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Ángel Serrano Alarcón and Andrei Boiko

Non-Invasive Cardiorespiration Monitoring Using Force Resistive Sensor

Akhmadbek Asadov[1] [0000-0003-3844-8866], Ralf Seepold[1] [0000-0002-5192-2537], Natividad Martínez Madrid[2] [0000-0003-1965-9481] and Juan Antonio Ortega[3] [0000-0001-9095-7241]

Abstract. ***Sleep analysis using a Polysomnography system is difficult and expensive. That is why we suggest a non-invasive and unobtrusive measurement. Very few people want the cables or devices attached to their bodies during sleep. The proposed approach is to implement a monitoring system, so the subject is not bothered. As a result, the idea is a non-invasive monitoring system based on detecting pressure distribution. This system should be able to measure the pressure differences that occur during a single heartbeat and during breathing through the mattress. The system consists of two blocks signal acquisition and signal processing. This whole technology should be economical to be affordable enough for every user. As a result, preprocessed data is obtained for further detailed analysis using different filters for heartbeat and respiration detection. In the initial stage of filtration, Butterworth filters are used.***

Keywords -- FSR sensors, Polysomnography (PSG), signal processing, Butterworth filter, heart rate, respiratory rate.

I. Introduction

Humans spend almost a third part of life sleeping. Sleep is essential in recovering mental and physical health [1, 2]. Getting enough quality sleep is necessary for a person's mental health, physiological well-being, quality of life, and safety. Sleep disorders, medical conditions, and mental health can result from poor sleep quality. Sleep issues affect people of all ages and genders [3].

A Polysomnography (PSG) will document the sleep process in professional medical environments. This technique is used in sleep laboratories where patients are monitored during their sleep. PSG is the primary method to identify possible sleep disorders. Various physiological parameters are recorded: Electro-encephalography (EEG), Electro-oculography (EOG), Electro-myography (EMG), Electrocardiography (ECG), Pulse oximetry, Oral and nasal airflow, Respiration effort [4]. Measuring all of these signals requires being in the medical lab and in the presence of sleep experts, which can lead to patient discomfort.

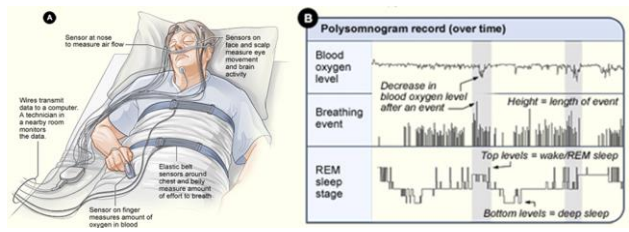

Fig. 1. A) Typical polysomnography measurement B) Current sleep analysis system used in Hospitals [5].

PSG is the standard monitoring method to determine sleep stages and possible sleep disorders [6]. Various information is collected with high accuracy and resolution. However, subjects have to sleep in an unfamiliar environment (sleep lab) and are strictly connected to sensors, which could lead to uncomfortable sleeping behavior compared to regular sleep [7]. Despite the apparent feasibility of the PSG to provide real-time and accurate information about sleep disorders, it introduces some limitations, i.e., complexity, invasiveness, intrusiveness, physical limitation, time-consuming, high cost, and lack of privacy. Furthermore, not all gathered information by PSG are necessary to detect anomalies in sleeping behavior. Therefore, alternative approaches are of high interest [8].

In the proposed approach, a resistive pressure sensor was used to detect the pressure under the mattress. FSRs (Interlink Electronics, Camarillo, California, United States) are sensors that detect physical pressure, squeezing, and weight, which operate on the principle of a variable resistor whose resistance is directly proportional to the applied force. These sensors are easy to set up and are excellent for measuring pressure.

The idea is to do experiments comparing data from the PSG system and data from the FSR sensors with different distributions under the mattress and attempt to answer the question: what is the optimal distribution of the sensors for the heart rate and breathing rate measurement?

II. Methods

The proposed system consists of two blocks of signal

[1] HTWG Konstanz, Alfred-Wachtel-Str. 8, 78462 Konstanz, Germany
{akhmadbek.asadov,ralf.seepold}@htwg-konstanz.de
[2] Reutlingen University, Alteburgstr. 150, 72762 Reutlingen, Germany
natividad.martinez@reutlingen-university.de
[3] University of Seville, San Fernando 4, 41004 Sevilla, Spain
jortega@us.es

acquisition and signal processing, verified with an experimental design. All three blocks are presented in the following subsections.

A. *Signal acquisition*

The system includes pressure sensors installed under a bed mattress and a computational unit. The choice of pressure sensors is essential for unobtrusive data measurement. According to [9], pressure sensors have been chosen, particularly the 406 Square Force Sensing Resistor (FSR), to integrate into the system. The sensor's shape is well-suited for installing the bed structure. Moreover, they preserve low-cost and high sensitivity (Figure 2).

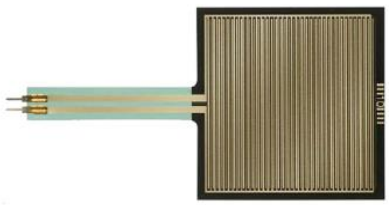

Fig. 2. FSR 406 Resistive pressure sensor.

We aim to identify the efficient sensor distributions and the most contributing sensors in different sleep positions. Several ways of sensor layout under the bed mattress have been investigated earlier [10]. Thus, it is necessary to define the sensor arrangement. Considering preliminary tests and studies, we have come up with the arrangement set of four sensors in a line on the chest level, as it is proven to be more efficient in detecting body movement, which might represent the respiratory and cardiac activities on this line [11].

It is important to note that one line of sensors distributions with a similar arrangement designed, such that this line can be located either at chest level or stomach level, as the belly and thorax exert the most significant pressure on the plane [11]. However, as there are two areas where a person can exert the most pressure during breathing movements, we decided to choose five distributions of sensors to investigate different distributions and study the sensors' contributions to each respiratory and cardiac activity independently (see Figure 3).

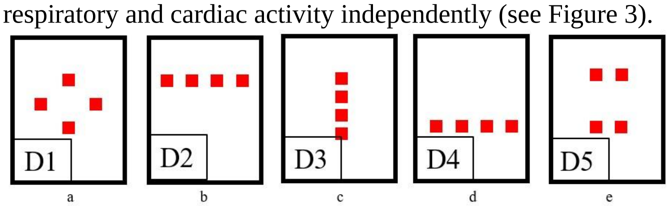

Fig. 3. Distribution of FSR sensors.

The sensors should be connected to a computational unit that will convert the analog signal to digital. Raspberry Pi 4B has been chosen as a computational unit for the system concept because it fulfills the requirements such as low cost, a powerful embedded system, is capable of real-time data acquisition and processing, and supports a wide range of data communication protocols. This is due to the availability of video output, a high processor clock speed, and sufficient RAM. Moreover, Raspberry Pi 4B has several advantages:

- It is small in size, which allows it to be located under the bed.
- It is decisive for signal processing visualization and transmission.

A PSG system with two-electrodes ECG and a Respiratory Inductive Plethysmography belt (from SOMNOmedics GmbH, Randersacker, Germany) for thorax and abdomen signal recording was used as reference data. The ECG, respiration rate, and FSR sensors were recorded with a frequency of 256Hz and 32Hz, and 78Hz, respectively. The FSR sensors and system were deployed under the bed frame. The data collected from FSR sensors were compared with the reference standard sensors.

B. *Experiment design*

During the experiment, four subjects participated in the study. For each subject, four positions (prone, right side, supine and left side) are recorded for 80 seconds in each position. FSR distributed sensors with four sensors and five distributions (shown in figure 2).

The participants were asked to put on the PSG system before lying on the bed, under which the sensors are pre-installed in different distributions, in a prone position. From each position and recording, 10 seconds of beginning and end are cut. It is important for the cleanliness of the data recording in order to ensure removing (reducing) the effect of an artifact. It was also necessary to change position every 80 seconds to the right, supine, and left sides.

C. *Signal processing*

In order to process the data acquired from the FSR and reference sensors, the acquisition, preprocessing, and comparison took place as the following steps:

- Time synchronization of data received from PSG and FSR systems
- Four windows corresponding to the position of the patient on the bed were highlighted (supine, prone, left and right sides)

The analysis of the pre-processed data was performed. For this purpose, second-order Butterworth filters were used for the data from the FSR sensors first: Low-Pass Filter with a cut-off frequency of 0.3 Hz for the respiratory data and Band-Pass Filter: 0.7-5 Hz (low cut and high cut frequencies) for the cardiac analysis.

III. Results and Discussion

We have conducted a preliminary study to process the data and improve our understanding of the FSR sensor's functionality under different positions. We performed the preprocessing, including the offset removal and data synchronization, to perform the next study steps applying different filters to detect heart and respiratory signals. More specifically, time synchronization of two-time series data, separation of four windows of 60 seconds duration, and comparison of recording frequencies. Also, an attempt to apply second-order Butterworth filters to data from FSR sensors.

As this study is at an early stage, it is necessary to analyze the signals against a gold standard to determine the sensors' location to achieve the most accurate results. An example of data visualization is shown in Figure 4. It shows the data from one subject, from the first position (on the chest), and for 10 seconds.

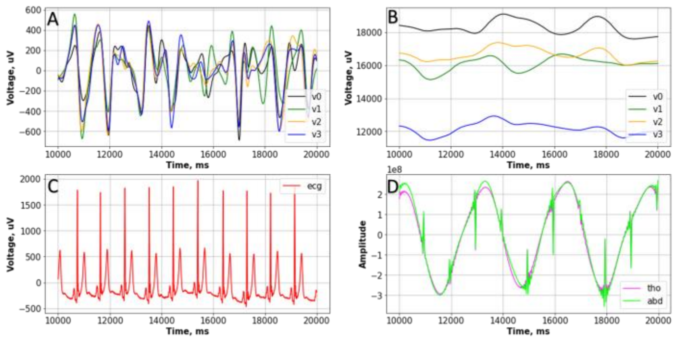

Fig. 4. Data visualization: A) band-pass filter applied to FSR data (vi - sensor); B) low-pass filter applied to FSR data (vi - sensor); C) data from the PSG system for the ECG; D) data from the PSG system for the respiratory signals (thorax and abdomen).

We compared the number of peaks when using the band-pass filter to detect heartbeat (A) with the number of R peaks from the ECG signal (C), it is possible to monitor heart rate. The same can be seen in graphs B and D and it is then possible to detect respiratory rate.

IV. Conclusion and Future Work

As part of this work, it has become possible to monitor a person's heartbeat and breathing through FSR sensors deployed under a mattress. Firstly, the data was obtained from raw data for further analysis. Secondly, compare the number of peaks received from the filtered data from the FSR sensors with the reference data. In the future, however, there will still be areas where further improvements are possible. One possible way to use discrete wavelet transform for spectral analysis of signals for detecting heart rate. So it is possible to evaluate and analyze the data even more precisely. Another possible direction of future work is to use many combinations of sensor locations under the bed. Perhaps a different configuration can be found to allow a more accurate heart and breathing rate estimation.

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