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Non-invasive sleep analysis with intelligent sensors

Maksym Gaiduk, Ralf Seepold
Ubiquitous Computing Laboratory
HTWG Konstanz
Konstanz, Germany
makSYM.gaiduk@htwg-konstanz.de, ralf.seepold@htwg-konstanz.de

Simone Orcioni, Massimo Conti
Dipartimento di Ingegneria dell’Informazione
Università Politecnica delle Marche
Ancona, Italy
s.orcioni@staff.univpm.it, m.conti@univpm.it

Natividad Martinez Madrid
Internet of Things Laboratory
Reutlingen University
Reutlingen, Germany
natividad.martinez@reutlingen-university.de

Abstract — Sleep study can be used for detection of sleep quality and in general bed behaviors. These results can helpful for regulating sleep and recognizing different sleeping disorders of human. In comparison to the leading standard measuring system, which is Polysomnography (PSG), the system proposed in this work is a non-invasive sleep monitoring device. For continuous analysis or home use, the PSG or wearable Actigraphy devices tends to be uncomfortable. Besides, these methods not only decrease practicability due to the process of having to put them on, but they are also very expensive. The system proposed in this paper classifies respiration and body movement with only one type of sensor and also in a noninvasive way. The sensor used is a pressure sensor. This sensor is low cost and can be used for commercial proposes. The system was tested by carrying out an experiment that recorded the sleep process of a subject. These recordings showed excellent results in the classification of breathing rate and body movements.

Keywords — sleep study; pressure sensor; sleep; signal processing.

I. INTRODUCTION

The average human spends about one third of his or her life sleeping [1]. Depending on how the sleep designated hours are expended, our daily routine can be either positively or negatively influenced. Studies show that the recommended sleep duration varies based on age group. The recommended sleep duration for an infant lies between fourteen to seventeen hours, whereas that of an adult lies between seven to nine hours, being about half the recommended sleep hours for an infant. However, the amount of sleep alone does not assure the possibility of a good quality rest [2]. In order to accurately evaluate the quality of sleep, it is a necessity to identify the sleep stages and their durations.

As a result thereof, sleep can be categorized into stages, which can be ascertained by the use of various electrophysiological signal recorded during sleep. The electrophysiological signals can be for example Electroencephalography (EEG), Electromyography (EMG) and Electrooculography (EOG), which enable the brain and muscle activity as well as the eye movements to be captured severally [3]. The recorded signals follow the method determined by Rechtschaffen and Kales (R-K) [4] to identify which one of the six sleep stage the body is in.

Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM) are the two main stages of sleep. 25% of the sleep occurs in the REM stage, while the remaining 75% occur in the NREM stage [5]. REM, also known as the dream stage, is the stage where the muscles are shut down with the exception of the eye muscles, with the intention of preventing the physical manifestation of activities or movements being executed in the dream. The eye muscles during this phase are engaged in random movements under the lids, thus the name [6]. NREM comprises of four stages of sleep. The first NREM stage, known also as light sleep, is regarded as the transition between being awake and sleep. In other words, it entails the process of falling asleep. The person in this stage of sleep is still a bit conscious of his or her surrounding and can easily be awakened by sounds. This phase usually lasts between a period of 5-10 minutes [7]. When the second NREM stage is reached, the subject is really sleeping. The person not only becomes less conscious of his or her surrounding, but also breathing and heart rate become more regular and the body temperature drops. People spend approximately 50 percent of their total sleep in this stage [5]. Last but not least are the third and fourth sleep stages. The N3-4 is also called deep sleep. Starting in N3 the delta waves or extremely slow waves appear to be occurring in the NREM stage the body is in.

Having a good night of sleep is important. Lifestyle as well as age influences our sleep patterns [12]. Furthermore, understanding a person's sleep behavior can significantly improve and change the quality of life. Nowadays there are many sleep laboratories where sleep can be analyzed with help of electrophysiological signals. Unfortunately, it is not possible to simulate the sleep environment in such a way that patients feel totally at home. This makes it therefore even more difficult to obtain valid results, that are high in accuracy. The aim of this project is to find an efficient way to collect information.
about movement of a patient while he sleeps without any physical impairments such as wearable sensors. This information should aid the analysis of the quality of sleep.

II. STATE OF THE ART

In order to detect the sleep phase, different electrophysiological signals have been recorded during sleep. EEG, EOG and EMG are examples of electrophysiological signals that capture the brain and muscle activity. The conventional R-K method obtains data through the brain wave polygraph. This is a commonly used method that submits the subject under stress, thereby leading to the subject encountering even more difficulty in falling asleep. Therefore, a low-cost home diagnostic system that can be comfortable, practical, non-invasive, automatic and ensures reliable results is likely to be advantageous [13]. Not only respiration and heart rate, but also body movements are important in determining sleep behavior [14]. Besides that, monitoring body movement during sleep can aid the detection of apnea and myoclonic [15].

Polysomnography (PSG) [16] is widely used for measuring sleep patterns. PSG includes data such as EEG, that collects the brain activity. Electrocardiography (ECG) is a method that recognizes and measures the small electrical differences caused by the heart muscle on the skin, which results in the electrical activity of the heart over time. Whereas Electrooculography (EOG) recognizes and measures the standing potential that exists between the back and the front of the human eye. These measurements permit the determination of the sleep stage and the behavior of the eyes like REM and NREM. Muscle activity can be recorded through Electromyogram (EMG).

Apart from PSG, there are other methods used in monitoring sleep. Methods like actigraphy involve the use of time based worn motion sensors, that measure the body motion [18]. The normal actigraphy method entails that the data is read after a time period on a computer. New studies have shown a new way to work with wearable devices and read real time data [19]. The demand for the continuous wearing of the devices makes the patient uncomfortable, resulting in the practice of these methods being difficult for long term use. The demand for the continuous wearing of the devices makes the patient uncomfortable, resulting in the practice of these methods being difficult for long term use. Not only actigraphy but also PSG possesses some complex procedure. They are in general not long term monitoring devices and can only be put into service in designated environments like sleep laboratories. It also remains uncertain if the patient exhibits the same sleep pattern as exhibited in the laboratory while asleep at home. Combination of methods are also found in several research papers. A good example is the combination of actigraphy and respiratory data [20]. The newest sleep monitoring methods in comparison to PSG cannot provide all data as described by R-K Method, but provide enough to classify the sleep stages and diagnose sleeping disorders.

III. SYSTEM MODEL

Because of knowing that the system is used to detect movements in order to support sleep analysis, the system does not present a hazard to human health. Besides there is no discomfort, inconvenience, molestation and disturbance incurred by the usage of this system. No skin breakage, no contact with mucosa or any internal body cavity beyond a natural or artificial body orifice. Listed above characteristics are some of those that characterize the definition of a non-invasive system [21].

The bed is part of the system. The bed consists of a mattress, bed frame, a slatted frame. The bed frame has an open structure in the test phase, so that changing the sensors and checking the system does not prove any difficulty.

The sensor used to detect the movement of the body is an inexpensive rugged force sensor. Besides this sensor is flat, flexible and the force range covers the range pressure of the lying body. Moreover, the sensor is capable of detecting the respiration movements. An array containing points of pressure detection is built with the sensors. The sensors are a part of the system and its only duty is to receive the data resulting from the body, as well as the respiratory movement. For this reason, a peripheral component is connected to each sensor so that the data can be read and sent to the main component. To control and synchronize the communication between the main component and the peripheral components, a bidirectional communication system is needed. This bidirectional communication ensures that the main component can send a message to the peripheral components requesting data. This data includes import information like physical position and sensor value. In addition, the peripheral component can send the information to the main component once requested. Furthermore, the sensor has as an already described interface that is adequate for qualitative force. For this reason, the peripheral component needs an analog input channel, so that the sensor value can be read. If some problem exists with the peripheral component, it should be able to send a signal or be able to draw attention somehow.

The last component to be described is the main component of the system. This component has the task of controlling the system, synchronizing the sensor values, saving the data and sending the data to be analyzed. The system proposed in this paper is an open embedded system. The main component has an integrated system with a microelectronic control used for performing complex tasks, but does not have a user interface. This is the primary definition of the main component. The main component is an open embedded system containing at least a microcontroller with 32-bit and multicore systems that permits the execution of more complex tasks.

Figure 1 shows the overview of the system. It also shows the concept of the layout described in this chapter. This figure is important because it gives an idea what the system will look like. The image clearly shows where the sensors are positioned as well as the position of the main components. Moreover, the peripheral component and the communication channel are only designed for demonstration purposes. Their functions are described in this chapter and the real implementation will follow these instructions and not the picture. The communication channel is demonstrated with 1-wire communication, but as long as the implementation follows the demand written in this chapter, a wireless communication as well as Bluetooth can also be into service.
For the evaluating of system work results, experiment with sleep recording of a real person was planned and executed in line with this project. The system was fully mounted, including all components, presented on the Figure 1.

The test was done in the Ubiquitous Computing Laboratory. The candidate for the sleep study is a 31-year-old male. The candidate sleeps between 6-8 hours at night and takes a nap of about 20 min in the afternoon. This nap was recorded in order to be analyzed. While the candidate sleeps, he hasn’t the habit of moving, which facilitated the analysis for breathing. Despite the fact that he carries out very little movement during sleep, at least three movements can be identified in the Figure 2 below. The first movement happened as he fell asleep. Between 15:44 and 15:45 the candidate scratched his nose. This shows that even a small gesture such as the raising the arms can be identified. The second movement is a very subtle movement, which was the moment he woke up between 16:59 and 16:00, the third movement shows the time the candidate got out of bed. Compared to the first and second movements where the body does not get up from bed, the last movement showed radical differences in value.

For collecting of significant amount of data, further experiments with several persons has been planned and will be executed in future.

Following it is possible to get an overview of recognition results, got by executing the first experiment with one test person.

IV. RESULTS

The results of work of the proposed in this paper sensor grid for pressure and movement detection showed that different parameters for sleep phase analysis can be measured. For preparing this paper in addition to other mentioned papers some content from [17] has been used. In addition to that, it proved to be a system that neither come in contact with the
subject nor initiates any form of discomfort during sleep. It was demonstrated that the FSR sensor is very useful in obtaining body movements and respiration signals. This result indicates that the system is well suited for supporting sleep study by providing data concerning the following activities carried out during sleep: respiration rate and body movements. The integration of the sensors under the mattress gave a new perspective on how a system is implemented for sleep analysis. Sleep record has been obtained from one subject and compared using an algorithm. This confirms the extraction of respiration signals and body movements through the FSR sensor. Moreover, the system is completely scalable and can be transferred to any bed of the same kind. The designed system shows a promising result with successful validation. Besides the technology is low cost and can be implemented for commercial use.

Future work would include the comparison of results with other devices to prove the breath recognition. Furthermore a connection to the sleep stage classifier should be executed. This works with a sleep algorithm [3] that provides a sleep stage classification and a sleep quality analysis. A development of new version of system with FSR sensors should enable the monitoring of blood pressure and heart rate.

REFERENCES


