NON-INVASIVE ANALYSIS OF PHYSIOLOGICAL SIGNALS (NAPS): A VIBRATION SENSOR THAT PASSIVELY DETECTS HEART AND RESPIRATION RATES AS PART OF A SENSOR SUITE FOR MEDICAL MONITORING

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INTRODUCTION

To date, there are few systems that provide a low-cost, passive way of acquiring important sleep monitoring data that requires no additional action from the subject outside of their normal daily routine [1]. There is, however, a great need for research in this area because of the large number of people affected by sleep related conditions who could benefit from knowing more about their sleep habits. About 40% of all American adults suffer from some kind of sleep disorder while about 70 million Americans are chronically sleep deprived [2]. Many feel that little substantial improvement can be made to correct their problems since 70% of sleep sufferers don't discuss the problem with their physician [2]. Objective sleep research has existed since 1922 when Szymansky ran the first such study [3].

The current gold standard for sleep research is polysomnography (PSG), which involves at least the recording of an electroencephalogram (EEG), a measurement of brain waves, an electrooculogram (EOG), a measurement of muscle activity in the eye area, and an electromyogram (EMG), a measurement of muscle activity in specific areas such as the arm or leg [4]. These electrode hook-ups prove valuable to assess sleep quality, but their attachment to the patient's body affects sleep.

In an effort to provide a less obtrusive way to study sleep on a longer-term basis, actigraphs have been developed. These devices can be attached to any of the limbs to provide movement data based on the same principles behind accelerometers. They are also used in activity studies [5] and can provide 24 hour monitoring of the subject. This type of sensor, however, has its limitations in acquiring data that can be interpreted definitively to provide a good assessment of sleep quality. Researchers are dependent on patient journals to help correlate the data recorded on the actigraph and it is hard to distinguish different events that can occur throughout the night [3]. In addition, problems researchers have interpreting results from actigraphs are a direct result of the one-dimensional nature of the data recorded [4].

It is believed that valid sleep assessments can be made through the analysis of physiological characteristics such as body temperature, sleeping position and movement, breathing rate and heart rate. This approach uses an array of passive sensors that takes advantage of these physiological characteristics to develop a less intrusive method to study sleep. In addition to providing quantitative assessments of sleep quality, this proposed sensor suite could also be used in other applications such as deployment in easy chairs, intensive care unit hospital beds and pediatric applications.

METHOD

Materials

One of the goals of designing this patent pending sensor suite used to monitor physiological signals was to incorporate as much "off-the-shelf" hardware as possible to create a system that could be provided at low cost compared to existing systems that acquire similar information. With this goal in mind, the basic design is centered on a sensitive vibration sensor that detects the pulsing generated through the blood vessels as well as body movement related to respiration. This particular sensor consisted of an ultrasensitive piezoelectric transducer that has very good low-frequency response characteristics, which allows the sensor to provide heart rate and breathing information. The sensor is used in conjunction with an air-filled bladder to pickup the signal.

Though the raw output provides little information, signal-processing techniques that involve using a low pass anti-aliasing filter, an instrumentation amplifier, band pass filters, and non-inverting amplifiers separated the two signals of interest.

Typical output used in collecting data points for each of the subjects is shown in figure 1. The top waveform represents the output of the signal through the pulse filter while the bottom waveform represents the output of the signal through the breathing rate filter.

Other aspects of the sensor suite have not yet been fully integrated into the system. These sensors will provide multi-dimensional data that help to give a clearer view of the person's characteristics and will be implemented into the next phase of the design. The other types of sensors that are part of this suite include momentary contact switches, temperature sensors, humidity sensors and carbon dioxide sensors.

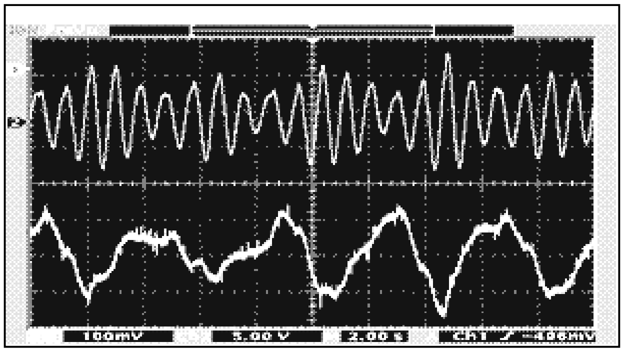

Figure 1. The outputs of the two band-pass filters. The top waveform represents the heart rate of the subject while the bottom waveform shows the breathing rate of the subject.

Procedure

During initial testing, only data collected from the vibration sensor was analyzed to determine if the sensor could provide reliable data when tested on different subjects. Eleven subjects were tested where the sensor was placed in two different locations to record pulse and respiration data, resulting in 22 points to test the reliability of the pulse and breathing rate recording. A pulse oximeter, with an accuracy of (±1%) [6], was used to obtain a clinically accepted pulse reading while the subject was asked to count their breaths during the trial period.

During the first portion of the test, the subject had the vibration sensor pad placed underneath their calf while they were lying on their back on a bed. After it was certain any movement artifacts were no longer present in the signal, an oscilloscope was used to capture 20 seconds of data. This data was then normalized to 1 minute for analysis purposes. The same test was done with the subject lying on their stomach on the bed and the sensor placed under their chest. For each test run, three measurements were taken from the pulse oximeter and these were then averaged and compared to the actual number recorded by the vibration sensor.

RESULTS

The average heart rate as recorded by the pulse oximeter was used as the standard measurement for comparison to the actual results from the vibration sensor. This data displayed in figures 2 and 3 show the results from both locations tested. The lines surrounding the data represent the ±5% deviation from the standard measurement. It is clear from the figures that the pulse information inferred from the recorded data was within ±5% error of the pulse oximeter's heart rate reading.

Similarly, the breaths counted by the subject corresponded exactly (data not shown) with the number of peaks in the breathing waveform recorded by the sensor. Since the person was counting their breaths, the number was rounded to the nearest half of a breath.

DISCUSSION

In comparing the vibration sensor results with the pulse oximeter readings, the data shows that the sensor works over a wide range of pulse readings varying from as low as 49 to as high as 84. All but one of the 22 data points is outside of 5% range denoted on the graph and over 68% of the measurements (15 of 22) are under 2% error. This level of accuracy illustrates that 60-second samples are not necessary and that the sensor could be accurate enough to monitor heart rate variability based on small sample windows.

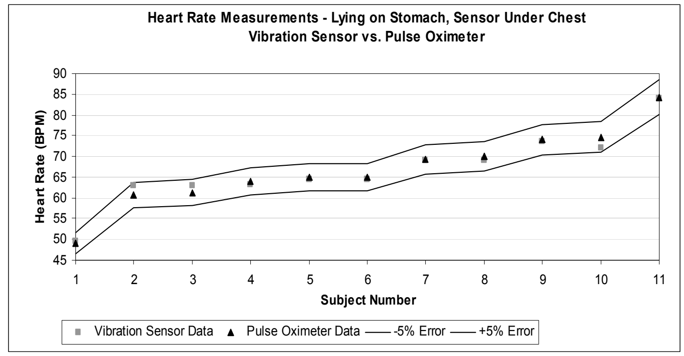

Figure 2. Heart rates recorded from both the pulse oximeter and the vibration sensor, under chest.

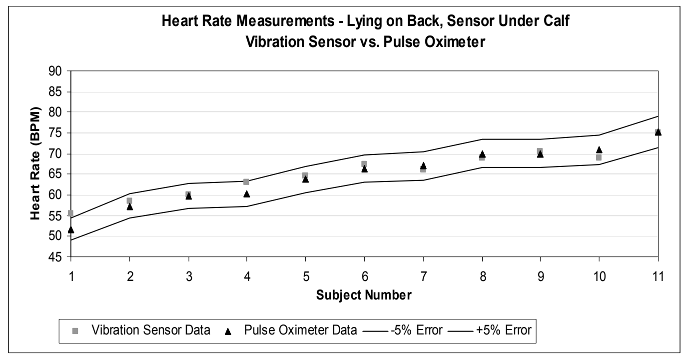

Figure 3. Heart rates recorded from both the pulse oximeter and the vibration sensor, under calf.

For the breathing rate analysis, the sensor data did not vary from the counted breaths of each individual and showed clear peaks. As can be seen from the illustration back in figure 1, one can see why the data for the respiration did not vary as it was easy to denote breaths rounded to the nearest half of a breath. If more precise measures were made, there undoubtedly would be some variability, but little would be present.

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