the present project. The aim is to test if the Wiimote is able to reproduce the results obtained with infrared cameras in respiration tracking and to discuss the suitability of using it in that purpose together with game-based feedback to empower pulmonary rehabilitation.

3 Requirements and specifications

This chapter will present the requirements taken into account in this thesis. It is divided into external requirements and system requirements. Some of the recommendations in IEEE Guide for Developing System Requirements Specifications were followed (IEEE 1998). Framework specifications for the tests are also commented in this section.

3.1 External requirements

External requirements comprise all the constrictions in a framework established by external factors. They are usually given by laws and regulations, but also by studies and health-care professionals.

Before the topic of this work was decided, a meeting with a physiotherapist from the University Hospital of Tromsø was arranged. She explained the rehabilitation program that COPD patients are already addressing here.

3.1.1 Use case

As commented in chapter 1, standard therapy include lower extremity training. In this case, the exercise carried out by the patients was cycling instead of walking. A normal session includes some cycling series with small breaks for recovering. In those breaks, they are encouraged to perform some respiratory exercises to improve their breathing skills. But their experience says that most of the patients just ignore the respiratory exercises, missing an important part of the rehabilitation. While doing this recovery breaks, patients remain sitting on the bicycles.

The use case identified comprises a patient sitting on a stationary bicycle without exercising but performing breathing exercises.

3.1.2 Environmental requirements

The system must be non-invasive. Invasive systems do not simulate the environment where the patients will use the system.

3.1.3 Risks

The law requires to inform of all the significant risks of harm that could arise from the use of the system. Non-existent potential for harm is known since the patient wears just a simple Velcro belt with some markers.

3.1.4 Confidentiality

Finally, in case that any personal information would be stored or sent over the Internet, the standards and regulations must be met. But this scenario is beyond the scope of this thesis

3.2 System requirements

The system requirements are those for the system to work properly and to achieve the goals. These requirements were gathered from conversations with the supervisors, from the literature reviewed and from problems that showed up during the development.

3.2.1 System purpose, scope and overview

The purpose of the prototype is to acquire breathing signals and present feedback to the user.

COPD patients are usually avoiding the respiratory exercises included in the rehabilitation program. The system will provide guidance and feedback to encourage them to perform the exercises. It should be a game-like application to provide fun and motivation.

The prototype can be divided in two parts: software and hardware. The hardware is comprised of infrared light illuminator, markers, Wiimotes and a computer. The software implements a graphical user interface and the methods to acquire and manage the data.

3.2.2 General description

System context

The prototype works in a isolated way. No interacion with other systems is implemented. No network connection is required.

System modes and states

The system should have two modes: calibration mode and running mode. Calibration mode should facilitate the setup of the system. In running mode, it must acquire and save the data and present feedback in the computer screen.

Major system capabilities

The Wiimote must be able to detect the markers over the body of the patient and provide the distance between them avoiding any noise.

Data acquired must be saved into files to perform an exhaustive analysis of it. It must also be processed to present feedback to the patient.

User characteristics

The user of the system is mainly the patient. Health-care professionals or relatives may interact with it in the calibration phase. It is important to note that COPD ill may have an anomalous breathing pattern because of their disease. The prototype must be accurate enough to cope with very tiny movements due to impaired lungs. Abnormal situations such as apnea, which means absence of breathing, or hyperinflation, when the patient is not emptying completely its lungs reducing its pulmonary capacity, should be detected properly.

Assumptions

A prerequisite for the suitability of the system proposed is that the user must stay as still as possible to avoid wrong measurements. A study by Orimoto et al (2009), proves the feasibility of acquiring breathing signals with an infrared camera, but they only tested their prototype with patients totally immobile laying on a bed. It was assumed that sitting on the bike without doing exercise, the user would stay still enough to enable respiration measurements through cameras. Anyway, this assumption was checked during the tests.

Operational scenarios

The operational scenario can be either at home or at the rehabilitation center. The patient is in both cases sitting on a stationary bicycle performing breathing exercises.

Maintenance

Only the batteries of the illuminator and the Wiimotes require maintenance. The user should be aware of switch discharged batteries for new ones.

3.2.3 Hardware requirements

The system must be non-invasive and low cost. It should also be a comfortable and wearable prototype.

In order to build it as comfortable as possible, it was decided to use passive markers despite they are less visible than active ones. Passive markers must reflect enough infrared light to be detected by the Wiimote camera. In addition, they must have a curved shape so they reflect light to the camera independently of the relative position between them, the source and the camera. The most curved the shape the widest the angle of the reflection.

These factors, intensity and angle of reflected light, are inversely proportional. For instance, a sphere has a very wide angle, bigger than 90° , but the reflection is very dispersive and very little light hits the camera. A balance between dispersion and intensity must be met by choosing an adequate reflective material and shape (Figure 3.1).

Shape of the markers must be also as regular as possible and without wrinkles to avoid noise, as explained in chapter 2.

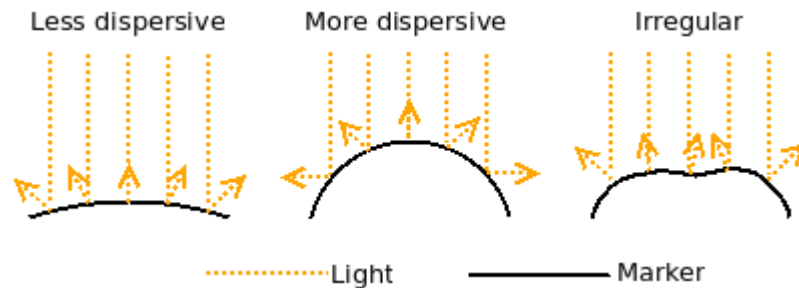


Figure 3.1. Markers light dispersion

Choosing the right infrared light source is also important. Taking into account that most of the light is dispersed, it must emit a quantity of light so the small percentage that hits the camera is enough to be detected. The angle of emission should be wide enough to cover the area where the markers are going to be.

Standard exercise for COPD patients is cycling on a stationary bike. Therefore, the prototype could be mounted on one of those to test its feasibility. In this case, the Wiimote must be able to see the markers at least at a distance of 20-30 centimeters. This is more or less the distance it would be between the Wiimote placed on the handlebar and the user while sitting on the bike (Figure 3.2). This is the setup chosen for the proposed solution. If the prototype is not mounted on the bicycle but close to it, the distance should be greater.

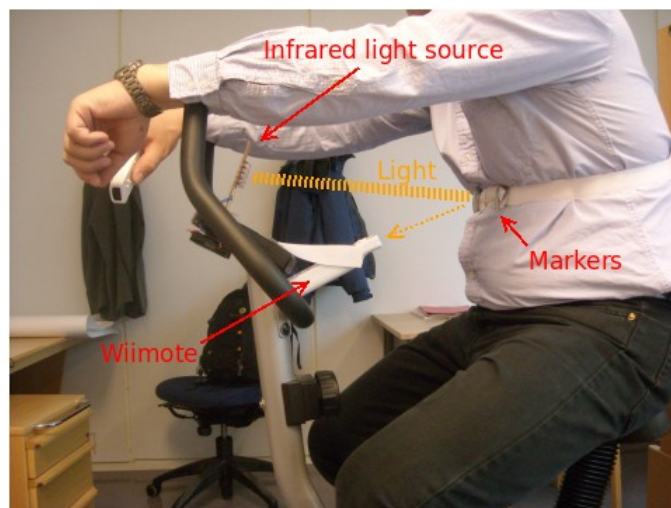


Figure 3.2. System setup.

3.2.4 Software requirements

When it comes to the software, it should accomplish some characteristics to allow reliable tests. It must present the feedback destined to the patient, in addition to all the information that may be interesting. A real time application would be the best, but a small delay, tenths of a second, is also an acceptable solution, having in mind that frequency of respiration is very low, less than one Hertz in most of the situations.

Data acquired must be saved in order to analyze it in detail after the tests and calculate the reliability of the system. No confidential data must be involved.

The prototype is just a proof of concept, thus the software could be a partial implementation with a simple GUI. There is no intention in implementing a real system from the prototype.

For a next version of the system, it would be necessary to develop a complete, stable version of the software, fixing all the possible errors in the prototype. It must be ensured a proper operation for, at least, the duration of the breathing exercises. Exhaustive documentation about the software must also be provided.

3.3 Specifications for test framework

Once the prototype of this research was built, exhaustive evaluation tests were performed in order to get reliable results to be discussed. Nevertheless, despite all the medical and rehab respiration sensors available, there is no gold standard measure for respiratory rate in no-intubated patients (Brookes et al. 2003). Assuming that medical devices, such as pneumotachometers or capnographs, are the most accurate way to obtain a reference to compare with, they would be the best choice for tests. But access to them is not easy as they are expensive, complex and scarce in-hospital equipment. They are also quite invasive and do not simulate the environment where the patients will use the system as it was said before. Therefore, a different test protocol must be pointed out.

As it was said previously, mechanical transducers included in sensing belts are quite accurate, although far from being precise. They are used mostly in rehabilitation. The inconvenience is that the respiration rate is acquired through the same indirect way since it is also calculated from variations in chest circumference. Every deviation related to this indirect method would remain undiscovered.

The last option of observer counting respirations is the simplest and the most traditional one, but valid after all. A study by Khoo et al (2008) was validated doing this, in addition to

the use of a thermistor placed under the nose. Corbishley et Rodríguez-Villegas (2007) designed a variation of this method. Their protocol included some tests under different conditions to prove the reliability of their solution. Instead of measuring breathing rate, they were trying to detect apnea episodes (absence of respiration) by asking the user to hold breath and continue breathing in a specific sequence.

3.4 Summary

External and system requirements were explained in this section. Some evaluation techniques have also been commented, concluding that there is no standard to compare with. An evaluation protocol should be designed in order to test the prototype adequately.

4 Architecture

This chapter explains the procedure followed until the breathing detection prototype was finished. It is divided into three subsections. First, it presents an overall look on the entire system. Then, the different parts are explained separately: design and implementation of the infrared light source, how the markers are attached to the patient with the belt specially built for this and, finally, the software developed for testing the prototype.

4.1 Respiration tracking system

The aim of this system is to prove the feasibility of using the Wiimote for respiration tracking using passive markers. Those markers reflect the light emitted from the source so they can be seen by Wiimote's camera. Every time the Wiimote detects movement from the markers, it sends the new position to the computer via Bluetooth. The design of the prototype comprises the following parts (Figure 4.1):

- Array of 30 infrared LEDs (light emission diodes) as light source.
- Belt with attached markers.
- Wiimotes.
- Computer with Bluetooth connection.

System operation is very simple. The LED array emits infrared light that, when it hits the markers, is reflected in all directions. Wiimote's camera is able to detect this light reflected by the markers, providing the coordinates where the infrared dots (corresponding to the markers) are in the image. Calculating the distance between two of this dots it is possible to estimate the distance between the camera and the markers. If the distance between the points is high, it means that the markers are close to the camera and vice versa.

Assuming that the Wiimote and the body of the user are not moving, all distance changes would be consequence of respiration. Even with some movement from the user, in some cases breathing is still capable of being detected analyzing the data acquired.

Signal processing usually requires a lot of resources from the computer or device. The quantity of data involved tends to be very high, demanding a proportional memory space to store it. Although the purpose of the data is hardly ever just to be stored, but to be analyzed to extract information from it. Depending on the analysis, it would take more or less

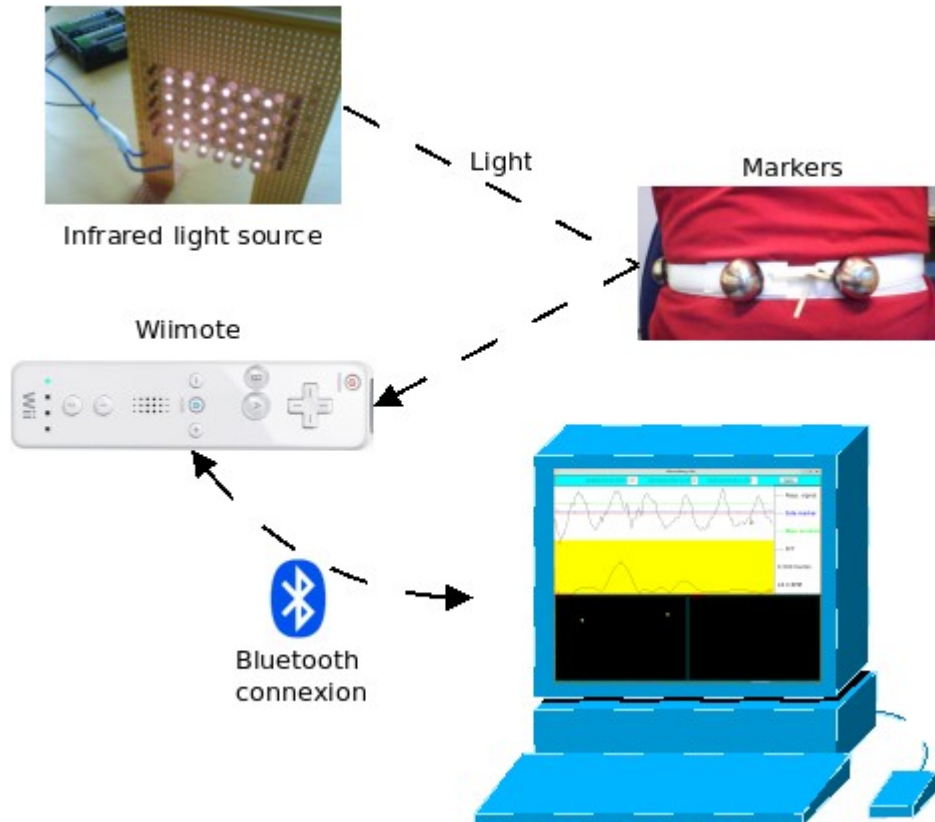


Figure 4.1. Respiration tracking system

calculations, despite even a relatively simple frequency analysis needs a huge quantity of calculations that increases in quadratic proportion to the number of data.

When it comes to real-time applications, it leads to a need of resources proportional to the calculations. Data is acquired periodically, and it has to be allocated in memory and analyzed before the next incoming data arrives. Fast processor and memory are crucial. Sometimes, old data may be deleted if the information has been extracted. In this case the memory could be smaller.

In most cases, this situation is addressed with DSPs (digital signal processors). A DSP is a piece of dedicated hardware prepared to carry out calculations with large data arrays very quickly. But, in this case, a normal PC is enough since breathing signals are low frequency signals and the data involved is not that large. Although a PC wastes a lot of resources in unnecessary services, it has enough to do a real-time analysis of the respiration signal if the application configuration is adequate. This configuration is discussed in next chapter.

4.2 Infrared light source

An infrared light source could be any thing able to emit radiation in the infrared spectrum. It could be a bulb, a hot metal or even a candle, but the best way to obtain it is the LED. Most of commercial infrared illuminators are built with a number of LEDs. They are power-saving, due to their efficient conversion of energy from electricity to light, and not expensive at all, costing between 30 and 40 US dollars the smallest built-in devices. Because of the simplicity of the electronics involved with these devices, it was decided to develop a custom solution. Spare parts needed are cheaper than the commercial illuminator but, on the other hand, is quite time-consuming to implement it.

Once the first design was done, the following electronic components were bought:

- Infrared LEDs:
 - Nominal forward voltage: 1.5 V
 - Max forward current: 100 mA
- Resistors:
 - Resistance: 15 Ohm
 - Max power dissipation: 250 mW.
- Batteries:
 - Nominal voltage supplied: 1.5 V.
 - Battery holder
- Boards
- Wires

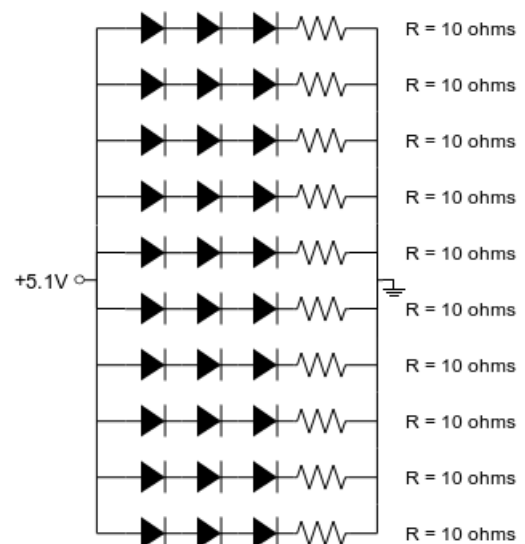


Figure 4.2. Second version of the LED array

Designed LED array is made of 30 LEDs, 10 resistors and 4 batteries in a row. This first implementation presented some problems. The batteries had not a stable output voltage. Initial voltage was 1.7 V instead of 1.5 V. In addition, average forward voltage of the LEDs was around 1.4 V, 0.1 V lower than the nominal forward voltage. As a result, the resistors were dissipating more power than the maximum allowed.

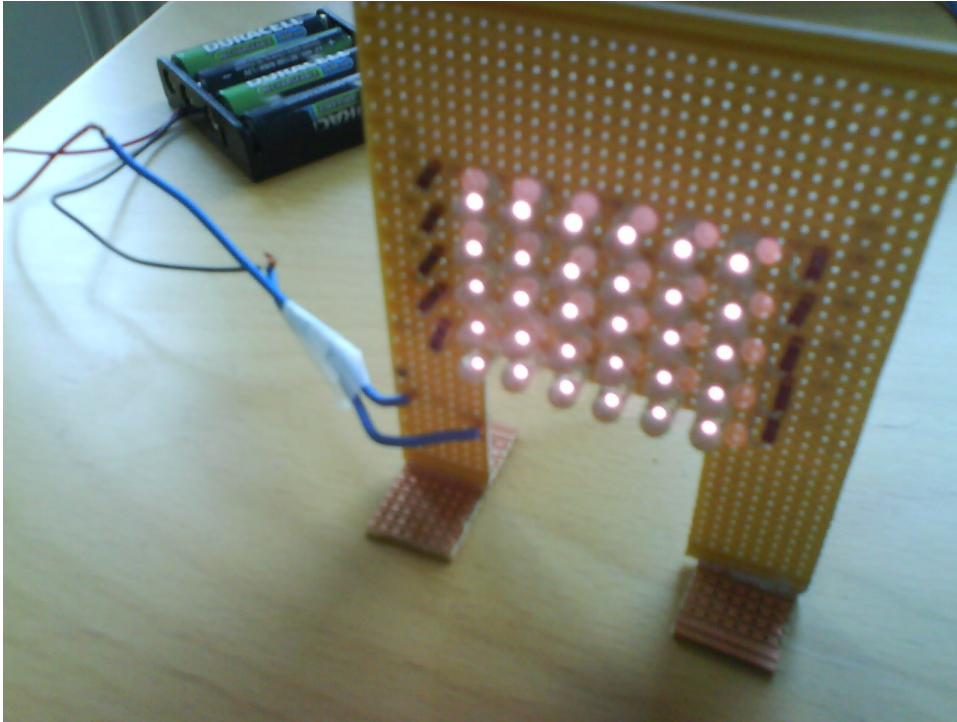


Figure 4.3. LED array designed for the respiration tracking project.

Therefore, a second design was carried out (Figure 4.2) in order to fix these problems. Normal batteries were replaced by rechargeable 1.2 V batteries, which have a more stable output and an initial voltage of 1.25 V each or around 5.1 V all four together. 15 Ohms resistors were replaced by 10 Ohms resistors.

Although the first design was improved, the first board mounted was still usable for tests with semi-discharged batteries.

Final aspect of one of the implemented illuminators is shown in Figure 4.3.

4.3 Markers

In Johnny Lee's system (Lee n.d.), commented before, passive markers seemed to be adequate enough to be used in this project. They were visible for the camera at distances above 1 meter, and that is more than enough for this project.

Reflective tape was not available during the development of the prototype, so some experiments with different materials to achieve best performance were done. A piece of aluminum film, a very common thing in every kitchen, had very good results reflecting light, but there were some problems trying to maintain a curved shape without wrinkles. Because of this, the image was very noisy and, therefore, useless. A piece of shining metal was also tested. Acceptable results were achieved with the convex part of a spoon. In the end, two

types of markers were built from pieces of spoons. The shape of them is very regular avoiding noise problems and intensity of the reflexion was strong enough to test with them.

The only difference between the two types of markers was the shape. The rounded one, similar to a half sphere, is the most dispersive one. It is difficult to detect at longer distances. On the other hand, there is no problem about the angle of incidence of light because it reflects light in all directions. It is quite the opposite with the other one, the Wiimote and illuminator has to be right in front of it because the angle of reflexion is smaller, but it is less dispersive and easier to detect.

Attaching the markers to the body was done with Velcro strips. Pieces of Velcro were placed under the markers to attach them to a Velcro belt to be situated on the chest (Figure 4.5). The front part of the belt, just between the markers, was replaced by an elastic band. While the user is breathing, belt tension is released through the elastic band, receding and approaching the main markers. Measuring distance between those markers will be the way to estimate breathing.



Figure 4.4. Sticky markers



Figure 4.5. Belt with markers

The second type of markers is also lighter than the rounded one, so it was possible to make some sticky markers to be placed on a tied T-shirt (Figure 4.4).

A third marker was placed aside the user. When using two Wiimotes, the main one in front of the user and the other to the right, the function of the third marker is to detect if the user is getting closer or farther from the main Wiimote.

Front and back view of the markers can be seen in the picture below (Figure 4.6).



Figure 4.6. Markers

4.4 Software development

4.4.1 Choosing a library

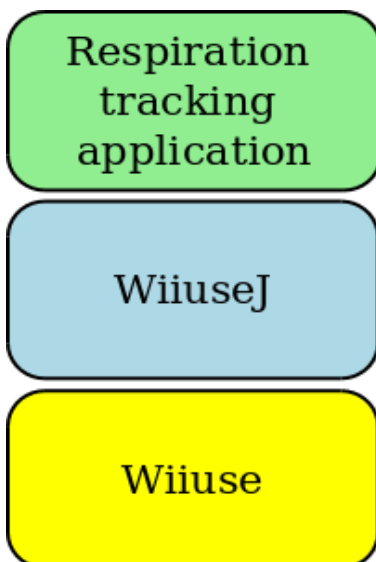


Figure 4.7. Software layer diagram

As starting point in the software development, it was decided to take a look on open source libraries and other related work to get some knowledge about the field. It was easy to find a huge quantity of information, summed up at the beginning of this chapter. Thanks to all the work done by software developers and fans, there is a lot of code available to work with so it was possible to avoid starting from scratch. Multiplatform Java libraries were the preference since they are transportable from one operating system to the other. In the early stage, MoteJ library was picked because its extensive documentation. But after some time trying to get it work without success, WiiuseJ was the second choice. WiiuseJ showed to be simpler and easier to deal with, having a very good and exhaustive example of how the API works.

Therefore, WiiuseJ was selected among the collection of open source libraries. It is a Java API built on top of another open source library called Wiiuse⁷. Although Wiiuse is written in C, it works natively in both Linux and Windows, becoming an efficient and lightweight API. It is able to connect several Wiimotes at the same time and bringing full support to all Wiimote features, including addons as the nunchuk or the classic controller. WiiuseJ works perfectly as a Java interface for Wiiuse, providing high level routines to communicate with the Wiimote. The library itself comes with a very clean GUI example for programmers to learn how to use the code (or for simple users to play with it for a while).

The application developed is sitting on top of WiiuseJ and, therefore, needs Wiiuse to work properly (Figure 4.7).

4.4.2 Development framework

Eclipse⁸ was the development environment in which all the code and testing was developed. It is a open source application that integrates a lot of useful tools for programmers. It is specially popular among Java programmers.

The process for getting Eclipse ready for the application is easy to do. First, the library must be installed. This is, basically, to download "WiiuseJ 0.12b.zip" file from WiiuseJ webpage. Inside it, in addition to WiiuseJ software, they are included the Wiiuse libraries (either .dll files for Windows or .so for Linux). Further instructions to install the required packages can be found at the wiki of WiiuseJ project webpage: <http://code.google.com/p/wiiusej/w/list>.

An important step that is not very clear in the documentation is how to set up the run configuration. WiiuseJ will not work if the following variables are not configured properly:

1. Go to "Run Configurations" menu in Eclipse (Figure 4.8). Create a new "Java Application" configuration. After setting up the name and main class (which for the Respiration Tracking application must be IRtracking), select Arguments tab. In VM arguments write the following string, changing the path to where you installed the Wiiuse libraries:

```
-DJava.library.path=/home/julian/Desktop/prueba/PFC
```

2. In the same menu, click on Environment tab. Add a new variable to the list called LD_LIBRARY_PATH. The value of this variable must be the same path than in the previous step.

7 More information: <http://www.wiiuse.net/>

8 Eclipse project webpage: <http://www.eclipse.org/>

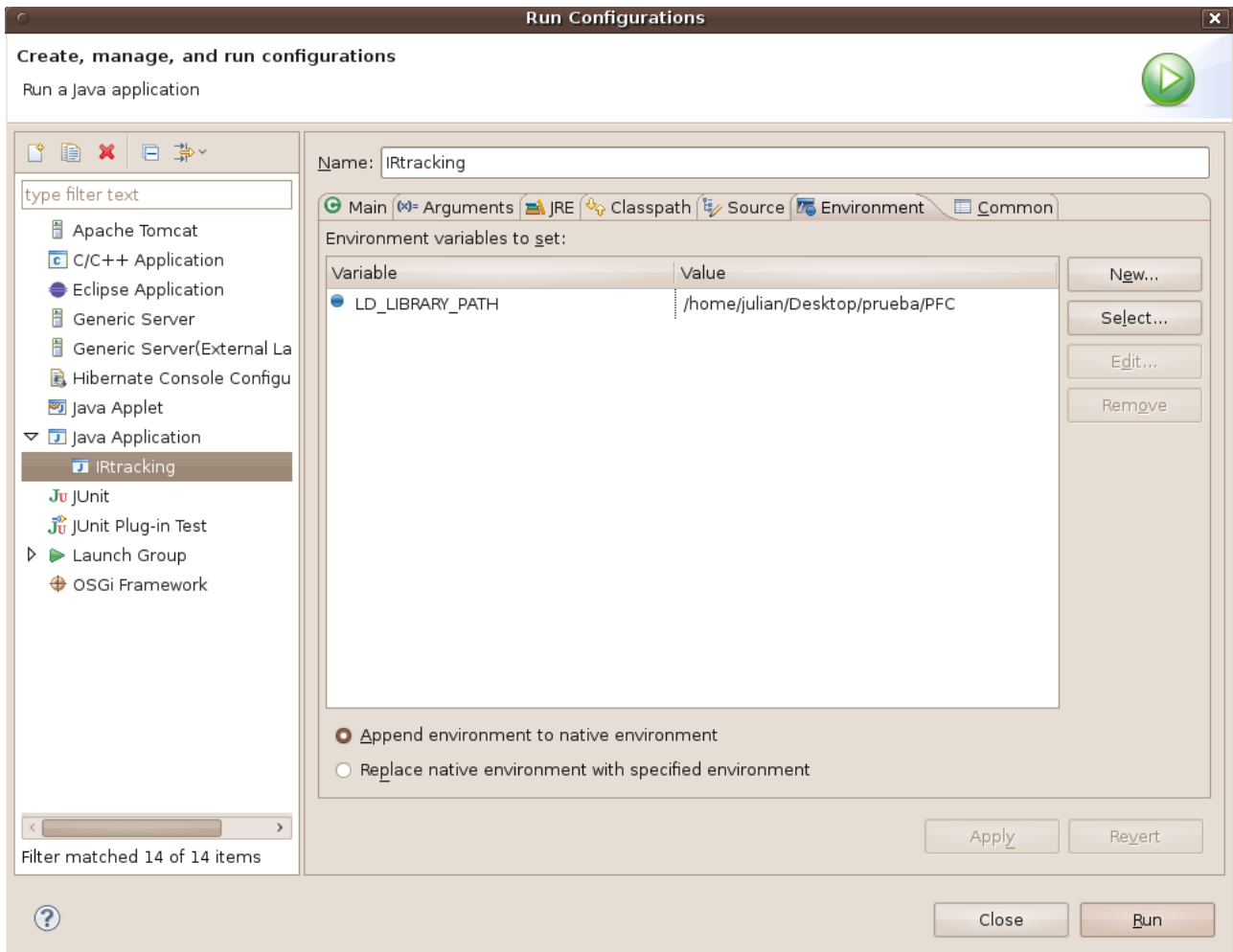


Figure 4.8. Eclipse configuration

This indications are for Linux users, under the Windows version of Eclipse these indications may not be correct.

4.4.3 Software architecture

Code written was split into three Java files: 'IRtracking', 'IRGUI' and 'utils'. 'IRtracking' implements WiimoteListener class from the library, as suggested in its documentation for third party apps, and contains the core of the application. It connects to the Wiimotes when the application is launched and handles the events produced by them. 'IRGUI' is the code for the graphical user interface. Routines to create the graphs are included in it. a significant part of the GUI implemented was adapted from a code example by Richard Baldwin⁹. The last one, 'utils', is a collection of functions to perform some auxiliary math calculations. It is compound of three classes featuring Fourier transforms, interpolation and operations on arrays.

This is a list of features in the respiration tracking application.

⁹ Available in: http://www.developer.com/Java/other/article.php/10936_1554511_1/Plotting-Engineering-and-Scientific-Data-using-Java.htm

Connection to one or two Wiimotes.

When the application is run, it searches for active Wiimotes (to activate a Wiimote, buttons 1 and 2 have to be pressed at the same time). The program will terminate if none Wiimotes are found after three scans. If one or two Wiimotes are found, they will be automatically connected. Additional Wiimotes are ignored.

Acquisition of breathing signal.

Every time the distance between the main markers changes, an event is produced by the Wiimote. The application handles this events to store time series corresponding to breathing signal from this distance. The events produced by the Wiimote are asynchronous so it is impossible to fix a time interval between them. To calculate the BPM (breaths per minute) some signal treatment techniques were implemented: interpolation and time-frequency transformation.

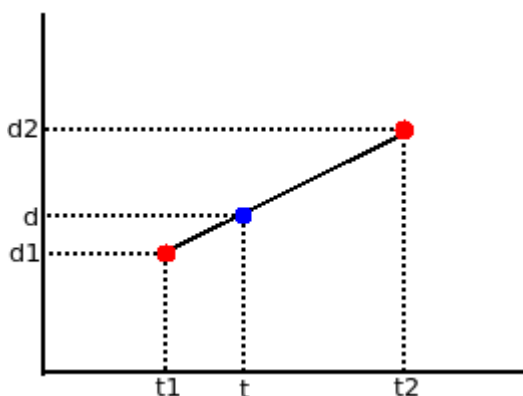


Figure 4.9. Interpolation technique

To set the sampling time, interpolation techniques are addressed to estimate the value periodically (Figure 4.9). Having two data, d_1 and d_2 , acquired in time t_1 and t_2 respectively, it is estimated the value d in t with the equation (1) (t is the instant we need determined by sampling time).

$$d = d_1 + \frac{(d_2 - d_1) * (t - t_1)}{t_2 - t_1} \quad (4.1)$$

A frequency analysis is the way to estimate the BPM. To do so, a DFT (discrete Fourier transform) (2) function was implemented. It computes and returns the amplitude spectrum of an incoming time series. The amplitude spectrum is computed as the square root of the sum of the squares of the real and imaginary parts. It returns an array of points in the frequency domain equal to the number of samples in the incoming time data. By searching the highest value in this array, frequency of the respiration signal is found. Finally, BPM is obtained with a simple conversion of the respiration frequency (3).

$$X_k(f) = \sqrt{\left[\sum_{k=0,2,\dots,n-1} (x_k * \cos(2 * \pi * f * k)) \right]^2 + \left[\sum_{k=0,2,\dots,n-1} (x_k * \sin(2 * \pi * f * k)) \right]^2} \quad (4.2)$$

n = length of incoming data

$$BPM = 60 * \text{Respiration frequency} \quad (4.3)$$

Some control data can be easily changed to configure the following parameters:

- Quantity of samples stored with variables DATA_LENGTH and FREQ_LENGTH.
- Sampling time can be changed through variable SAMPLING_TIME. It also fixes the maximum frequency that can be calculated according to (4).
- High-pass filter. Changing HPFILTER, the application avoids a number of points corresponding to the lowest frequencies so they do not interfere with the respiration signal.
- Signal decimate. It gives the option to decimate the array data sent to the Fourier transform function. Decimate means to take only one each x samples (being x an integer value), dividing the number of samples by x. The consequence is that automatically the maximum frequency calculated is also divided by x (4). It can be configured by the variable DECIMATE.

$$\text{Max. Frequency} = \frac{1}{2 * \text{Sampling Time (Sec)} * \text{Decimate}} \quad (4.4)$$

Sampling time affects to GUI refresh time, GUI is refreshed only when new data is stored. High-pass filter and decimate control the frequency window the application will work with. This window should be as tied as possible to breathing signal frequency interval.

If a second Wiimote is connected, the side marker can also be tracked to know if the user is moving.

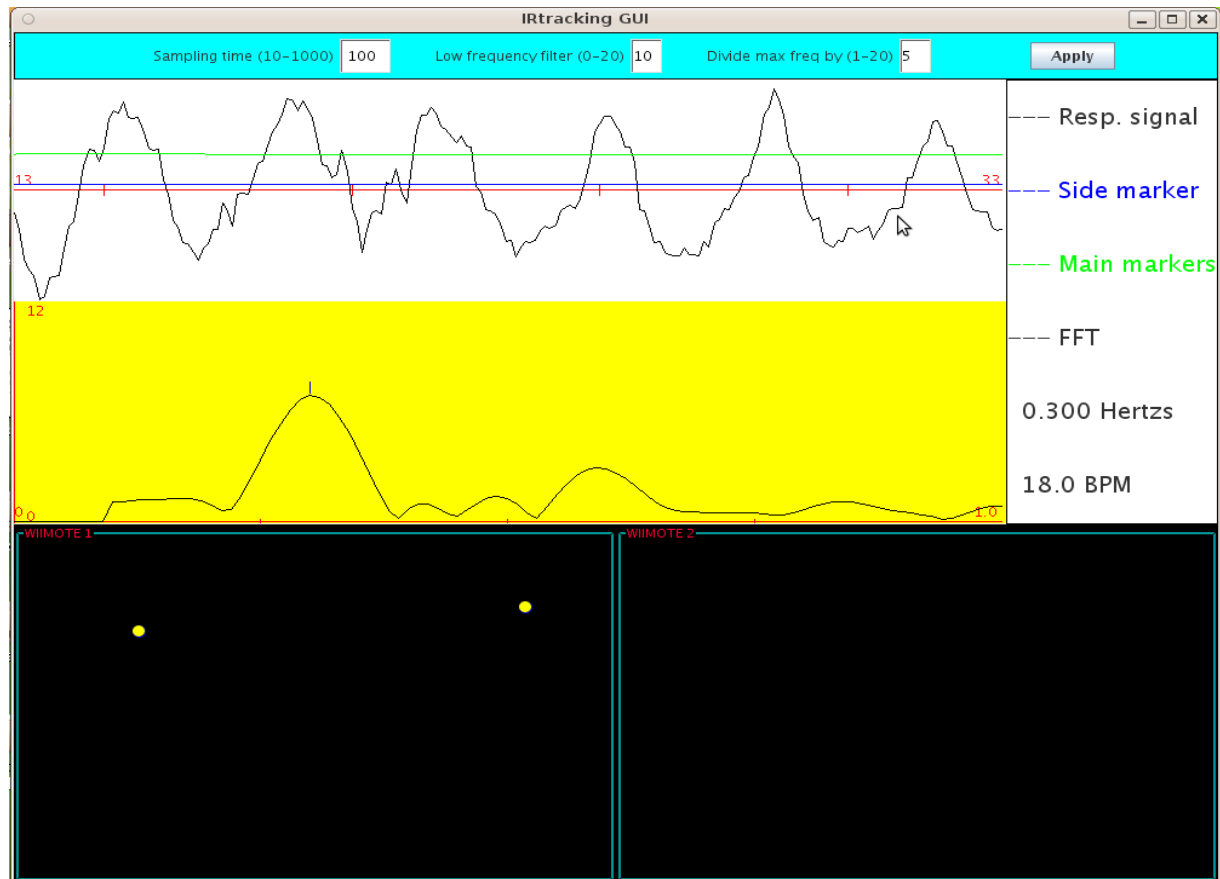


Figure 4.10. Graphical user interface layout.

Graphical user interface.

As soon as at least one Wiimote is connected, the GUI is launched (Figure 4.10). It is divided into three parts.

- Control panel in the upper part to configure the application. The user can choose sampling time, low frequency filter and decimate values.
- Two graphs showing respiration data in real-time. White graph shows the respiration signal (black), distance to main markers (green) and side marker position (blue). X-axis units are seconds and y-axis is normalized between -1 and 1. Yellow graph shows frequency spectrum of the respiration signal in which the x-axis are hertz. The highest frequency peak is marked with a line. The legend is located in the right part together with the frequency of the respiration signal (highest peak in yellow graph) and BPM.
- Post-processed camera images from the Wiimote(s) connected can be seen in the lower part of the GUI. Yellow dots are detected infrared light sources. These images make easier the calibration phase, the markers must be correctly placed and the user close enough so the two yellow dots appear on the screen.

All data above, graphs and camera images, is refreshed in real-time.

Controlled from the Wiimote.

The basic commands are set using the Wiimote itself.

- Buttons 1 and 2 activate and deactivate the camera.
- Buttons + (plus) and - (minus) configure the sensitivity of the camera.
- Buttons 'up' and 'down' start and stop processing data received. A session is successfully saved when button 'down' is pressed (only if 'up' was pressed before).

Save to files.

Every time a session is started, respiration signals and BPM are automatically stored and labeled with actual time and date for testing purposes.

Wiiuse and WiiuseJ libraries in which the Respiration Tracking application is based on are licensed under the General Public License version 3 (GNU GPLv3). This free software license guarantees the freedom to use, distribute and/or modify the libraries without restrictions, but it also establishes that any version of the code or program based on these libraries must inherit all the free software characteristics included in GPLv3. That means that the Respiration Tracking application should also be free software in case of distribution, and it must be licensed under a compatible license with GPLv3.

Thus, the Respiration Tracking application is free software licensed under GPLv3.

4.5 Summary

Architecture of the whole respiration tracking system has been presented. It is composed of four different parts: light source, passive markers, Wiimotes and a computer with Bluetooth connection.

5 Evaluation

This chapter recopies all the testing done with the prototype. The application employed to analyse the results is presented in the first section. The second and the third show the tests without and with users respectively.

5.1 Evaluation tests framework

For evaluation of the data collected with the tracking application, GNU Octave¹⁰ was the choice as development environment. It is a free, open source alternative to the more popular Matlab. GNU Octave is a high-level language primarily intended for numerical computations, but capable of doing some other tasks with the tool collection included in it. It provides a graphical interface and the language it mostly compatible with Matlab.

Octave was used to check the algorithms lately implemented in the Java application. Also some Octave scripts were written mostly intended to show the data gathered into graphs (Appendix 3). Most relevant of this scripts are mentioned in following subsections and appended in the end of this document.

5.2 Tests without users

During the development of the system, some tests were done in order to check different parameters.

5.2.1 Main markers performance

After using the whole system for a short period of time, the limitations of the markers were discovered.

The rounded markers worked well at a distance up to 25 centimeters from the illuminator and Wiimote. At longer distances, it was difficult for the Wiimote to detect them all the time and the points in the GUI were blinking. The spoon-like markers were a little better in this aspect, they worked well up to 30-35 centimeters. There are about 5 centimeters of difference depending on the part which produced the reflexion, this markers are not symmetrical.

When used with the belt, the spoon-like markers presented some additional problems. Even being close enough, sometimes there were no reflexion hitting the camera because a displacement of the marker. Angle of reflexion of this markers is not so high and, although this

¹⁰ GNU Octave project can be visited in <http://www.gnu.org/software/octave/index.html>

provides a less dispersive reflection, sometimes the camera goes out of this angle, turning the marker invisible. The rounded markers did not present this issue.

5.2.2 Side marker

To detect movements from the user getting closer or farther of the Wiimote, a marker was placed aside of the body. A couple of tests were done with this configuration to get an idea of the possible benefits of using a third marker. They consisted in getting closer or further from the Wiimote (about 10 centimeters) while breathing normally (Figure 5.2). Data from the main markers and the side marker was stored.

The results showed that movement of the body can be detected from this marker, but also respiration movements were detected by this marker because of the belt. In Figure 5.1 it is shown the results of one of the tests. The first graph represents the data acquired from the distance between the main markers and the second one correspond to the horizontal position of the side marker. Y-axis in both graphs is measured in Wiimote camera's pixels. In the image we can see how the prototype responds when the user gets closer (11 seconds after starting the test) and farther from the Wiimote (after 35 seconds).

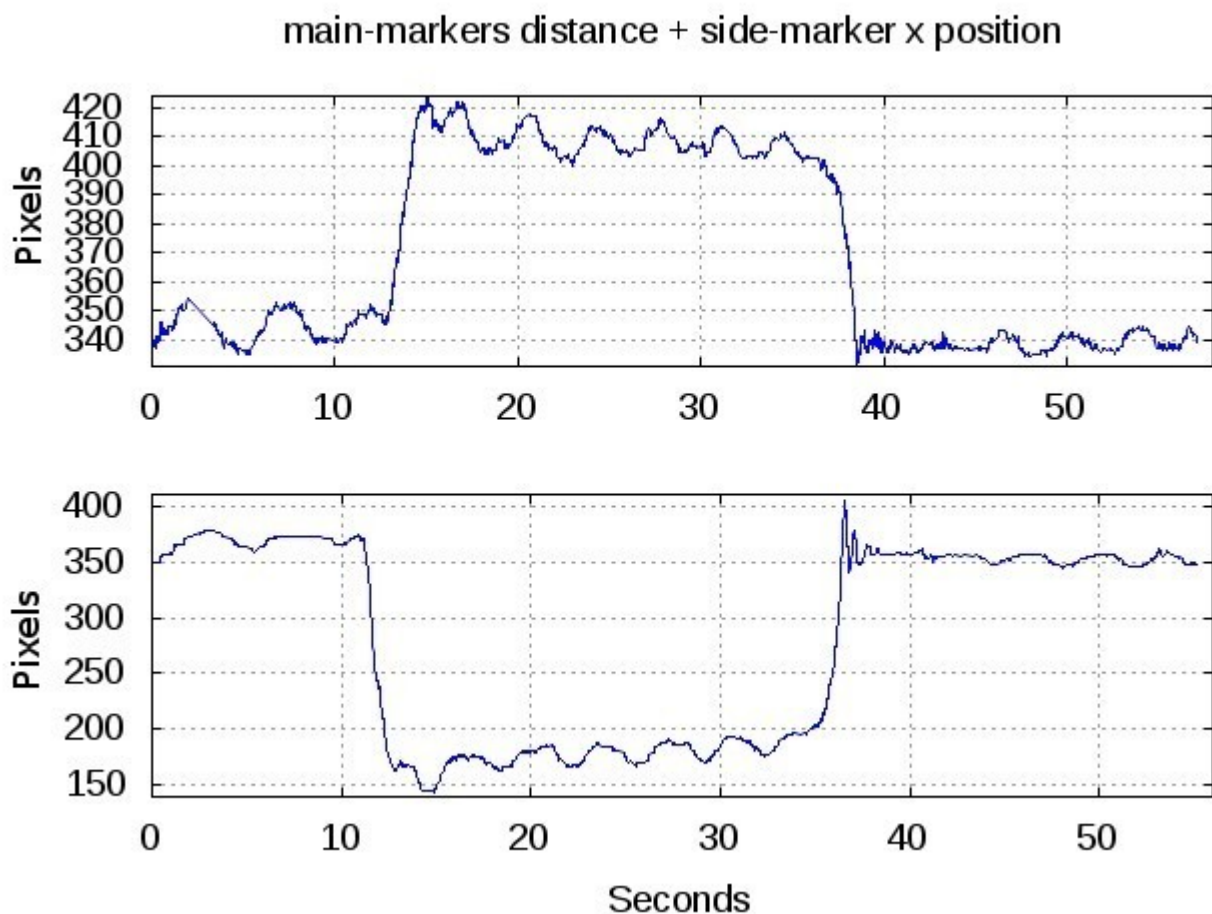


Figure 5.1. Side marker test. Above: main markers distance. Below: side marker position.



Figure 5.2. Side marker test

5.2.3 Software configuration

As it was commented in previous chapter, an adequate configuration of real-time applications is very important. Java applications are at very high level. They are executed on a Java Virtual Machine, which is not the most efficient way to access to computer's resources so far. Fourier's transform needs a lot of calculations, therefore a balance between amount of data and fastness must be met.

Sampling time may be the most important parameter. The refresh frequency of the GUI is set by this parameter. High refresh frequency will consume a lot of resources meanwhile low refresh frequency will have less accuracy. Sampling time also fixes the maximum frequency the system will work with as shown in equation (4). Maximum frequency must be higher than respiration frequency. Very low sampling time means low maximum frequency of the system and may end in errors if respiration frequency goes beyond it.

Data length and frequency length affect to the refreshing time of the GUI. The higher the number of data to represent, the higher the time to refresh the graphs. Frequency length also affects the time to compute the DFT.

Other configuration parameters are HP filter and decimate. They do not modify the resources consumption of the application, but bad values could end in erroneous outcomes. HP filter deletes low frequency data and decimate divides maximum frequency.

Some tests were done in order to find optimal values for these parameters. Finally, the following values showed good results and were set as default configuration:

- A sampling time value of 100 milliseconds was shown as a good option. Maximum frequency is therefore set to 5 Hertz (corresponding to 300 BPM) that is much more than needed.

- Data length was set to 200 to have 20 secs graphs in the GUI.
- Frequency length was set to the maximum value (the same of data length) of 200 to have the maximum resolution in the frequency graph.
- HP filter was set to 10 to delete frequencies below 0.1 Hertz assuming that normal breathing will never be under 6 BPM.
- Decimate was set to 5 to reduce maximum frequency from 5 Hertz to 1 Hertz assuming that normal breathing will never be over 60 BPM.

5.3 Tests with users

5.3.1 Evaluation protocol

In chapter 3 it was explained that there is no standard within acquiring respiration signals. Anyway, it would have been beneficial to have any of the sensors commented previously as a reference. But during the tests, there was no breathing sensor available to compare with. Therefore, an evaluation protocol was designed to know the accuracy of the data shown to the user. It is a variation of the method of counting respirations from the literature (Khoo, Brown, and Lim 2008; Corbishley and Rodriguez-Villegas 2007). The protocol is as follows:

In the beginning, the user was asked to wear the belt with the markers tied but in a comfortable way. If the volunteer was wearing a tied T-shirt, it was asked to use the sticky markers at least during one of the three tests. The markers were placed over the abdomen since it is the place with larger displacement as explained in chapter 2. In most of the tests, the rounded markers were chosen because, if close enough, they are always seen by the camera.

The volunteer was in charge of counting its own respirations. This data provided by the user is lately compared to BPM calculated by the system. While one of the wiimotes was tracking the markers, a second one was given to the user. In every respiration, when the lungs were full and the expiration phase was about to start, the user was told to press a button on the wiimote. Every time the button was pressed, a time stamp was stored in the computer, making the count easier for the user and saving the data to validate systems' outcomes.

Before starting the tests, the volunteer was said to concentrate on breathing, but doing it normally. Talking was not allowed while acquiring data, since it affects to the breathing pattern.

Three tests were carried out by every volunteer:

1. Sitting on a chair (Figure 5.3).
2. Sitting on a stationary bicycle before doing exercise (Figure 5.4).
3. Sitting on the bicycle after doing 5 minutes of exercise.

All tests duration is between 3 and 4 minutes. The application on the computer's screen is not shown to the user in any of the tests to do not to interfere with the counting process.

Finally, user's opinion about the system is gathered. It was asked about the comfortableness of the belt and, if used, about the sticky markers.

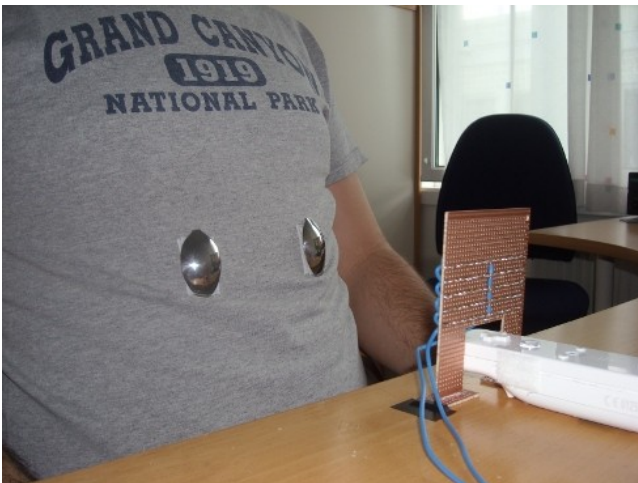


Figure 5.3. Test sitting on a chair.



Figure 5.4. Test sitting on a bicycle.

5.3.2 5.3.2 Volunteers recruitment

Volunteer recruitment was done among university students and Norut workers. An e-mail was sent inviting them to participate in this research. A consent form (Appendix 2) with all the indications to perform the tests was sent to them in advance. Those who answer the e-mail were recruited for testing.

5.3.3 Results analysis procedure

Data collected was analyzed in Octave. An Octave script was written to automatize the process. The script imports the data stored by the tracking application and presents a figure with two graphs (Figure 5.5):

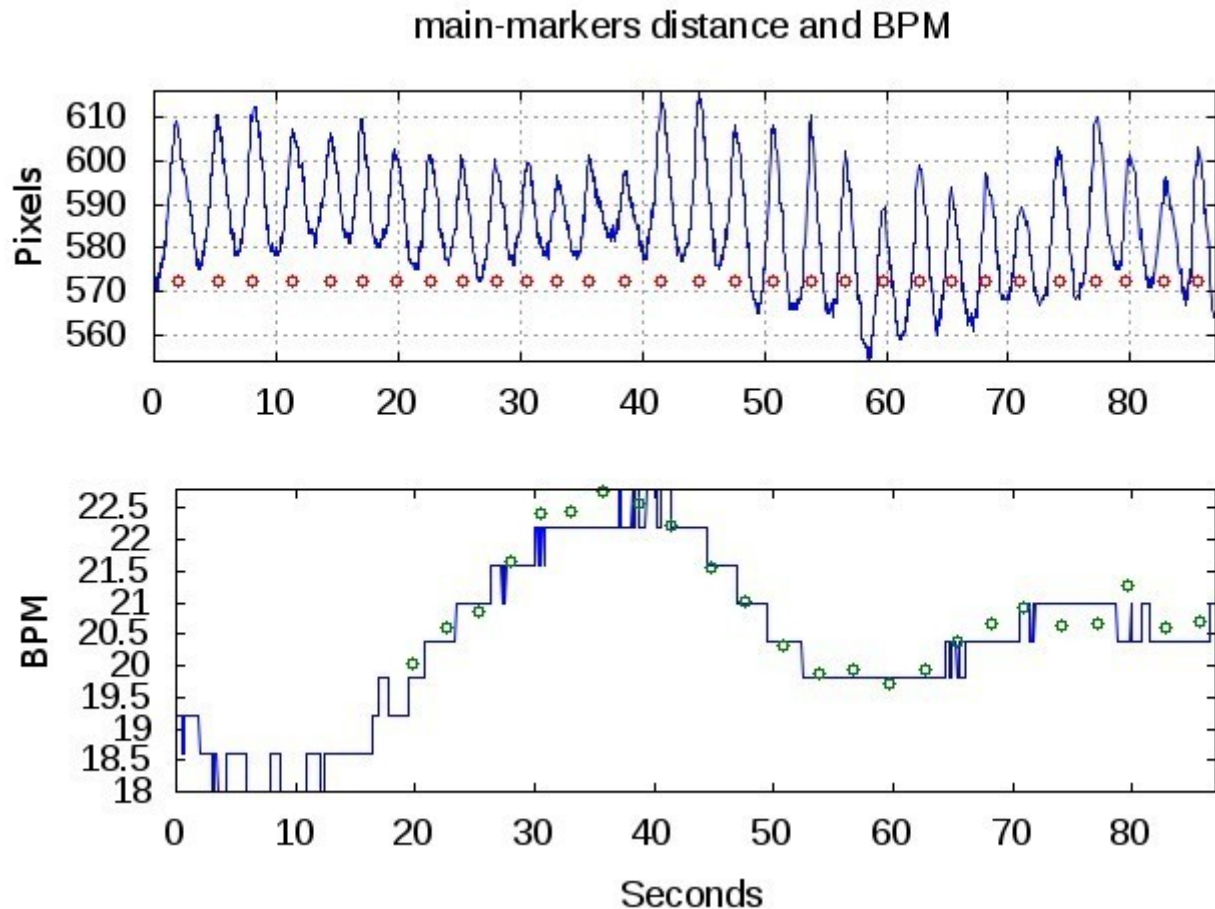


Figure 5.5. Results analysis example. Above: signal detected by the wiimote and user's input. Below: BPM calculated from the signal and from user's input.

- The first graph, in the upper part, shows the respiration signal acquired by the Wiimote (distance between the main markers) and input from the user. The respiration signal, the blue line, is presented as acquired by the Wiimote, without any transformation or deleted data. Units in y-axis are distance between markers in pixels as received from the Wiimote. The red dots are the time stamp of every pulsation from the user. In this graph, it can be checked if pulsations correspond to respirations. For instance, in Figure 5.5 every dot matches with a local maximum of the signal.
- The second graph shows BPM calculated from the two sources in the other graph. The blue line shows BPM calculated from the respiration signal by the tracking application and presented in the GUI. The green dots are BPM calculated from the input of the user. The script takes every red dot and the six previous ones (if available) to estimate BPM. It was chosen to take seven dots because with an average of 20 BPMs, interval of the signal taken to calculate BPM in both methods is the same. With very high values of BPM, the input from the user has a higher response time than the one from the wiimote

when BPM value is changing. Very low values end up in low response time. In Figure 5.5 there is an example in which BPM from both methods is very similar.

The script also provides as output maximum error and RMSE (root mean square error) between both BPM data series. Maximum error is the maximum difference between the two series. It is not very representative of the precision of the system since just one punctual wrong measure drives high this value, but it is useful to detect punctual errors. RMP is more appropriate to estimate precision of the measurements. RMSE is calculated according to (5).

Table 5.1. Results error in Figure 5.5

	Absolute	Relative (%)
Maximum error	0.87	4.14
RMSE	0.34	1.64

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (x_{1,i} - x_{2,i})^2}{n}} \quad (5.1)$$

Script's output consists in maximum error and RMS error in absolute and relative values. In Table 5.1 there is an example of the output values for the results in Figure 5.5. Relative values are related to the average value according to (6).

$$Relative\ error\ (\%) = \frac{Error}{\frac{\sum_{i=1}^n x_{1,i}}{n}} * 100 \quad (5.2)$$

5.3.4 Results

In the end, seven volunteers tried the system. In Table 5.2 it is shown the precision the system had in every test. The numbers in every cell correspond to maximum error and RMSE in both absolute and relative values. Background colour indicates anomalous circumstances happened during that test.

Table 5.2. Evaluation test results

	Test 1 (Sitting)		Test 2 (Before exercise)		Test 3 (After exercise)	
User 1	2.8	22.84	2.43	27.45	4.08	28.26
	1.09	8.85	0.73	8.29	0.92	6.37
User 2	2.01	8.55	0.57	3.73	1.4	10.17
	0.85	3.6	0.29	1.87	0.53	3.83
User 3	0.89	5.37	0.66	3.93	0.86	3.78
	0.35	2.12	0.29	1.71	0.35	1.54
User 4	0.7	5.71	1.23	11.63	5.14	43.55
	0.32	2.59	0.45	4.22	1.9	16.07
User 5	0.86	8.24	1.45	14.04	1.01	5.72
	0.44	4.23	0.6	5.8	0.45	2.56
User 6	0.94	9.81	0.75	7.63	5.67	25.08
	0.5	5.24	0.4	4.09	2.41	10.65
User 7	15.18	138.78	4.46	42.32	19.46	143.4
	10.62	97.07	1.04	9.83	10.31	75.97

Results legend

Absolute max error	Relative max error (%)
Absolute RMSE	Relative RMSE (%)

	Normal test
	Error induced by the user
	Punctual error
	Critical error

Tests outcomes were classified as follows:

- **Normal test:** The test was realized without incidents. Error values can be considered as a measure of the prototype's precision.
- **Test with errors induced by the user:** The user made a mistake pressing the button during the test. There were registered two types of errors induced by the user. One of these types was 'double pulsations', some pulsations were stored twice. The other type was 'missing pulsations'. These errors lead to errors in BPM estimation. Thanks to the graphs obtained from the analysis procedure, it was easy to detect errors induced by the user (Figure 5.6).
- **Test with punctual errors:** The application presented an erroneous BPM for a short period of time (less than one breathing cycle) (Figure 5.7). In all cases, it was provoked by user's movements getting closer or farther of the Wiimote. Most of the body movements are inside the frequency window used in the tests (From 0.1 to 1 Hertz) and, therefore, they were not filtered and interfered with the respiration signal.
- **Tests with critical errors:** The application did not acquire breathing correctly or the BPM showed was wrong longer than a breathing cycle.
 - In some cases, breathing signal was not correctly acquired due to the markers, Wiimote's camera could not detect at least one of them properly. One or both

markers were blinking on the screen, which means that they were detected only from time to time. When they were seen most of the time, the application worked well, but when they remained most of the time undiscoverable the system failed. The causes may be that the markers were beyond the limits explained above or displacement of the marker on the belt.

- Erroneous BPM data had different causes. In the third test made by the user 4, it was because a longer inspiration (Figure 5.6). Low frequency components were not correctly filtered. Respiration signals acquired from the user 7 presented two frequency components, respiration and another one that may be displacements of the belt over the abdomen (Figure 5.8). It is likely that the belt was not tighten to the body.

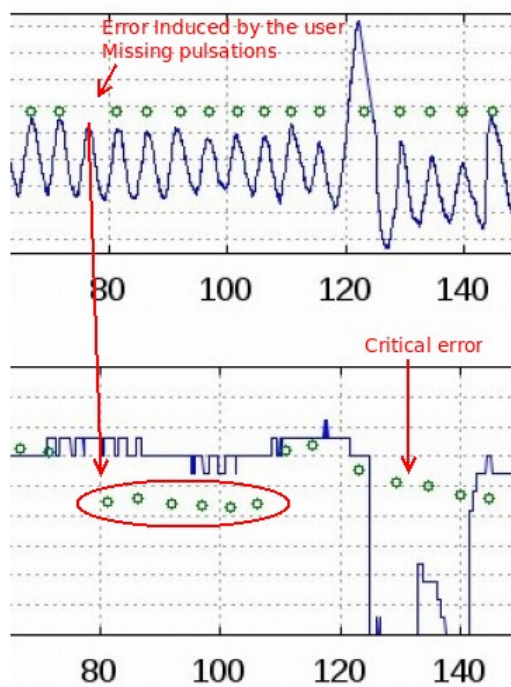


Figure 5.6. User 4, test3. Critical errors and errors induced by the user

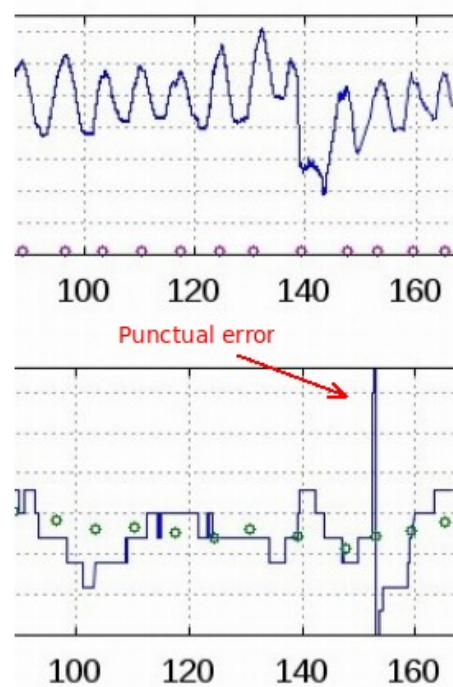


Figure 5.7. User 1 test 3. Punctual errors

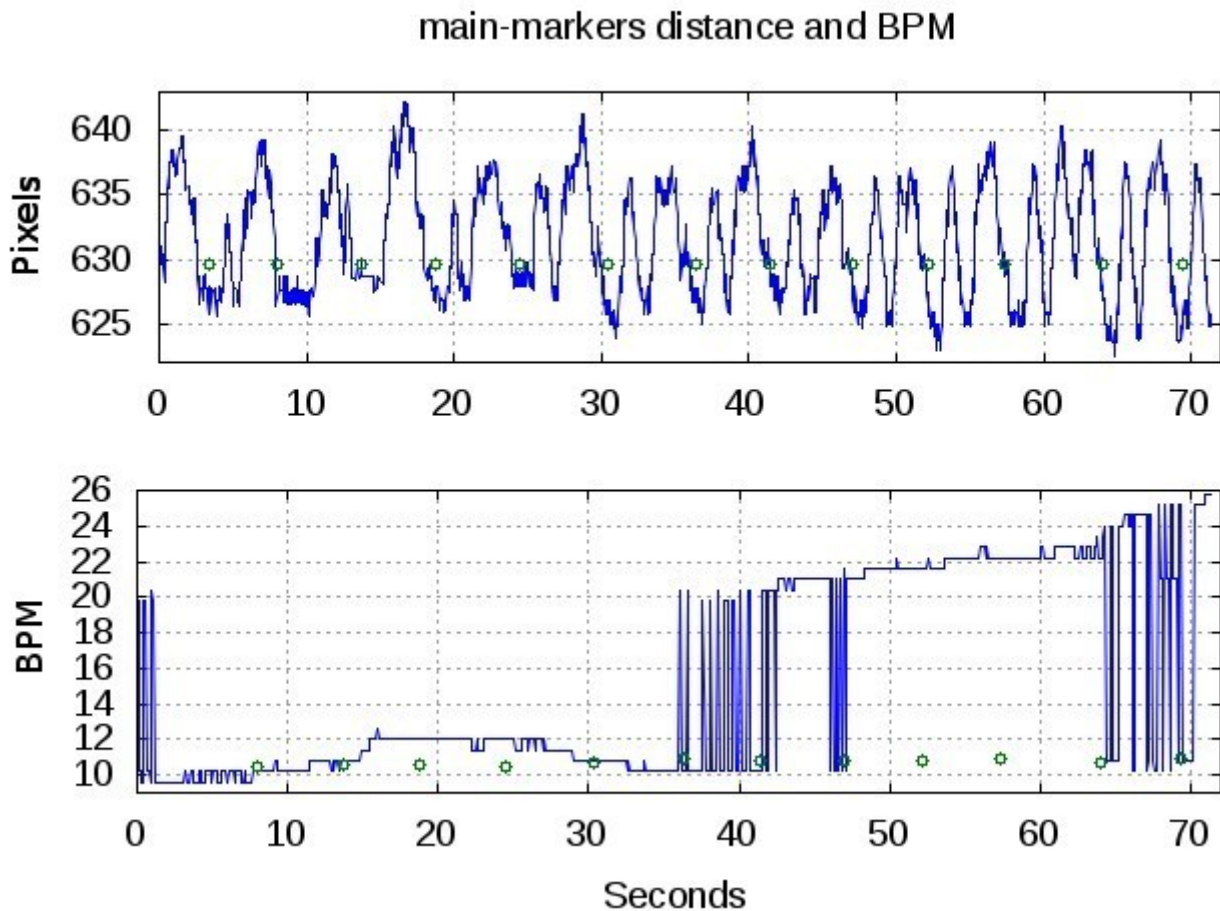


Figure 5.8. User 7, test 1. Critical error.

The figures below are examples of tests without errors. They show respiration signal and user's input in the first graph and BPM calculated from both inputs. BPM calculated by the Respiration Tracking application (blue line in second graphs) is very similar to BPM calculated from the user pulsations. The outcomes had less than 15% of maximum error in all these tests and less than 10% in most of them (10 of 12). The RMSE was lower than 6% in all of them.

After the tests, the volunteers were asked about their feelings about the system. They all agreed about the comfortableness about the belt and no one found any negative aspect about it. Five of them felt very surprised about the system because it was based on a Wiimote. One of the users said 'I never thought that a remote controller could be used to acquire respiration'.

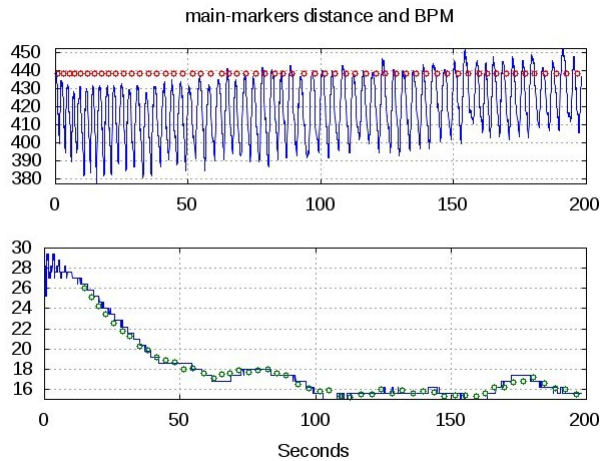


Figure 5.9. User 5, test 3.

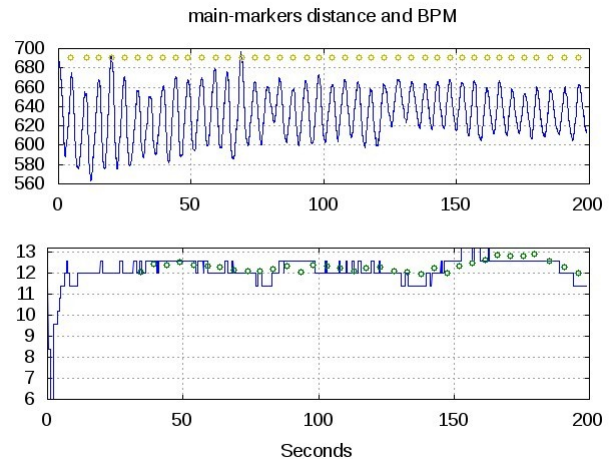


Figure 5.10. User 4, test 1.

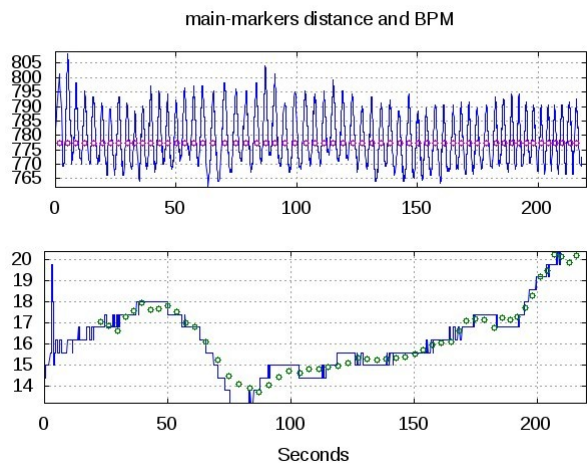


Figure 5.11. User 3, test 1.

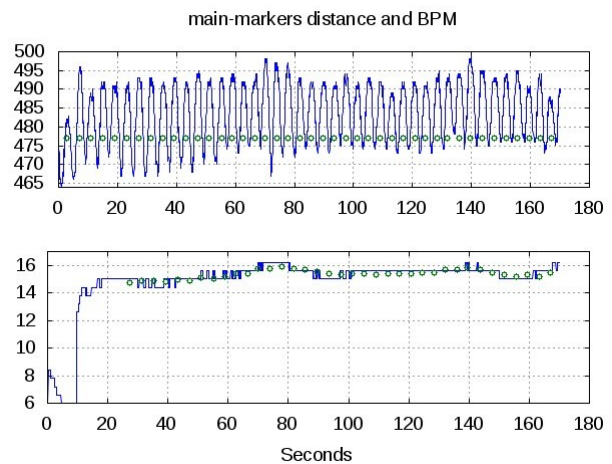


Figure 5.12. User 2, test 2.

Only two volunteers (user 3 and user 6) made test 2 and test 3 with the sticky markers on a tight T-shirt. Both of them agreed that this type of markers is more comfortable than the belt. They would preferred the sticky markers over the belt if they had to attend a rehabilitation program. This solution did not show to be more accurate than the belt, it showed more or less the same precision.

5.4 Summary

All the tests addressed with the prototype were explained in this chapter. The tests without users gave us data about the potential and limitations of different configurations of the system. The tests with users show the precision of the system acquiring breathing signals. Also the weaknesses of the system were gathered in this part. Errors involved were studied in order to find out their sources.

6 Discussion

The Wiimote has demonstrated to be a very versatile device with lots of applications. It has been used in the rehabilitation field with success, as shown in the literature gathered together in the background chapter. In this thesis, another possible usage of the Wiimote within this field has been explored.

The prototype implemented acquires breathing data and provides feedback to the patient about how slow or fast its respiration is. It is a non-invasive, low cost system, composed of a normal computer, a US\$40 Wiimote, a US\$5 belt with markers and a illuminator about 30~40\$ expensive. It is also a comfortable solution without wires, batteries or any kind of electronics, the patients only wear a Velcro belt or a tight T-shirt with some passive markers.

6.1 Outcomes within respiration tracking

The system developed has proved to be able to acquire breathing signals with surprising precision having in mind the materials involved. All the data collected by the application showed the user's respiration signal without any doubt. Since access to a breathing sensor was not available during the development of the prototype, it was impossible to compare the respiration signal and its accuracy remains unknown. Therefore, a different evaluation protocol was addressed in order to know the potential of the application and its limitations. BPM calculated from this signal was compared to a test signal obtained from the user.

During the tests, some volunteers tried the system and they were encouraged to count their own respiration cycles. User-provided data was employed to estimate the test signal, which consisted in BPM calculated from this data. Uncertainty of this test signal is also high, so the outcomes from the evaluation tests should be taken as approximate values instead of ensured.

Among the tests without any incident, twelve in total, only two of them had a maximum error above 10% (10,17% and 14,04%). About RMSE, which is a good estimator of precision, in only two of these tests was higher than 5% (5,8% and 5,24%). It means that difference between both signals was quite low in all these tests.

The outcomes demonstrate that the Wiimote is able to acquire useful respiration data for rehabilitation purposes. Thus, the first research question is solved.

6.2 Challenges within respiration tracking with visual devices

The second research goal was to point out the challenges that need to be solved to develop a Wiimote-based system to acquire breathing.

In chapter 3, the system requirements were identified and gathered so the prototype was implemented following them. They are an exhaustive list of all the challenges addressed but the most important ones are further discussed below.

The system showed to be a low cost and non-invasive system. Furthermore, it is a comfortable alternative to cope with respiration signals acquisition.

Wiimote's camera sensitivity is not very high, and therefore one of the main challenges is the markers. An appropriate reflective material must be selected to build them. Although acceptable results were achieved with the poorly built markers used in this work, markers made of reflective materials such as reflective tape have shown to result in better outcomes in previous studies. The shape of the markers is the other important factor. As commented before, passive markers may present dispersion and noise problems if the design do not meet certain characteristics. To avoid noise, the shape of the markers must be rounded and without wrinkles. Otherwise, the noise must be eliminated employing software techniques and algorithms. In the solution presented here, noise problems were avoided implementing curved markers. Depending on the degree of curvature, dispersion effect is more or less relevant.

The software is another important challenge. It must communicate with the Wiimote to acquire the data, process it and present feedback to the user in real time. The respiration signal is a low frequency signal, so the resources consumption to do this is not high, a normal computer is able to do all the calculations. But the processing of the data have to be very well designed. Even having the patient relatively immobile, several situations may occur. The software should be ready to ignore little movements, detect large inspirations and even warn about possible apnea or hyperinflation episodes.

The illuminator designed must provide enough light intensity in a wide angle to cope with all the use cases

6.3 Limitations

The prototype developed has several important limitations that were uncovered during the tests.

Some of the errors produced during the evaluation tests were consequence of the impossibility of differentiating chest movements due to respiration from body movements. In the two studies collected about using visual devices to acquire breathing, and also in this case, a prerequisite is that the user must be immobile. Detecting respiration with visual devices while exercising, cycling on the stationary bike or walking on a treadmill for example, is something that remains being an unsolved challenge. Although some tests using two Wiimotes were addressed, no solutions are proposed to solve this issue.

Performance of the markers was also an important limitation. Range of proper operation was very low, allowing the user to be at a maximum distance of the Wiimote of 20-30 centimeters. The cause of this was the material used to develop them, it has not the appropriate reflective qualities.

The evaluation tests were only carried out by healthy users. COPD patients may have an anomalous breathing pattern or smaller chest movements due to their impaired lungs. The outcomes of the prototype with real patients have not been tested and it might present additional issues.

Abnormal situations such as large inspirations are not correctly treated by the application and lead to errors. Apnea or hyperinflation episodes are not detected.

6.4 Feedback and game-based solutions.

The application was able to provide a valid feedback in most of the tests. As we know from the background chapter, feedback, if presented in a proper way, may end in better outcomes in a respiration rehabilitation program.

In addition, this feedback information can be used to develop game-based solutions. A game may improve rehabilitation by doing it more distracting and fun, motivating the patients to continue doing the exercises. In this case, the respiration signal can be used as input for a little game. For instance, a spaceship controlled by the respiration up and down in a screen which have to dodge meteorites to survive could be an option. BPM data may also be used as input for gaming.

7 Conclusion and future work

A prototype based on the Wiimote to acquire respiration signals has been developed and presented. Although the system is a proof of concept and a lot of improvement is needed until it becomes available to be used by real patients, during the evaluation it has been demonstrated that it is possible to acquire breathing signals with relative precision. The software developed was able to show user's breathing rate as feedback, despite the limitations that were uncovered in the tests. Therefore, the first research question is solved: the Wiimote's camera can be used to acquire useful data about the breathing for rehabilitation purposes.

The second goal was to find out the challenges that need to be solved to develop a Wiimote-based system that uses breathing as user interface. In chapter 3, the requirements to be met in order to implement the prototype successfully were presented. The most important ones are:

- Low cost.
- Non-invasive and comfortable system.
- Accurate enough for rehabilitation purposes.
- Provide feedback in real time.
- Lightweight reflective markers

In chapters 5 and 6, the limitations and problems of the system were showed and discussed.

7.1 Future work

The prototype developed may be improved in many ways. In this section, some of them are commented.

The low performance of the markers highlight them as the first thing that should be improved. Better materials must be pointed out in order to have higher reflectiveness from the passive markers. Active markers is another option that should be researched. Nowadays, the electronic components are so tiny that an active marker might be as lightweight as a passive one. An active marker would be composed of a LED, a resistor, a switch and a button-size battery. Performance of an active marker may be in all likelihood better than a passive one.

About wearability, the tight T-shirt showed to be the best approach. The two users that used this solution declared that it is more comfortable. The suitability of the implementation of a T-shirt with some reflective zones should be researched further on. It may be a better solution than the belt, more comfortable and, perhaps, more accurate.

The software is something that due to lack of time could not be fully researched to test a larger variety of use cases. The next step done to improve the application would be to implement an adaptive window in the frequency analysis. From the evaluation tests we know that some movements interfere with the respiration data because they have frequency components inside the analysis window used in the tests (0.1~1 Hertz). Since the respiration is a signal that varies very slow in time, instead of using a fixed window as in the tests, it could be a good idea to make it adaptive. For instance, once the respiration is detected, the window can be reduced to the respiration frequency ± 0.1 Hertz and adjusted every few seconds following the respiration frequency if a change occurs. Doing this, the impact of interferences due to movements would have been less critical.

The system was only evaluated with healthy users. Tests with COPD patients must be addressed to detect additional issues related to anomalous breathing patterns.

Detection of apnea and hyperinflation episodes might have been easy to implement. Apnea is when the user stops breathing, so it would be as easy as showing apnea warnings if the signal remains flat for a period of time. Hyperinflation, when the patient is keeping a growing residual amount of air in its lungs, might be detected if the mean of the distance measurements is raising for a while. Nevertheless, to detect properly hyperinflation it would be necessary to cope better with body movements.

The real challenging thing when it comes to respiration tracking through cameras is to avoid the limitation of body movements. The user has to be immobile to allow proper detection, and this requisite limits widely the potential usage of this solution. In this study, a couple of tests using a second Wiimote to detect user's movements towards the main Wiimote were done. The outcomes did not seem to be very promising, but it needs further research. Some studies commented in chapter 2 employed two Wiimotes to achieve a kind of stereo vision or 3D vision that showed to be very accurate. This technique could be a good approach to cope with body movements. Attaching another two markers to the user, not over the chest but somewhere else, as reference point it is likely that distance and position of the body can be estimated. Therefore, interferences due to movements may be partially avoided, allowing breathing detection even when the user is moving.

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Appendix 1: Project management

Some techniques have been used during the development of this thesis for decision making and improved control over the project management.

Shared documents

From the very beginning, Google Docs has been a very useful tool to share documents among all the collaborators. Online access to the latest versions of the documents permits to the supervisors to add comments at the same time the document is being written. Documents shared with this method comprise:

- **Project diary** with short comments on the most important achievements made every day, explanation of small issues and suggestions from the supervisors on certain aspects of the development.
- **Working time table** resuming the hours and days spent in every task (Figure a).
- **Drafts of the documentation**, including reviews, state of the art and the thesis itself.

Time control

Time spent on the thesis has been stored in a spreadsheet weekly. Hours spent have been divided into six possible classes:

- **Previous work.** It comprises the meetings and collection of information addressed before the topic of the thesis was decided.
- **State of the art.** All the work done searching for information and setting the background was classified under this category.
- **Requirements.** Time spent gathering the system requirements belongs to this category.
- **Design and development.** It comprises the system development efforts.
- **Testing and evaluation.** It is compounded of both tests with and without users and the analysis of the results.
- **Documentation.** Time spent to complete this document.

In Figure a, a graph resuming the time spent every week by category is shown. At the date of closing the project, the worked hours summed 733 hours in total.

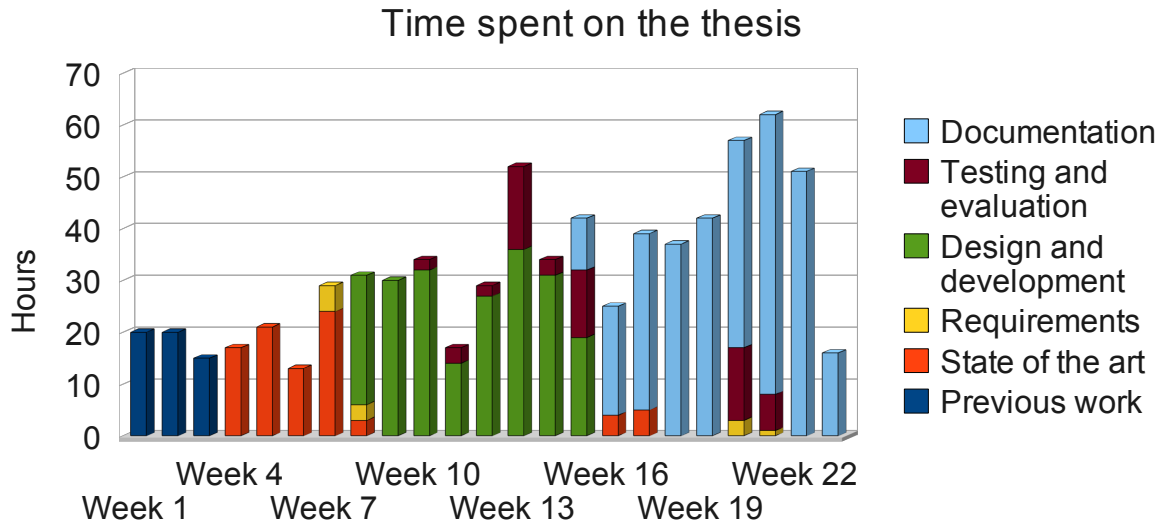


Figure a. Weekly time spent on the thesis.

Some milestones were established in order to manage time spending in every part of the project (Table b). These milestones were flexible, and some of them were changed when needed. The deadline to present this document was fixed in the middle of week 23 (1st of June).

Table b. Milestones

Description	Expected date	Accomplished
Study of the art	Week 8	Week 8
Elaboration of a proof of concept	Week 16	Week 15
System evaluation	Week 18	Week 21
Documentation	Week 22	Week 23

Internal meetings

Some meetings were arranged when every time a milestone was achieved.



Appendix 2: Consent form

Respiration tracking with the wiimote: Consent Form

You are invited to participate in a study aiming to prove the feasibility of using the wiimote (Wii remote controller) for respiration tracking. To validate the results achieved with the prototype developed, we need some volunteers for testing so we can gather some data and feedback. If you are willing to help, please read this form and feel free to ask any question before you agree to participate.

This study is part of the master thesis carried out by the student of the Polytechnic University of Valencia and the University of Tromsø Julián Guirao. It is supervised by Luis Fernandez Luque, Gustav Bellika and Vicente Traver

Background Information

Respiration exercises are an important part of the pulmonary rehabilitation in COPD (chronic obstructive pulmonary disease) patients. Furthermore, there is evidence that showing feedback about their respiration pattern helps them to improve their breathing skills. This study will test the feasibility of monitoring respiration using the wiimote's infrared camera and showing BPM (breaths per minute) as feedback.

Your participation

If you agree to participate, you will spend between 20 and 30 minutes completing all three tests explained here. In the beginning you will be asked to wear two or three metal markers (pieces of spoons) attached directly to a T-shirt or through a velcro belt made for that purpose. Then, you will carry out the three tests: in the first one you will be sit on a chair in front of the wiimote and in the second and third you will be on a static bicycle, before and after doing a little exercise on it (5 minutes) to modify a bit your breathing pattern. In all tests you will be asked to breathe normally during 3-4 minutes while pressing a button (wiimote's A button) in every respiration (once every time your lungs are full, finishing inspiration and starting expiration). Finally, a couple of questions about your feelings with the system will be asked to you.

Risks and Benefits of being in the Study

There are neither risks nor benefits associated to this study. No confidential data will be involved in this study. You will be asked for permission to take some photos of the system while testing. Your face will never appear in any of the photos. You can decline this permission at anytime during and after the test.

Compensation

There is not compensation.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify you. Research records will be stored securely and only researchers will have access to the records. You can request your records or photos to be deleted.

Voluntary Nature of the Study:

Participation in this study is voluntary.

Contacts and Questions:

This study is conducted by the student Julián Guirao and supervised by Luis Fernandez, Gustav Bellika and Vicente Traver. If you have questions, you can contact Julián at juguia@teleco.upv.es, telephone number 61793794.

You will be given a copy of this information to keep for your records.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature: _____

Date: _____

Signature of Investigator: _____

Date: _____

Appendix 3: Evaluation scripts (Octave)

```
function [MaxERR,RMSERR] = show_graph (offset_beggining, offset_end)

%Los parametros de entrada son los puntos a
%eliminar al principio y al final del vector

load -ascii z.wii
load -ascii time.wii
load -ascii dis.wii
load -ascii BPM_GUI
load -ascii BPM_TEST
load -ascii BPM_ERR

dis=dis(offset_beggining:end-offset_end);
z=z(offset_beggining:end-offset_end);
time=time(offset_beggining:end-offset_end);
BPM_GUI=BPM_GUI(offset_beggining:end-offset_end);

BPM_TEST = BPM_TEST - time(1);
time = time - time(1);

time=time/1000;
BPM_TEST = BPM_TEST/1000;

dummy=ones(1,length(BPM_TEST));
dummy=dummy*dis(1);

n=6;

for i = 1 : (length(BPM_TEST)-n)
    timeBPM=BPM_TEST(i+n)-BPM_TEST(i);
    timeBPM=60/timeBPM;
    newBPM=timeBPM*(n);
    BPM(i)=newBPM;
endfor

subplot(2,1,1)
plot(time,dis,BPM_TEST,dummy,'o')
grid("on")
title("main-markers distance and BPM")

subplot(2,1,2)
plot(time,BPM_GUI,BPM_TEST((n+1):end),BPM,'o')
grid("on")

xlabel("Seconds")
print('graph.jpg', '-color', '-djpg')

MaxERR(1)=max(abs(BPM-BPM_ERR((n+1):end)));
MaxERR(2)=100*MaxERR(1)/mean(BPM);
RMSERR(1)=sqrt(sum( (BPM-BPM_ERR((n+1):end)).^2 ) / (length(BPM)));
RMSERR(2)=100*RMSERR(1)/mean(BPM);
endfunction
```