Recognition Algorithm for Sleep Postures using a Smart Fabric Pad with Multiple Pressure Sensors

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ABSTRACT
The existing studies suggest the following methods for measuring sleep postures: installing cameras and record the sleep postures then analyze the postures or measuring the change of the posture by attaching the sensor to the user's body. However, the installation of high-cost devices such as a camera or direct attachment of sensors on the subject's body present issues relating to the cost and convenience. As a solution, this paper develops a recognition algorithm for analyzing sleep postures using a smart pad with embedded fabric type pressure sensors. This algorithm is applied using a fabric-made smart pad with multiple pressure sensors. The sensors detect the distribution of the body pressure on the pad during sleeping, and the collected body pressure distribution data determines the sleep postures of the users. Further, this smart fabric pad does not require any additional analytical devices. This pad allows the users to monitor own sleep postures continuously. With the analyzed sleep posture data, the user can recognize one's typical sleep postures. In order to verify the effectiveness of the algorithm, this paper conducts an experiment to validate using the sleep posture data defined as nine categories. As a result, the algorithm had an average of 91.4% accuracy rate.

CCS Concepts
• **Computer systems organization → Embedded software**

Keywords
body pressure analysis; pressure sensing; sleep disorder; sleep posture; recognition algorithm.

1. INTRODUCTION
Sleep is an essential element for humans for maintaining physical and mental health, and it is known that man consumes one-third of his life to sleep [1]. Humans are mainly active in the daytime and sleep in the nighttime. There are studies proving that in the daytime, the preparation state of the body is not supposed to fall asleep. Thus, long-term nighttime workers often suffer from sleep disturbance, accumulation fatigue, and gastrointestinal disorders [2]. In addition, sleep is a crucial procedure for strengthening and reconfiguring memory by organizing the memory information collected by the brain during the day [3].

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Sleep posture is also closely related to health. As an example, there is a study showing obstructive sleep apnea is essentially related with sleeping position [4][5]. However, people living in a modern world do not have enough and qualified sleep because of the lifestyle [6]. Therefore, by being aware of, analyze, and put effort to improve own sleep posture for effective sleeping, one may improve one's health significantly.

It is also reported that an inappropriate sleep posture can be a cause of disability of the temporomandibular joint, one of the frequently used joints in oral communication such as chewing and swallowing, talking and speaking. [7] Therefore, it is supported that poor sleep posture has adverse effects on human health in many ways.

There have been many attempts to measure sleep posture using scientific methodology. A representative example is the DC Body Position Sensor (1566-kit, Sleepmate Technology, Great Britain). This is a method of attaching a sensor to the center of the user's chest and measuring the rotation angle of each sleep posture as the small beads inside it rotate according to the user's movements [8]. Such a method has an indeterminate factor of restricting natural behavior due to inconvenience and disturbing sleep because the measurement is performed by wearing a sensor directly on the body. Therefore, there is a need for a sleep care device and an analysis algorithm that can recognize a sleep posture without requiring physical intervention such as physical restraint by the user.

Thus, this paper proposes an algorithm to recognize sleep posture by modeling a smart pad device equipped with multiple fabric pressure sensor pads that measure and analyze human body pressure distribution reaching the bed matrix during sleep. Unlike conventional methods, the algorithm developed in this paper has an advantage that the user senses less discomfort during the analysis. The recognition algorithm presents a method that does not constrain the body of a person and the surface is made of fabric like a mattress of a bed for user comfort. For implementing this algorithm, a smart fabric pad with multiple pressure sensors is used, which reduces the number of cases where the experiment procedure interferes with the subject, adding to the reliability of the measurement. In addition, these sensors are resistant to many disasters that can occur in everyday life, such as bending or getting wet. Further, this algorithm reduces the user discomfort experienced at the hospital with the conventional methods and provides more active solutions for improving sleep quality to users by allowing users to recognize and analyze one's typical sleep postures during in the daily life.

In Section 2, this study explores the six types of typical sleep postures and the necessary characteristics of pressure sensors for measuring sleep postures. Based on this, in Section 3, this paper develops the modeling of a smart fabric pad and suggests the sleep posture recognition algorithm to be embedded in the pad. In Section 4, this paper verifies the effectiveness of this algorithm through an experiment.

2. RELATED WORKS

2.1 Classification of Sleep Postures

Figure 1 shows typical sleep postures that can be taken by people during sleep [9]. Sleep Assessment and Advisory Service (SAAS) in UK conducted a survey of 1000 people for observing and analyzing their sleep postures; the result showed that typical sleep postures can be categorized in six groups.

Figure 1. Most popular sleep postures.

This paper defines the experiment results of sleep posture recognition algorithm to the six categories of sleep postures. In order to categorize the above postures, this paper analyzed each posture's characteristics. During this process, we discovered the bent elbow joints naturally changes the directions and positions of the arms. Further, head, chest (or back), abdomen are parts of the body that are not very affected by the joint position changes and stay as the core middle parts of the body. In order to measure the distributions and positions of the body parts during sleep, pressure sensors are needed for the experiment. The next part of this paper discusses the measurement method logic of the pressure sensors.

2.2 Principle of Pressure Measurement

If we can detect the main central parts of the body during sleep and the direction and shape of the joints being stretched, we can determine what posture a person is taking and lying down. In general, a pressure sensor of the FSR (Force Sensing Resistor) is used to recognize this.

The FSR type pressure sensor places a space between the electrically conducting semiconductor and the printed electrode. In this case, the pressure is measured by using the characteristic that the signal is transmitted by the distance electrodes that are being contacted when the pressure is applied. However, this method is vulnerable to external effects such as wetting or contamination of the semiconductor element, damage or bending of the electrode. In addition, since the surface is coated with a material such as a film, there is a concern that it may interfere with a natural sleep due to the discomfort of the user when lying on top of the material [10].

As another method, we can consider a sensor that can measure pressure using conductive cloth and memory foam as shown in Figure 2. The basic principle of this approach is similar to FSR. However, since it is a soft cloth and a memory foam, not a semiconductor, it is strong against water and pollution. In addition, even if it is wrinkled, it can be restored to its original shape, and pressure can be measured without problems. Further, as being made of a familiar material, it is more natural to install it on the bed mattress and it can be used without any sense of heterogeneity.

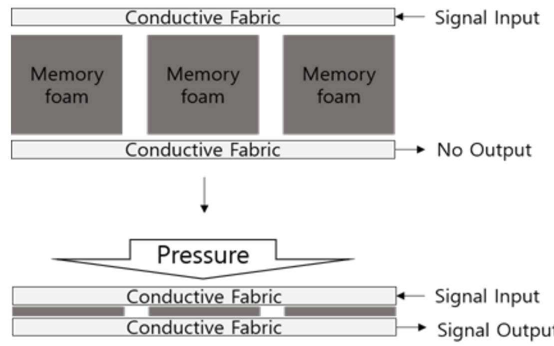

Figure 2. Pressure sensor using conductive fabrics.

The pressure sensor measures the pressure from the top to bottom with the weight of the body. As the strength and the position of the pressure are different depending on the posture and the body part, it is possible to simultaneously measure the pressure of all parts of the body necessary for the posture recognition by using several sensors. However, Figure 1 shows that Freefaller and Starfish postures are difficult to discern because of the similarities in pressure. The following addresses solutions to this concern.

2.3 Detection Method of Sleep Posture

Figure 3 is an example of an investigation and analysis by KRISS (Korea Research Institute of Standards and Science). In order to differentiate between the Freefaller posture and the Starfish posture as shown in Figure 1, it is necessary to divide the pressure receiving position into several rows and to calculate the sum of the measured pressure values, for which can be compensated. In the case of Figure 3, the pressure measuring mat is divided into eight rows, and the sum of the pressure and the pressure of each row is obtained,

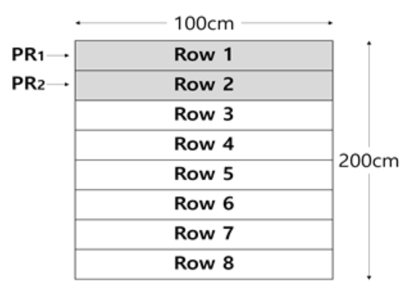

Figure 3. Sectors in the bed.

The pressure distribution in the right lying posture was concentrated on the hips and back, and in the prone position, the pressure on the hips and back was relatively low, and the pressure was concentrated on the abdomen.

Figure 3 shows the results of an experiment in which a single-person mattress with a length of 100 cm and a length of 200 cm was distinguished into eight equally divided parts. As described above, the sum of the pressure values detected in each row is used as the main data of the analysis. For example, the total pressure ratio of Row1 is PR1, and the total pressure ratio of Row2 is PR2. This method is effective in distinguishing Freefaller posture from Starfish posture. In this way, modeling for sleep posture recognition is proposed in the next chapter, taking into account the results of existing cases.

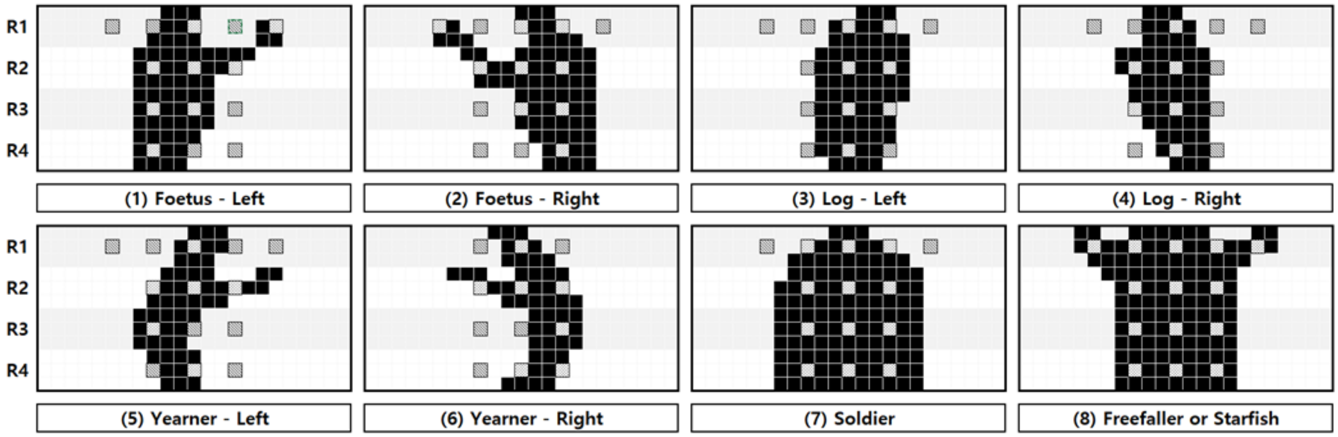

Figure 5. Functions of multiple sensors for each sleep posture.

3. RECOGNITION ALGORITHM FOR SLEEP POSTURES

3.1 Smart Fabric Pad

The proposed smart fabric sleep pad places 14 pressure sensors in the upper paddle as shown in Figure 4. The reason for this is to construct a minimal sensor to recognize the sleep posture of Figure 1. Among the parts of the human body that are solidly processed from the shoulder to the waist, the fabric pressure sensor pad is represented by a black circle.

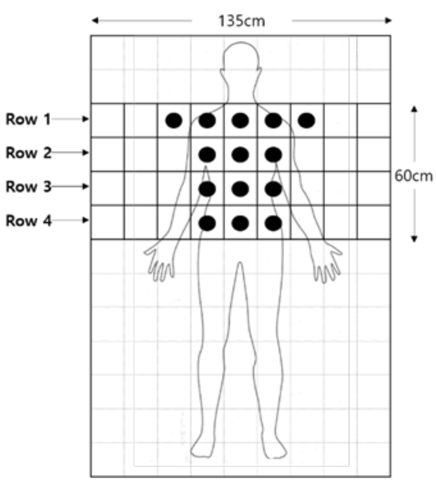

Figure 4. Sensor layout of smart fabric pad.

After dividing the pad into 15cm x 15cm squares, place the fabric type pressure sensor for each segment.

It is identified as Row 1 from the top and Row 4 as the bottom. There are five sensors in Row 1 and three in Row 2 through 4, requiring a total of 14 sensors. As shown in Figure 5, these sensors are arranged so as to match the sensed portion of the pressure in the eight sleep postures, and oblique lines indicate the sensors that are not detected.

Foetus, Log, Yearner postures were divided into left and right according to the person lying down. Freefaller posture and Starfish posture are equally configurable for all sensors.

3.2 Functions of Multiple Sensors for each Sleep Posture

To obtain more precise pressure data, 12-bit analog data is suitable as the measurement range of the sensor to be used. Therefore, the effective measurement range of the fabric type pressure sensor used in this algorithm is 0 to 4095. However, errors may occur due to noise. In other words, the sensor measures a certain amount of noise even when nothing is placed on it due to its electrical characteristics. Experiments using several sensors showed that the noise was measured from a minimum of 40 to a maximum of 200 random signal outputs. Based on this fact, the output signal of 0 to 4095 is divided into the sections from 0 to 3 and defined as shown in Table 1 below.

Table 1. Grade for Signal Output.

Signal Output	Grade
0 ~ 200	0
200 ~ 1500	1
1500 ~ 2500	2
2500 ~ 4095	3

Grade 0 means that no pressure is measured on the sensor. Grade 1 means that pressure is not applied directly but indirectly through the pad when there is a sensor around the body. Grade 2 is recognized at the borders of the body and Grade 3 is recognized at the body center, which is directly under great pressure. The attitude can be recognized by the analog data obtained by this method and the converted Grade value. The next part recommends the recognition algorithm.

3.3 Recognition Algorithm

First, we will define some elements and notation that are represented in the algorithm. When the Grade of the n-th sensor in the i-th row is specified, it is denoted by RGV (i, n). For example, the Grade value measured at the second sensor in the second row is RGV (2, 2). The total Grade of the sensors in the i-th row is denoted as SumRGV(i) while the average is denoted as AvgRGV(i). Also, the number of sensors having one or more Grades is defined as CntRGV (i), and the interval between the leftmost sensor and the rightmost sensor among the sensors is denoted by LenRGV (i).

Figure 6 is sleep recognition algorithm constructed using these factors. The algorithm begins with receiving the measured Grades by 14 sensors. The SleepPosture is the perceived posture as a result of the algorithm, and the postures from (1) to (8) in Figure 5 are classified as Posture 1 to Posture 8.

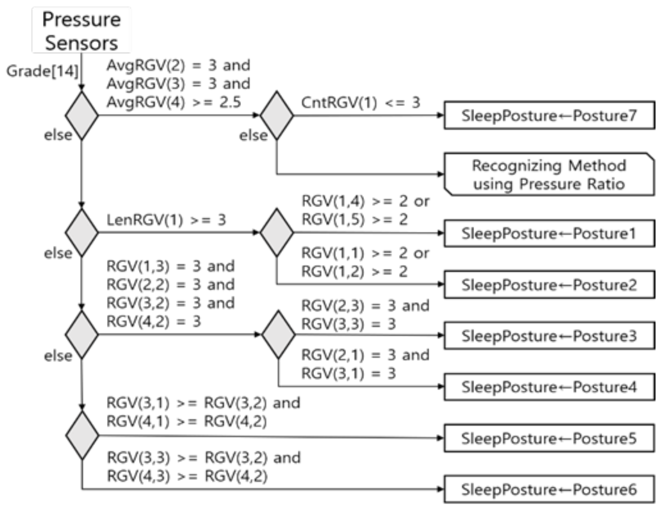

Figure 6. Sleep Posture Recognition Algorithm.

In the case of (7) and (8), the Grade of six sensors measured at R2 and R3 has a value of 3, and R4 has a Grade of 3 or a sensor value of 2 at all three sensors. Therefore, it can be said to be one of (7) and (8) postures when the Grade average of R2 and R3 is 3 and the Grade average of R4 is 2.5 or more. (7) and (8) are classified into the number of sensors whose Grade is 1 or more in R1. (8) is a posture that stretches both arms over the head, so the number of sensors measured in R1 is larger than that of (7). If the distinctions are fewer than three, it is defined as (7), and if there are more than three, it is identified as (8).

In addition, we use the total ratio of the pressure measurements in each row along with the Grade to perceive the posture (8) as Freefaller and Starfish. When the sum of the pressure values in row i is sum (i) and the ratio is PR (i), it is calculated as follows.

$$\mathrm{PR(i)} = Sum(i) \,/ \sum_{n=1}^{4} Sum(n) \quad i = 1,2,3,4 \qquad (1)$$

Figure 7 below shows a plot of the percentage pressure distribution for each row using this method.

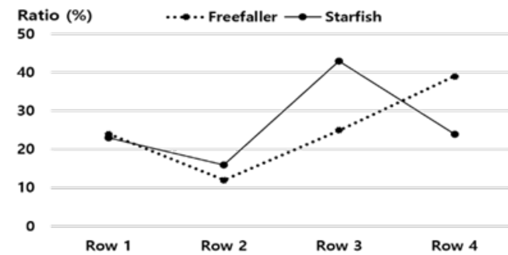

Figure 7. Pressure Ratio Result of Freefaller and Starfish.

The postures used in the analysis are Freefaller posture and Starfish posture. The pressure distribution ratio of the two postures, which could not be distinguished from the posture analysis according to the shape of the previous pressure distribution, is shown in Figure 7. Row 1 is the shoulder, Row 2 is the back (chest), Row 3 is the abdomen, and Row 4 is the hip (waist). The most notable features were in Row 3 and Row 4.

When the subject was leaning like Freefaller, a lot of pressure was applied to the abdomen and a little pressure was applied to the hip (waist). In contrast, as with the Starfish posture, when the back of the paw touches the pad and reaches up, more pressure is applied to the hip (waist) side.

Recognizing method using ressure ratio of Figure 6 applies the following algorithm. If the value of PR (3) is 0.32 or more and the value of PR (4) is 0.3 or less, it is recognized as Freefaller posture, otherwise it is recognized as Starfish posture. The recognized Starfish posture through this process is called the posture (9) in the future.

The sleep posture, which is not distinguished by (7) or (8), is a side lying on the posture from (1) to (6). In both postures (1) and (2), both arms are raised to the height of the head, which is measured at R1, the shoulder row.

Therefore, if the left and right width of Grade measured in R1 is 3 or more, it can be said as (1) or (2). In addition, when the Grade of RGV (1, 4) or RGV (1, 5) is 2 or more, the posture is (1) while if the value of RGV (1, 1) or RGV (1, 2) is more than 2, the posture is (2). The remaining postures are also classified according to this sorting method.

4. RECOGNITION EXPERIMENT

4.1 Experiment Environment

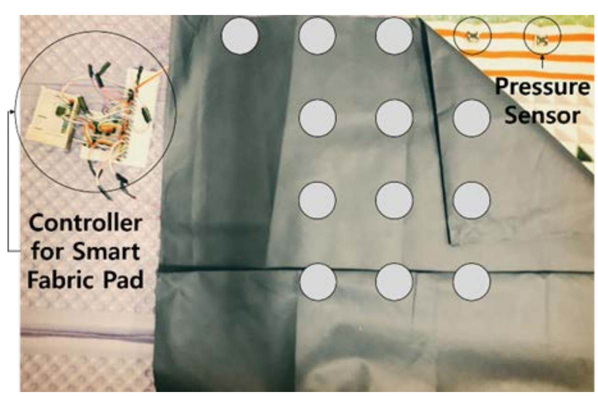

Figure 8. Smart Fabric Pad.

In order to confirm the validity of the proposed algorithm, this study conducted the accuracy test for the recognition algorithm. Figure 8 shows the pad used in the experiment.

The gray circles on the pads indicate where the fabric type pressure sensor is located and the two circles on the upper right are actual smart fabric pads with multiple pressure sensors taken from the top of the fabric. The controller responsible for measurement and analysis used the raspberry pi 3 B + model.

Experiments were conducted by extracting the pressure data generated by the subject lying down on the pad and forming a data set. The subjects who participated in the experiment were a 26-year-old male with a height of 176.8cm and a weight of 62.1kg.In order to confirm the recognition accuracy, we constructed 100 data sets for each posture and executed the algorithm by dividing ten by ten.The following results were obtained by comparing the perceived attitude with the actual dataset.

4.2 Experiment Result

Figure 9 and Figure 10 graphically show the number of matches of the perception of the algorithm for each posture. The horizontal axis is the experiment number and the vertical axis is the number of recognitions.

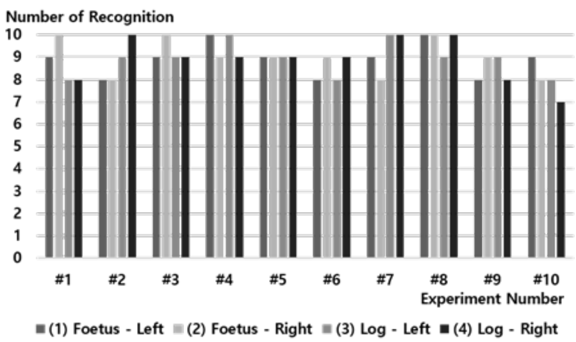

Figure 9. Experiment Result of Posture 1 to 4.

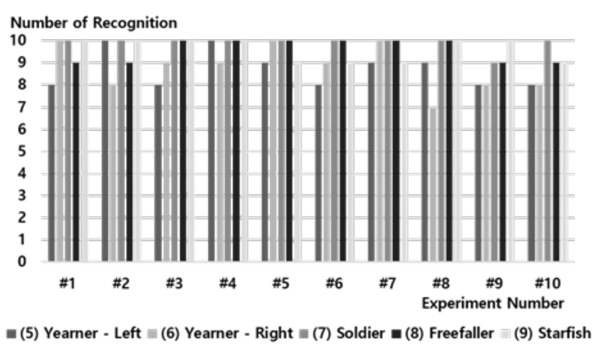

Figure 10. Experiment Result of Posture 4 to 9.

The experiment results show that from Postures (1) to (9) have a minimum of 88% and a maximum of 99% accuracy rate. Thus, in general, the postures that are not laid on the side, but laid front or down like Postures (7), (8), (9) have high accuracy rates.

4.3 Analysis and Evaluation

For (7), (8), and (9), postures that were not laid down on the side, the experiment resulted 97% on average, a high recognition accuracy rate. This is because the upper body part is in contact with the pad when lying on the bed, so the analysis algorithm is not complicated because of the relatively small number of joints that can be moved compared to other postures. However, posture of bending the upper body forward or reaching the arm while lying sideways like (1) to (6) was sometimes confused in the algorithm result. For example, (1) and (2) are the postures where the arms are raised to R1, which is the shoulder height, and extend to the front of the body. In this case, the arm was not detected due to the deviation of the sensor from the sensor posture, and the arm was not sensed as the posture (3) or (4). These errors are judged to be a result of a decrease in the recognition accuracy caused by a lack of the number of sensors or a wrong location. Therefore, to solve this problem, more sensors should be placed on the pad or the overall layout should be modified accordingly.

5. CONCLUSION

This study models a smart fabric sensor for sleep, experiments were conducted to compare the recognition results of the extracted data set and the algorithm. Experimental results show that the implemented algorithm has a recognition accuracy of about 91.4%. However, in the case of the Foetus, Log, and Yearner postures, the position of the arm was not recognized accurately due to the limited number of sensors. Therefore, additional enhancements are needed to increase the accuracy of the algorithm by adding sensors to the pad and configuring a more efficient layout. It is also necessary to optimize the algorithm by experimenting with other subjects.

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