An Accurate, Low-Cost, Easy-to-Use Sleep Posture Monitoring System

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***Abstract*—** Sleeping is one of the most important activities in our daily lives and affect our health. However, very few people could really understand their sleeping habits, which is important to avoid potential sleep-related diseases. Most current studies on sleeping posture studies aim at the monitoring of sleeping postures. However, they are limited to be used in hospitals and need experts to operate these equipment. In this paper, we proposed an automatically sleeping posture estimation system for ordinary people to use in their homes. The customers are only required to wear two sensors, one on chest and the other on wrist during the training process of the sleeping posture monitoring model. We adopted random forest algorithm in the model training algorithm. After this training procedures, users' sleeping postures can be recognized by only wearing one sensor on the wrist. Also, we proposed a data cleaning procedures to process raw sensor data to find the ground truth of sleeping posture. Our experiment results showed that the proposed sleep posture technique can estimate the body posture accurately.

I. INTRODUCTION

Sleep is an activity that we go through with no consciousness, so few people can know their sleeping habits. In fact, bad habits are related to some chronic disease[1], such as cardiovascular disease. Sleep posture is one of the sleep habits that can affect health. The functioning of body in the lying position is different from other positions, especially for the elders and patients.

The long term pressure on the skin in the same position can cause injuries to our body. Pressure ulcer/sore is such a typical disease. To avoid pressure ulcer, the patients and elders need to turn over every two hours with the help of their caregivers[4]. If sleep postures can be monitored, it can improve the sleep quality of patients and reduce the work of caregivers.

Moreover, some serious diseases are related to the sleep posture. Obstructive sleep apnea (OSA) is another common disease, related to the sleep posture. The symptom of OSA is the pause of breathing during sleep. This can cause permanent brain damage if the disease occurs too often. It was found that the frequency of breath pause of an apnea patient in the lateral posture is lower than that in the supine posture [2].

In the literature, some research works for sleep posture monitoring have been reported. An accelerometer is attached to the chest to determine the body posture during sleep[5], [6]. It is obvious that a patient wearing an accelerometer on chest may not be quite comfortable. A depth camera is adopted to capture the depth and image of the monitored patients [7]. The privacy is the major concern for this method. A pressure mat is placed under the patient to capture the pressure distribution of body, and recognize the posture [8], [9]. The cost of pressure mat is quite high. In [10], a Wi-Fi signal processing approach for sleeping events monitoring was suggested, but this approach cannot recognize the actual posture. To sum up, a cost-effective, accurate and use-friendly sleep posture monitor has been rarely seen.

In this paper, we present a sleep posture monitoring system, integrating the widely used wristband and smart watches. The monitoring system can recognize four common sleep postures: supine, prone, left lateral and right lateral. When the monitoring system is in the monitoring mode, the system requires only one accelerometer. The accelerometer is commonly equipped on smart watches and wristband.

The rest of this paper is organized as follows. Section II describes the system model. Section III discusses the framework of data processing. Section IV shows the experimental results. Our concluding remarks are given in Section V.

II. SYSTEM MODEL

Our proposed sleep posture monitoring system is shown in Fig. 1. Our proposed system includes acceleration sensors, smart phone and a personal computer. The wearable device consists of an accelerometer and a bluetooth communication chip. The sensed data are collected by the smartphone through bluetooth, then sent to the computer or the Internet for data analysis.

There are two modes in our system: the training mode and the monitoring mode. The training mode requires two sensors. In the training mode, one sensor needs to be attached to the chest and the other needs to be strapped on the wrist. After the sleep posture model is learned, the training mode is switched to the monitoring mode. Only wrist sensor is needed in the monitoring mode.

III. DATA PROCESSING FRAMEWORK

The data processing framework of the system is shown in Figure 2. The sensed data of the chest and wrist sensors are processed in different ways, which are marked by th gray and red colors.

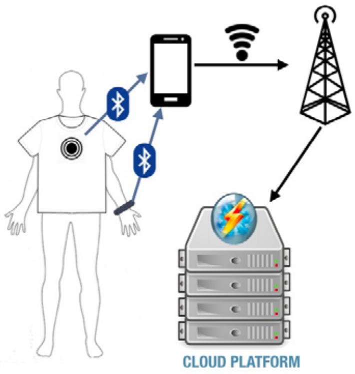

Fig. 1. System architecture.

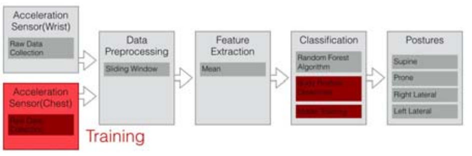

Fig. 2. Framework

In the training mode, the actual posture can be estimated based on the chest sensor data, while the wrist sensor data can provide the features of wrist positions, In the training mode, the correlation of wrist position data with the sleep posture data from chest data are established based on the random forest decision tree approach. The processing method of chest sensor data will be discussed in this section.

A. Chest Sensor

The process of chest sensor data is important in this system because it is the target label for sleep postures. In the initialization phase (first three seconds), the system needs to identify the angles of the chest sensor as shown in Fig. 3. Usually, the customers are requested in the standing or sitting straight positions in this phase.

After the initialization phase, we can obtain angle ϑ according to (1) and a rotation matrix formula (2). The effects of rotation matrix are shown in Fig. 3.

The processing flows from raw data to sleep postures are illustrated in Fig. 4.

- Step 1: The raw data of chest sensor will be modified based on the calculation of the rotation matrix.
- Step 2: The noise will be removed in this step. The system calculates the variance within a sliding widow. When the variance is larger than the specific threshold, the system will remove all the data that nears zero. After the noise is removed, the system will calculate the mean of the data within a sliding window.
- Step 3: In this step, the system will determine the dominating axis by comparing the magnitude of each axis. When the dominating axis is Y or Z axis, it indicates that the user is in the lying position.
- Step 4: In the final step, the system determines the sleep posture according to the positive or negative of the three axises. Sleep postures can be determined based on the values of Y axis and Z axis, as shown in Table I.

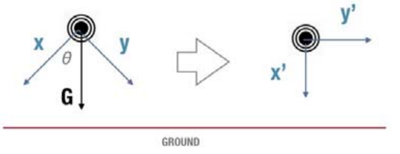

Fig. 3. The effect of rotating matrix.

$$\vartheta = arctan(y,x) \tag{1}$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\vartheta & \sin\vartheta \\ -\sin\vartheta & \cos\vartheta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{2}$$

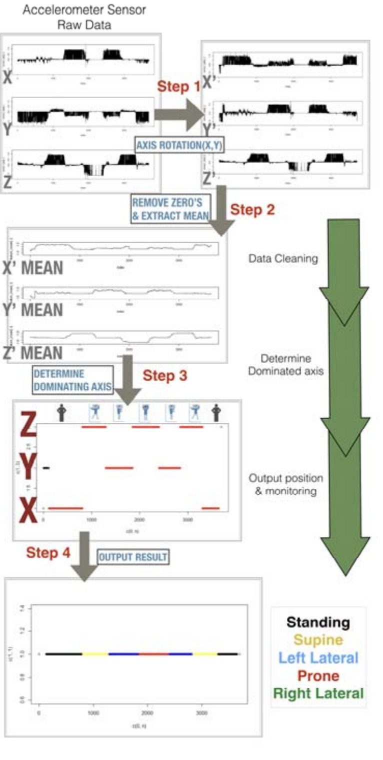

Fig. 4. Data process for chest sensor data.

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TABLE I
DECISION MANNER.

Dominating Axis	+/-	Body Posture
Y	Positive	Left Lateral
Y	Negative	Right Lateral
Z	Positive	Prone
Z	Negative	Supine

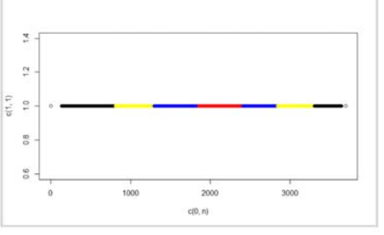

Fig. 5. Colored points represents body postures: black as standing or sitting, yellow as supine posture, blue as left lateral, red as prone and green is right lateral.

B. *Wrist Sensor*

The processing of wrist sensor data aims at obtaining the feature of wrist movement. The proposed sleep posture monitoring system will segment the data by sliding window, and then calculate the mean of wrist sensor data in each window, which is called the feature data of wrist position in this paper. The detail of the data process of wrist sensor data are reported in our previous work [11].

IV. EXPERIMENTAL RESULT

We performed experiments to collect sleeping posture data for training and testing the proposed random forest decision tree approach. Here we show the results how the chest sensor data can be translated to sleep postures.

As shown in Fig. 5, the horizontal axis presents the time line, and the colored points represents body postures. Hence, the designed process for chest sensor data can accurately represent the sleep postures. This is the key point to train a accurate model for sleep posture monitoring.

V. CONCLUSIONS

In this paper we presented a system that can monitor sleep postures. We designed a process to automatically recognize the body posture in training stage. This process can save labor-intensive tasks for labeling the postures in the training stage. We suggested a noise removal procedure to transform the noisy raw data to the clean right data, which is of importance for sleep posture calculation. With this procedure, the accelerometer data can be easily used to calculate the sleep postures. The proposed sleep monitoring system has the advantages of low cost, easy to deploy, and comfortability. It is suitable for ordinary people or elders to monitor their own sleeping habits.

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