Research on sleeping position recognition algorithm based on human body vibration signal

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***Abstract*—Sleep position monitoring plays an important role in sleep health care and intervention. In medical diagnosis, sleep posture is an important index for the diagnosis and treatment of postural sleep, breathing, heart and cardiovascular diseases. The accurate identification of sleep posture is of great significance for the diagnosis of human sleep disorders. In terms of Social Nursing, the pressure of monitoring and nursing for the elderly caused by population aging is becoming more and more severe. For the elderly who have lost or partially lost their mobility, automatic sleep position monitoring will remind them when necessary or forcibly change their sleep position through technical means, which will be of great significance to improve the sleep quality. In terms of treatment intervention, according to clinical medical research, forcibly changing patients' sleep posture through technical means will greatly improve patients' sleep quality and sleep structure. Human body vibration signals contain rich information, such as BCG signals, respiratory signals and so on. These signals also have a close relationship with sleeping posture. Based on this relationship, this paper proposes an algorithm for sleeping position recognition. Firstly, the intelligent mattress is used to collect human body vibration signals, and the relationship between human body vibration strength and sleeping position is obtained through a series of processes such as signal processing and model training. Compared with the traditional sleeping position recognition methods such as infrared camera, this algorithm ensures the user's privacy and reduces the influence of human body movement on the sleeping position recognition results.**

Keywords—Sleep position monitoring, Human body vibration signals, sleeping position recognition, intelligent mattress

I. INTRODUCTION

Relevant studies show that insufficient sleep has become a serious public health problem. Modern people have realized their sleep problems and started to pay for their healthy sleep. There are more and more researches on auxiliary products to improve sleep comfort and help people get a good sleep quality. Sleep is an important physiological process for human recovery and storage of resources. Sleep quality is an important indicator to measure the quality of life and mental health. Good sleep is the guarantee for human to maintain normal life and activities. As one of the indicators to evaluate sleep quality, sleeping position not only affects the sleep quality of people's psychological and physical health, but also many diseases are induced or aggravated by improper sleeping position. Suffering from different diseases, the sleeping position should be different, such as vascular sclerosis patients should not sleep on the side; Bedsore patients should not keep the same sleeping position too long. Human sleeping position recognition is one of many human posture and motion recognition, and has been a research hotspot in the field of pattern recognition at home and abroad. Sarah Ostadabbas et al. [1] used pressure sensors to obtain the pressure distribution of the human body to identify the sleeping position. Because the collected signal is a kind of absolute pressure signal, it is greatly affected by the motion of limbs and other positions. Kubota T [2] et al. use infrared cameras to collect users' sleep images throughout the night and identify sleeping positions based on image processing, but this method will violate users' privacy. So based on these methods, we optimized.

Pressure ulcers are injuries to skin and underlying tissues as a result of prolonged pressure. They may develop quickly (e.g. in multi-hour surgery or within a few days recovery after surgery) and are difficult to treat and must be taken seriously. If left unchecked, an ulcer can lead to amputation or even death [3]. Once developed, pressure ulcers increase hospital stay costs and impose an enormous burden on our healthcare system. A system that can monitor and record patient's sleeping postures unobtrusively over time has a unique value for the researchers in the pressure ulcer field as well as better management of hospital resources [4]. Electronic pressure monitoring systems are commercially available in the form of pressure mats that can cover beds and wheelchairs [5]. Patient's sleeping posture detection using pressure mapping systems is an active area of research and several works have been done at the University of California at Los Angeles [6] and the University of Texas at Dallas [7]. There are also a number of existing works regarding the body limb identification problem. An algorithm presented in [8] used segments and superpixels to propose candidates for limbs. Although this algorithm showed good performance in the test phase, it highly depended on the resolution of the original camera images. In [9], authors modeled the human body in terms of its constituent body parts. Then for each part, a multiview eigen model that combined image views from numerous calibrated cameras was built. Using a deformable triangulation method, a body part segmentation algorithm presented in [10] based on the body postures.

In this paper, we propose a sleeping position recognition method that can effectively reduce the influence of body motion and ensure user privacy. This template is realized based on the human body's lift signal. By studying and analyzing the distribution of body vibration strength, the position of people on the mattress is depicted, and the mapping relationship between sleeping position and body vibration strength is established through training. In the second section, we introduce the acquisition system needed for the experiment. In the third section, we introduce the process of the algorithm in detail, and the method used in each step. In section 4, we introduce the experimental results. In section 5, we draw a conclusion based on the experimental results.

II. SYSTEM DESIGN

Sleeping position recognition system is an intelligent medical mattress system, which includes sensors, operational amplifier circuits, microcontroller, SD memory cards and other modules.

A. Piezoelectric ceramic sensor

The piezoelectric ceramic sensor of the mattress converts pressure signals into electrical signals. When the ceramic plate is subjected to the force in the vertical direction, the plate deforms, and the two electrode surfaces formed by the two discs produce a potential difference, and the potential difference is proportional to the magnitude of the force, that is, the piezoelectric ceramic plate has a piezoelectric effect. In the experiment, the voltage signal of ceramic chip was sampled to obtain the change of the vertical vibration pressure. Sixteen piezoelectric ceramic sensors are embedded in the mattress, as shown in Figure 1. When a person lies on the mattress, vibration signals from the chest and abdomen can be collected at least one way.

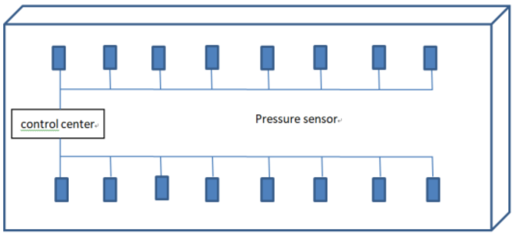

Fig. 1. The 16-way sensor is embedded in the mattress schematic

The electric signal induced by the piezoelectric ceramic sensor is very weak. The electric signal is amplified by the two-stage amplifier circuit composed of the integrated voltage lifting circuit and the operational amplifier chip of the mattress system, and then sampled by the STM32F103RET6 microcontroller, analog-to-digital conversion to obtain 16 digital signals. Then the path with the best signal quality is selected as the original vibration signal by the energy minimization algorithm.

B. Control system

Mattress system control center is STM32F103RET6 single chip microcomputer, its unified coordination and control signal acquisition sensor, boost circuit, operational amplifier module, sampling module, data storage module, data transmission WiFi module and other integrated sub-hardware modules, cache user data, Embedded routing algorithm and future sleep posture monitoring, sleep staging, sleep apnea monitoring algorithm.

After sampling and quantization, the 16 sensor signals are stored in the SD card, and the optimal route selection signals determined by the route selection algorithm are stored as the original collected signals for the follow-up study of physiological characteristics such as heartbeat and respiration.

Hidden in the original signal acquisition to human physiological characteristics of abundant information, including heart rate, respiratory rate, sleep posture, sleep apnea syndrome, sleep stages, heart rate variability, such as by monitoring these physical characteristics can provide the preliminary screening for people in their daily lives as a result, and further provide advice about sleeping position and forced intervention, It has great research significance and application prospect.

III. SIGNAL PROCESSING

The collected original body vibration signals include BCG signal, respiratory signal, body movement signal and environmental noise, etc. The time domain diagram of the original signals is shown in figure 2. The signal with smaller frequency and larger amplitude is the respiratory signal, which represents the mechanical activity of the body as a whole and is the main energy component of the signal. And the signal with larger frequency and smaller amplitude is BCG signal, which is the mechanical activity of the heart and is the main energy component of the "burr" on the signal.

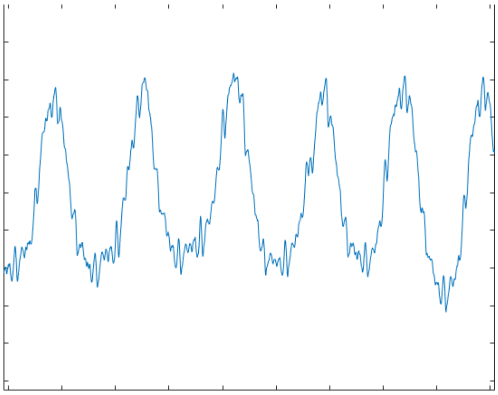

Fig. 2. Time domain diagram of the original signal

A. Raw signal processing

When we do a spectrum analysis of the signal, we can also find that the high energy is concentrated in the low frequency part, which is also the part that mainly reflects the strength of the body vibration. The spectrum is shown in figure 3.

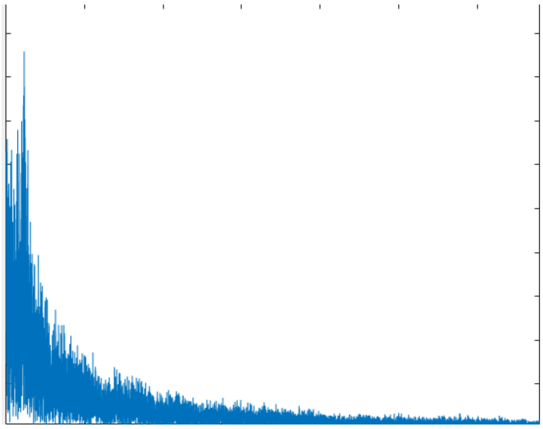

Fig. 3. Spectrum diagram of the original signal

In the low frequency band, in order to reduce the influence of some low-frequency noises on the results, we smoothed the amplitude of the low frequency band. We could take the frequency band between 0Hz and 5Hz and divide it evenly into 10 frequency bands. We took an intermediate value in each frequency band and averaged the intermediate value to make an approximate quantitative analysis of the volume vibration strength. The relationship between sleeping position and the distribution of body vibration was found out by horizontal and longitudinal comparative analysis. The formula for quantitative analysis is as follows, f(x) is the spectrum value of the original signal:

$$\mathrm{I(M)} = 0.1 * \sum_{i=0}^{i=9} f(i * 0.5 + 0.25)$$

B. Amplitude normalization

Different users have different body vibration intensity, and the vibration signal intensity of chest and abdomen collected by the sensor is also affected by the signal transmission medium between the body surface and the mattress hardware system, and the vibration activity of the body is different at every moment. Therefore, normalized processing is made in the lateral comparison and analysis, and the place with the strongest body vibration is set as 1. Sensors are distributed evenly on the mattress in a 2 x 8 array. Figure 4 shows the distribution of body vibration intensity at a certain moment, and Figure 5 shows the distribution of body vibration intensity after normalization:

16.4000	21.2000	322.9000	487.1000	453.8000	39.4000	23.1000	17.6000
14.2000	19.6000	273.5000	467.3000	414.9000	28.3000	14.3000	9.8000

Fig. 4. Intensity distribution diagram of body vibration

0.0337	0.0435	0.6629	1	0.9316	0.0809	0.0474	0.0361
0.0292	0.0402	0.5615	0.9594	0.8518	0.0581	0.0294	0.0201

Fig. 5. Normalized volume vibration intensity distribution diagram

It can be clearly seen from the normalization results that the strongest part of the body vibration is located in the position (1,4) of the sensor, and the overall distribution of the body vibration is about the sensors in the range 3-5 in the first row and the second row.

IV. EXPERIMENTAL RESULTS

A. Algorithm flow

We lie on your back, stomach, left side and right side four position of body vibration distribution were made a statistical analysis, the results found that under the condition of lie on your back and stomach these two position, body contact with the mattress with larger area, in view of the experimenter figure is relatively thin, generally body vibration distribution focus on the sensor of 2 * 2, in view of the experimenter body fat, Generally, the bulk vibration distribution is concentrated on the 2*3 sensor. However, in the side sleeping position, the contact area between the body and the mattress is small, and the weight of the body has little influence on the distribution of body vibration. Therefore, the first step of the sleeping position recognition algorithm is to separate the two distinct sleeping positions.

For the prone and supine sleeping positions, we found that cardiopulmonary activity was strongest at the heart. In other words, the closer the sensor was to the heart, the stronger the vibration was detected, and this was confirmed by the experiment. Whether supine or prone, the intensity distribution of body vibration is asymmetrical. For supine lying, the heart is on the left, the center position of body vibration will be more to the left. For prone position, the heart is on the right, so the center of the vibration will be slightly to the right. This idea can be used to design the algorithm.

For both left and right sleeping positions, we found that on the left side of the bed, the heart was closer to the mattress and the body vibration was stronger. On the right side, the heart was further away from the mattress and the vibrations were weaker. After experimental data of different transverse comparison, found that most of the experimenter, left side of the body under the vibration strength is stronger than the recumbent body vibration strength, the right side of the body vibration intensity is weak to lie under the vibration intensity, therefore can use the same body experiment under the different position of horizontal comparison, to distinguish between left side and right side. Figure 6 shows the algorithm flowchart.

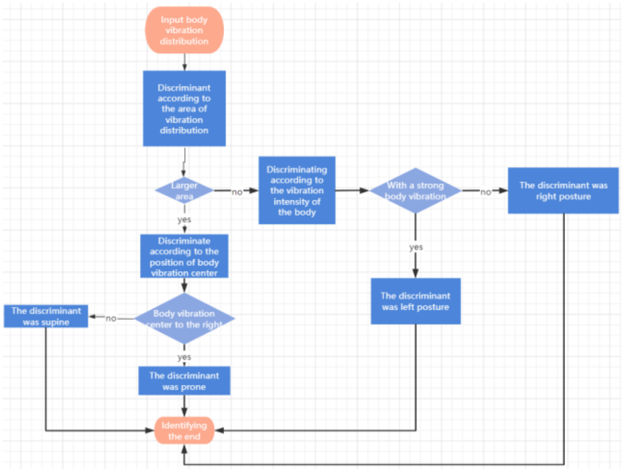

Fig. 6. Algorithm flow

B. Comparative experiment

In the process of algorithm recognition, we use the idea of sliding window, each time 2*3 as a sliding window, in the 2*8 volume vibration distribution matrix to do sliding processing. If the vibration intensity of the upper body of the sensor containing 4 or more in the window is greater than 0.5, it is identified as supine; otherwise, it is identified as lateral lying; If the judgment is recumbent, the mean values of the left and right parts of the area occupied by the body vibration are calculated respectively. If the left part is larger, the algorithm is recumbent; otherwise, it is prone. If it is judged as side lying, the strength of body vibration in recumbent position is recorded. If the strength of body vibration is greater than that in recumbent position, the algorithm is judged as left lying, otherwise, it is judged as right lying.

As a control experiment, we arranged a 2*8 common pressure sensor array to collect the absolute pressure of human body, and used the random forest method to establish the mapping relationship between human pressure and sleeping position. The experimental results are shown in Table I:

TABLE I. COMPARISON OF EXPERIMENTAL RESULTS

	Supine	Left posture	Right posture	Prone
Body vibration signal	90.15%	88.64%	87.97%	91.36%
Pressure signal	87.42%	85.18%	85.09%	89.48%

According to the comparison results, we can find that the accuracy of body vibration signal is higher than that of pressure signal for the discrimination of the four sleeping positions. The reason is that in the pressure experiment, the limbs will also produce pressure on the sensor and output signals, which will have certain deviation for the analysis of the contact area, thus causing the difference in accuracy.

V. CONCLUSION

The ultimate goal of sleep position recognition and monitoring is to provide reference for the treatment and intervention of sleep-related diseases, such as forcing users to adjust their sleep positions, etc. Research on sleep position-related intervention measures and convenient system have very broad application prospects. However, as a part of the smart medical mattress system, the sleeping position recognition algorithm in this paper has not been integrated with other functional modules, such as sleep apnea syndrome detection module, so there is still a broad space for the study of sleeping position combined with sleep apnea syndrome.

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