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Respiration Tracking Using the Wii Remote Game-Controller

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Abstract. Respiration exercises are an important part in the pulmonary rehabilitation of COPD (chronic obstructive pulmonary disease) patients. Furthermore, previous research has demonstrated that showing respiration pattern helps the patients to improve their breathing skills. We have developed a low cost and non-invasive prototype based on the Wii remote game controller infrared camera to provide BPM (breaths per minute) measurement as feedback. It can also be a comfortable solution without wires, batteries or any kind of electronics but just wearing passive markers. The lab evaluation with 7 healthy individuals showed that this approach is feasible when users are resting of their exercise. The BPM monitored during the tests presented less than 15% of maximum error and the RMSE (root mean square error) was lower than 6% in all the tests. Further research is needed to evaluate and adapt the system for COPD patients. In addition, more work is needed to develop applications that can be built to motivate and guide the users.

Keywords. COPD, Wiimote, camera, pulmonary rehabilitation.

1. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a common cause of death. According to the World Health Organization, there are 210 million people with COPD and it accounts for the 5% of all world deaths in 2005 [1, 2]. COPD is defined as a chronic airflow obstruction that can lead to reduced breathing skills and low exercise capacity [3]. Pulmonary rehabilitation is a key aspect of COPD treatment where exercise training and breathing techniques are essential aspects [4, 5].

There are some barriers within the pulmonary rehabilitation, such as lack of motivation and transportation problems [6]. However, a study by Collins et al [7] showed that giving feedback to the patients about how they are breathing has positive effects. If feedback could be combined with game-based rehabilitation, the outcome could be improved based on increased patient motivation [8].

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In our study we used a prototype based on the Wii remote controller (aka Wiimote) to acquire and process the user's breathing signal and visualize the information on a screen. Our approach uses the infrared camera inside the Wiimote, capable of tracking up to four light sources at the same time. Using those infrared cameras in the health domain has already been tested [9]. The Wiimore is a low cost device (its price is below 40€) that can easily be installed in the home of the patient as part of a telemedicine system, or integrated with a computer-game applications for improving motivation [10]. The aim of this project was to implement a prototype to evaluate the feasibility of using the Wiimote's camera for tracking tiny movements such as breathing chest movements and, therefore, to test the possibility of using the Wiimote within respiration rehabilitation. If such approach is feasible, the Wiimote could be used as the user interface for applications aiming at providing respiratory feedback to patients with pulmonary diseases.

2. Methodology

The developed prototype comprised of (a) hardware elements to capture the breathing signal and (b) software to process the data and provide feedback to users.

2.1. Architecture

The designed prototype includes following parts (Figure 1):

- Array of 30 infrared LEDs (light emission diodes) as light source.
- Belt with attached markers. These markers were round reflecting metal pieces of 3 cm in diameter and placed approximately 10 cm of distance between them. These markers were made by adapting ice-cream spoons.
- Wiimote connected to a PC using Bluetooth connection.
- Computer to receive the data and show feedback.

The system works as follows: light produced by the LEDs is reflected in the markers and captured in the Wiimote's camera. Therefore the camera is able to track markers on the user's chest and send the data to the computer. As they are moving according to the breathing, the computer processes these variations obtaining a signal corresponding to the breathing pattern

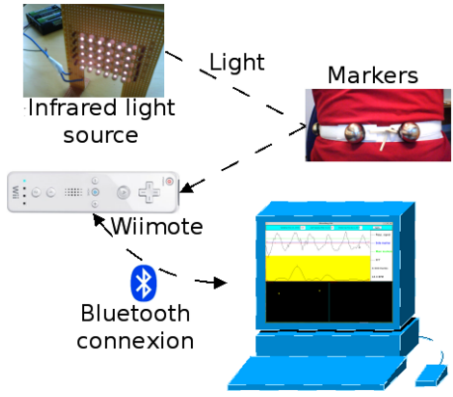

Figure 1. Respiration tracking system

2.2. Software

A desktop Java application was developed for calculations and signal processing. This application uses two open source Bluetooth libraries: Wiiuse and WiiuseJ. The first of

them establishes the communication link with the Wiimote to receive the raw data. WiiuseJ is written in Java and prepares the raw data from the Wiimote.

The Wiimote, once connected to the computer over the Bluetooth connection, automatically starts to send the raw data. This data is the preprocessed image of the camera, which consists of up to four dots corresponding to detected light sources. The developed application processes the data and visualizes: 1) the breathing signal, extracted from distance between the markers (detected as light sources), 2) a frequency analysis through Fast Fourier Transforms and 3) the "breaths per minute" (BPM) value from the last 20 secs, among some other things. All data and information was saved to files for later analysis.

2.3. Evaluation Protocol

During the evaluation, 7 volunteers, 3 women and 4 men, without breathing problems completed some tests. They were asked to wear a belt with markers on the chest in a tight but comfortable way. The exact position was over the abdomen because this is the place with the maximum displacement due to respiration. Every volunteer made 3 tests of 3 minutes each: sitting on a chair, sitting on a stationary bicycle before doing exercise and after doing 5 minutes of exercise. The Wiimote and the light source were placed around 25 cm away from the body.

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, saving the data to validate systems' outcomes. Finally, data provided by the user and calculated by the system was compared to get the results.

3. Results

Octave[2] was the chosen tool to address the analysis of the information gathered. Every test was classified in one of the following groups:

- Normal: no errors were detected during the test
- User induced errors: the user made a mistake pressing the button so the control signal is not valid.
- System error: the system failed and the data shown was wrong.

From the 21 tests realized (3 each volunteer), 12 of them were classified as normal. Only two of them had a maximum error above 10% (10,17% and 14,04%). The RMSE (root squared mean error), which is a good estimator of precision, was higher than 5% (5,8% and 5,24%) in only two of these tests. It means that difference between both signals was quite low in all these tests.

The rest of the tests were classified as user induced errors (3 of them) and system error (6 of them). The errors produced during the evaluation tests were consequence of the impossibility of differentiating chest movements due to respiration from body movements or insufficient light being reflected by the markers.

[2] More information available from: http://www.gnu.org/software/octave/

4. Discussion

The Wii video console has been introduced with success within the rehabilitation field in diseases such as stroke or cerebral paralysis. The COPD patients have also started to play with it to reduce the burden of their symptoms [11, 12]. However, using the Wii remote as respiration sensor, as proposed in this paper, has been never tested. The proposed system acquires the data and provides real-time feedback.

The implemented prototype records breathing data and provides feedback to the patient about how slow or fast the respiration is. It is a non-invasive, low cost system with the following components: 1) a standard computer, 2) a US$40 Wiimote, 3) a US$5 belt with markers 4) and a illuminator about $30~40. It is also a comfortable solution without wires, as the patient wears no batteries or any kind of electronics. The patient only wears a Velcro belt with some passive markers.

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 system and its limitations. BPM calculated from this signal was compared to a test signal obtained from the user. Among the tests without any incidents the RMSE was lower than 6% showing a relatively high precision. Maximum error was lower than 15%.

As a conclusion it is fair to say that the Wiimote is able to work as a breathing monitor device as a non-invasive, comfortable and low cost alternative.

4.1. Limitations

This project is a preliminary study to test the feasibility of acquiring breathing signals with the Wiimote's infrared camera. There are still many limitations that need to be addressed in order to create applications that are adapted to the needs of patients with COPD. In addition, the accuracy of the new prototype needs to be evaluated using a certified respiratory sensor and not just relay on subjects input.

Some of the errors produced during the evaluation tests were consequence of the impossibility of differentiating respiratory chest movements from body movements. In the literature reviewed related to acquire breathing through visual devices, and also in this case, a prerequisite is that the user must be immobile [10]. Detecting respiration with visual devices while exercising, cycling on the stationary bike or walking on a treadmill for example, is something that remains 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 limitation was the material used to develop the reflectors, it did not have the appropriate reflective qualities. These reflectors were modified ice-cream spoons and not expensive reflective devices.

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.

4.2. Future Work

At the end of the preliminary study, the conclusion is that the Wiimote is capable of acquire breathing signals. Therefore the next step is to develop the system further on to reach its potential and to find out the real limitations of this approach.

The low performance of the markers highlights them as the first thing that should be improved. Better materials must be found in order to have higher reflectiveness from the passive markers. Active markers are another option that should be researched. It would be composed of a LED, a resistor, a switch and a button-size battery, being as lightweight as a passive one. Performance of an active marker seems very likely to outperform passive ones.

A larger number of trials with COPD patients is also a milestone to achieve.The real challenge would be to avoid the limitation of body movements. Some studies employed two Wiimotes to achieve a kind of stereo vision or 3D vision that showed to be very accurate [13, 14]. It could be a good approach to avoid this problem.

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