A Lightweight and Affordable Sleep Quality Monitoring and Visualization System with a GSR Sensor for Users in Rural Areas to Facilitate Tele-Health

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Abstract. Having quality sleeping is very critical for individuals to maintain a healthy life. Over the years, thanks to the big advances in wearable and sensing technologies, a wide variety of wearable devices had been pushed to the market. However, for rural users including those in China, these devices are still largely inaccessible. In this paper, we describe the development of a lightweight and affordable real-time sleep monitoring system to serve such purpose. To significantly reduce its cost, a galvanic skin response sensor (GSR) was adopted. GSR sensor can be used to measure the conductivity of the skin and has been widely adopted in physiological assessment. In order to study the feasibility of our system, we performed two small pilot tests and obtained promising results.

The lightweight system is especially valuable in providing affordable solutions to Chinese users in rural areas where the higher-end wearable devices are not accessible. Meanwhile, the data could be automatically generated and sent to doctors in a remote site for further medical analysis as well.

Keywords: Sleep quality · Galvanic skin response (GSR) · Monitoring · Visualization · Tele-health

1 Introduction

Are you always awake in the middle of night, staring at the ceiling stunned and desperate to have a good sleep? Or maybe you are hard to stay a constant asleep which indicates that you wake up multiple times during sleep. Nowadays, more and more people are puzzled by these different kinds of low sleeping quality and demand an efficient way to obtain information on the quality of their sleep. Meanwhile, lack of quality sleep is also associated with obesity, diabetics [4, 12], mental problems and even accidents [19]. A sleep monitoring system would benefit the individuals as well as medical professionals.

Motivated by these previous works, in this paper, we present a lightweight integrated system consisting of a Galvanic Skin Response sensor (GSR) [5] and a laptop which receives and visualize the data obtained from the sensor. The moving patterns of the GSR value which is widely used to assess automatic activity, could then be

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examined by users and doctors (including those in a remote site to facilitate tele-health).

Two feasibility studies had been performed and described here to demonstrate the high potential of such systems, especially for rural users who do not have access to quality devices and medical services.

The organization of this paper is as follows. In Sect. 2, we present some earlier works on sleep monitoring via GSR and establish the motivation of our study by describing the link between GSR and sleep quality monitoring, GSR and GSR and pressure level in education settings. In Sect. 3, we show the key functions of system, followed by two small-scale pilot studies in Sects. 4 and 5. We conclude this paper and discuss our future work in Sect. 6.

2 Related Works

2.1 Sleep Quality Monitoring via GSR

Lack of quality sleep is also associated with obesity, diabetics [4, 12], mental problems and even accidents [19]. A sleep monitoring system would benefit the individuals as well as medical professionals.

With the advances of such technologies as sensing and wearable technologies, there are a number of commercial- as well as research-grade wearable devices for sleep monitoring [13, 21], among them, the pricey AMI MotionLongger (USD 795; excluding software), Microsoft Band 2 (USD 224, discontinued), to more affordable ones including Jawbone UP (USD 34, discontinued), Fitbit Alta (USD 130), etc. (See [8] for a review of home-use sleep monitoring system). However, most of these are not accessible to the large number of rural users including those in China, which motivates our study. In particular, in this paper, we present a lightweight and affordable sleep monitoring system consisting of a GSR sensor and a computer which receives and visualize the obtained data. Before we describe our system architecture, we will briefly discuss the link between GSR value and sleep quality.

2.2 The Link Between GSR and Sleep Quality Monitoring

Galvanic skin response (GSR) is often adopted as indicators of automatic activity; therefore, it has been widely applied in physiological investigations [15, 20].

A large number of previous works had linked GSR value to sleep quality measurement [3, 10, 16], mainly due to its association with the sympathetic nerve [6, 15].

Following these previous works and drawn from previous results, in our current system, we adopt GSR values to measure users' automatic activity during typical sleeping position (on bed). No specific postures had been considered.

2.3 The Link Between GSR and Pressure Level in Education Settings

GSR has often been adopted as indicators of pressure and/or anxiety levels; and widely applied in physiological investigations [15, 20]; with its high portability and opensource quite prototyping platform Arduino, it also has gained attention in the learning community to examine and assess learners' anxiety and pressure level to name a few, [2, 11, 14], since learners' emotional states have significant effects on learning activities [1, 18] and learning outcome [22]. However, most of the studies directly record and monitor learners' GSR values during various learning activities in order to measure their anxiety level [2, 11], instead of measuring their sleep quality, which differentiates our study from these earlier ones.

3 System Overview

3.1 Connecting the GSR Sensor via the USB Interface

The GSR sensor is collected to our main monitoring system via the typical USB. The major design rationale is to simplify the system setup particularly for those rural users who are not familiar with computer hardware.

3.2 GSR Data Collection

In order to find the relationships between sleep quality and the GSR data, we obtain the GSR data from users during their sleep, similar to the testing environment in [7, 9, 16], the GSR senor receives the GSR data and sends it back to the system (see Fig. 1 for our system user interface). The system automatically extracts the GSR data in every 3 s; the new value will be updated and shown in the system's user interface accordingly.

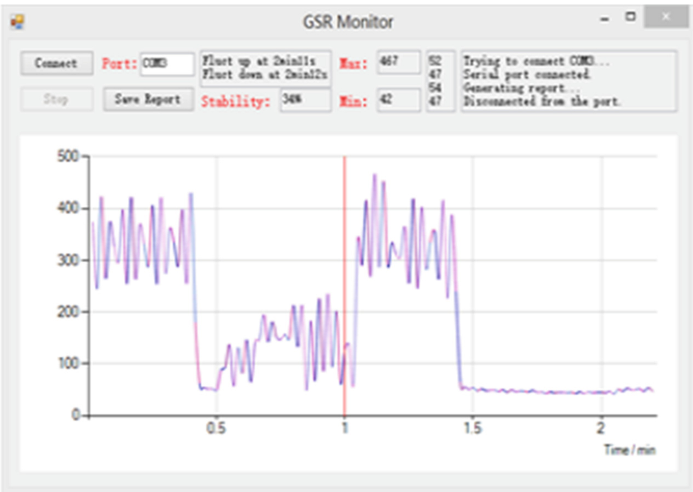

Fig. 1. The interface of the GSR data monitor

Besides, the maximum and the minimum value will be shown per unit time on the interface. In this way, users can directly observe whether or not there is a sharp change of the GSR value in a short period of time.

In the implementation part, we adopted the multi-threading strategy so that the system can run continuously without any conflicts and affecting the front-end applications.

3.3 Visualizing and Summarizing the Test Results

Our system can generate and visualize the GSR data at the user's request (see Fig. 2 for a sample of such graph). Refer to Fig. 2, the value on the X axis stands for the processing time and the value on the Y axis stands for the GSR value. Besides, the visualization offers to advantages to allow users and medical doctors (especially those at a remote site to support tele-health [17]) to directly and clearly observe the moving trend of the GSR value, which is in turn linked to their activities during sleep. Two functions had been built into our system to facilitate such process. The first is to dynamically update the data and users can check out the GSR values when they have time. At the end of test, the system will generate a text document which will show the result as shown in Fig. 4. This text directly provides the useful information for the user. In the text, the time when the curve fluctuates up and fluctuates down are shown.

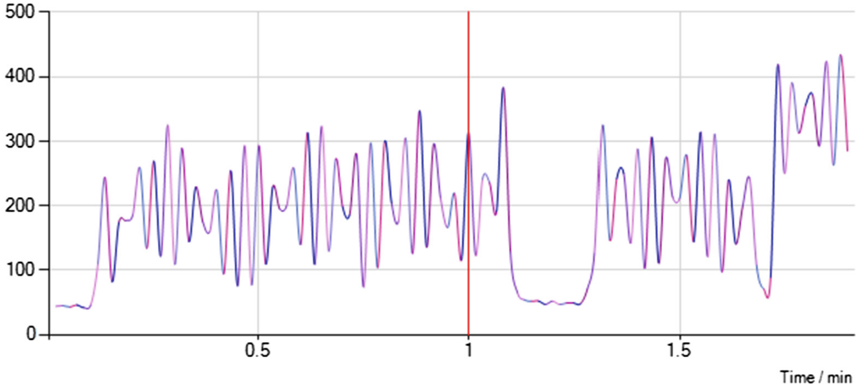

Fig. 2. A sample of the moving GSR data

The second function is to allow users to take a closer examination of their own data; to achieve it, the user only needs to move their mouse to the user interface and click the left button on the mouse. Then they need to press the button continuously and move it in the bottom right direction as shown on the Fig. 2.

Figure 2 can be compared with Fig. 3 to notice the variations. Also, if users can press the button on the top right corner to go back to the original display mode. The ease of use of our system offers rural users who might not have higher education better advantages.

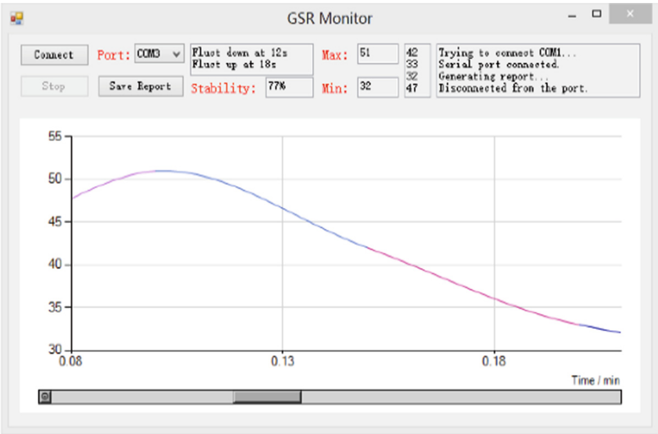

Fig. 3. The closer look at the GSR data in the user interface

3.4 Autogenerating the Data and Store It as a File for Remote Medical Analysis

The test results are considerably vital for users to analyze their sleep quality, so it is very important to store the result securely and reliably. In our system, the textual summarized results are autogenerated which can save unnecessary operation time for analysis (see Fig. 4).

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GSR Analysis Report 2018/3/12 16:09
Total Time Spent: 1min54s
Maximum GSR Value: 434 at 1min53s
Minimum GSR Value: 42 at 5s
Total Fluctuation Times: 96
Percent of stable time: 15%
Average Fluctuation Interval: 1
Details:
Fluct up at 7s
Fluct up at 8s
Fluct down at 9s
Fluct up at 10s
Fluct up at 12s
Fluct up at 13s
Fluct down at 14s
Fluct up at 15s
Fluct down at 16s
Fluct up at 17s
Fluct down at 18s
Fluct up at 19s
Fluct down at 20s
Fluct up at 21s
Fluct down at 22s
Fluct down at 23s
Fluct up at 24s
Fluct down at 25s
Fluct up at 26s
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Fig. 4. System generated summarizing report

The generated result file includes several important factors, such as the total time spent, maximum and minimum GSR value, the total fluctuation time, and the average fluctuation. With the help of these factors, users and medical professionals can have an overview of their sleep quality.

4 Pilot Study One and Discussion

In order to study the feasibility of our design, we conducted a preliminary study on one subject who is a college student and collect GSR values during his sleep at night. After collecting the research data, analyzing the result and obtaining the variation tendency of GSR value, his sleep quality is assessed and visualized. As shown in Fig. 5, each point stands for a GSR value and the distribution of these points indicates the trend of the GSR value development. The red line in Fig. 5 stands for the variation value's tendency. As the time increases, the GSR value becomes lower and constant which indicates that the user's sleep quality goes better. Besides, there is few relatively high GSR values existing at the latter half of test. Then compared with the first half of test, the GSR values changes stupendously and more frequently. The points in this area distribute irregularly which indicates that the user doesn't fall asleep during this period of time. After analyzing, the conclusion of the user's sleep quality comes out. This user didn't spend too much time falling asleep and his sleep relatively stay continuous so his sleep quality is satisficing.

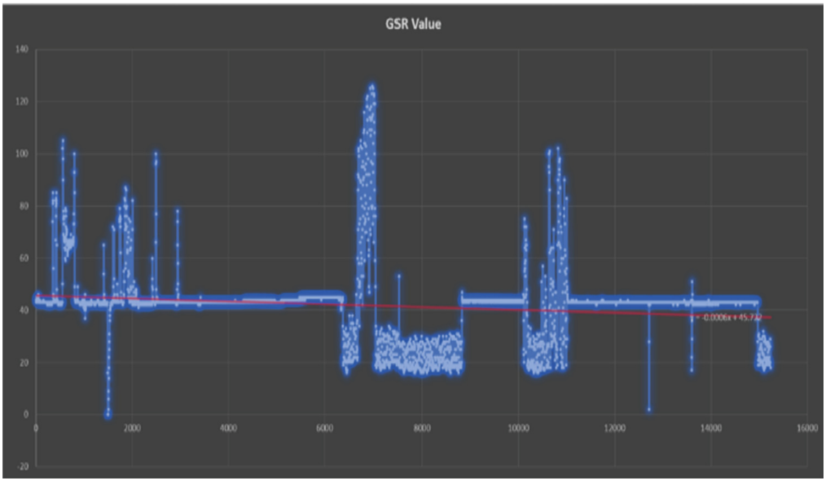

Fig. 5. The data analysis of collected GSR value in the pilot study (Color figure online)

4.1 Discussion

After accomplishing the resulting analysis, users can obtain the information that the tendency of the GSR values changes. They can directly judge the sleep quality by observing the number of percentages of stable time shown in Fig. 4. If this value is high, it indicates that the user's sleep quality is high Compared with other previous works, our system is more sensitive to the slight movements of users during sleep and the visualization can be shown in a real-time mode. When the users' GSR values changes, it immediately responses to the shifty curve. Besides, users can also observe the exact measurement number in the stored text result. Some systems depend on the user's movement to know the sleep quality and it comes to some problems. If the user is used to turn over body during sleep, will the system distinguish this action? Another problem is that when user keep static, they may sit in quietness without any movements. In this situation, these systems always assume that users are sleeping, which is the significant weaknesses. After the comparisons with these previous works, the galvanic skin response is more suitable for measure the sleep quality: the user's body causes the constant electrical characteristics changes on the user's skin. When users sleep, their GSR values stay in a relative constant level and the values are lower than when they are active. This feature offers a guarantee on detecting the quality of the user's sleep.

In order to examine the sensitive of the data collector in order to distinguish a user's emotion, we conducted a second pilot study. Details are shown in the following section.

5 Pilot Study Two and Results

The sleep quality monitor system is a quick, efficient and accurate way to examine people's sleep quality in different situations. In most cases, the changes of the GSR value measured by the GSR sensor will indicates the percent of stable time when testers are sleeping. If the percent of stable time is higher, the tester's sleep quality is better. We conducted a second study on a male college subject to examine his sleep quality before he was going to take an exam. Figure 6 shows the GSR data on the eve of this examination. According to the graph, we found the volatility of the GSR value. The volatility is very large which indicates that the subject's GSR value is not stable when he was sleeping. This result indicates that his sleep quality is not good which may be resulted from the coming exam, which might occur due to his anxiety.

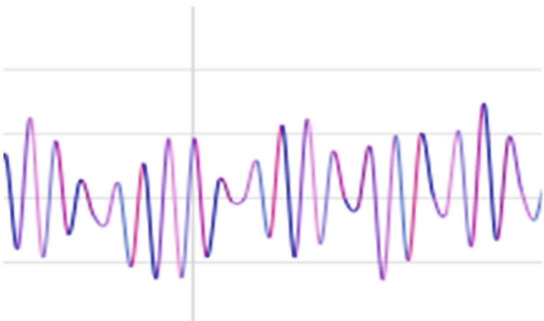

Fig. 6. The GSR value volatility of the subject's sleep on the examination day

To further examine whether there exists some differences of GSR value between his sleep on a normal day and the sleep on the coming test day, we compare the GSR value in these two situations. We found that the GSR value is more stable during the normal day sleep which is align with our expectation (Fig. 7).

Those said, we might be able to conclude that the pressure of examinations will influence student's sleep quality which can then be directly examined from the GSR value.

One immediate application of such findings is to allow users to self-regulate and self-manage their pressure level through monitoring their daily sleep quality, which might also offer remote therapists enough data to offer medical or physiological helps, if needed. Although such applications are commercially available, they are rarely adopted in rural areas.

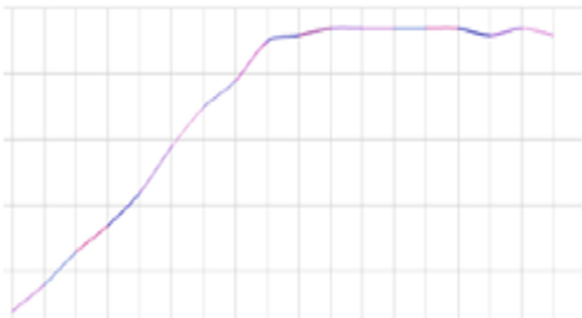

Fig. 7. The GSR value volatility of the subject's sleep on a normal day

6 Concluding Remarks and Future Works

Our sleep quality monitoring system is a quick, lightweight, efficient device with satisfying results to offer users to examine their own sleep quality; meanwhile, the collected data can also facilitate intelligent tele-health, which is a future path we are seeking in the future. of using GSR to test the sleep quality is still in its infancy at this point especially for users in rural areas. Hence, it is very urgent for researchers to greatly develop such affordable one for these users.

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