# i-Sleep: Intelligent Sleep Detection System for Analyzing Sleep Behavior

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***Abstract*—Sleeping is a naturally mechanism of body for help to repair the body. However, to monitor the sleep quality is not an easy task. In this research, we purpose sleep detection system, which can classify sleep postures and calculate Sleep Quality Index (SQI). Pressure sensing sensor, called i-Sleep sensor, with 48 embedded force sensors has been created in order to classify the sleep postures, several machine learning algorithms were adopted to classify the sleep posture. From the experiment, the successful rate of sleep posture detection is 86.7%. Finally, web application was implemented to show the real-time data, and sleep quality index in each day.**

***Keywords— Sleep posture, Sleep Quality Index, Sleep detection system, Pressure sensing, i-Sleep***

## I. INTRODUCTION

Sleep is caused by a complex pathology. That is a natural phenomenon of living organism and changes in various physical pathways to relax in a sleep posture. There is a lower level of consciousness like temporary unconsciousness, also no response to external stimuli or less movement. And sleep is an important for human health because sleep helps repair and refresh the body, relax and restore energetic activities. But not getting enough sleep will affect the body and mind, resulting in less efficiency in the next day. And if this issue becomes a serious problem, it will cause a neurosis.

There are many ways to manage sleep problem. Medicine is used most for helping sleep better. However, using medicine may cause health effects later including drug tolerance and addiction. Moreover, drug withdrawal, can result the reverse symptoms such as insomnia. The use of sleeping pills can manage sleep problem in the short term. But in the long term, relaxation is the best way, such as listening to music, to help the body reduce stress and help sleep better without any side effects to the body.

In addition, sleep posture and the period of sleep can show whether that person has an illness or not. The sleeping in the same posture may affect health, such as Office Syndrome and disease associated with muscle and bone. Although the illness has been treated, but if the person still has the same sleeping behavior, symptoms may occur recurrently.

To address this shortcoming, this research aims to create a system for identifying sleep posture by using a pressure sensors. i-Sleep sensor is introduced to measure the human force on bed, placed at various points under the mattress. Furthermore, several machine learning algorithms are used to analyze the data from the trials and training model, which can be used to classify an individual's sleep postures. 6 postures on bed consist of supine lying, left lying, right lying, sitting on bed, changing posture and getting out of bed. We compared 7 popular machine learning methods for sleep posture classification. The experiment results showed that K-Nearest Neighbors (KNN) method got the highest accuracy at 86.7%. The result from this research can be used to measure the sleep quality index or analyze the behavior of each individual or person who has sleep problem, whether they have adequate sleep or not.

## II. LITERATURE REVIEW

Sleeping is natural repeatedly mechanism of mind and body, inhibition of all voluntary muscles, and reduced interactions with surroundings. Normally, when we are sleeping, most of body's systems work on anabolism state. Anabolism state recruits immune system, nervous system, bone and muscular system. All of these processes are important to emotional and self-regulation memory and understanding efficiency. [1]

Sleep posture classification has been proposed in several researches. We can divide the input device for sleep posture classification into two groups: sensor-based technology and camera-based technology.

### *A. Sensor-based Technology*

In sensor-base technology, most of researches used Force-sensor resistor (FSR) sensor for detecting physical pressure, squeezing and weight. FSR mechanism is a resistor that change its resistive value depending on how much its pressed. Meanwhile, some researches proposed piezoelectric ceramic sensors, which can produce an electrical potential when it is subjected to mechanical vibration.

Hsia et al. proposed a pressure sensitive bed system for analyzing and comparing of sleep posture classification [2]. Two layouts of FSRs mat, consisted of 16 strip sensors and 56 sensors was conducted. Bayesian inference with Kurtosis and Skewness parameter were used to classify three main postures (supine, lying left, and lying right). They also compared three methods, which are PCA+SVM, Raw Data+SVM and Descriptive Statistics+SVM for classifying sleep posture. The average classification accuracy is 60%, 83%, and 77% respectively. In addition, sensor mats have

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been proposed in several researches [3-6]. A part of the type of sensors, optimization of the number, location, and size of pressure sensor are interesting themes that several researches focus. 2048 pressure sensor mat was presented in [4]. They used 3 methods, filtering, morphological operation and scaling, for data normalization. K Nearest Neighbor was adopted for classifying 8 classes. Sabri Boughorbel et al. [5] introduced machine learning algorithms for sleep posture classification. Four classes, including supine, pone, lying left, and lying right were classified.

Piezoelectric Ceramic sensor was also used to get information on bed. Bed posture classification by neural network and Bayesian network using noninvasive sensor for elder care was proposed by Viriyavit et al. [7]. Sensor panel, with 2 FSRs and 2 Piezoelectric Ceramic sensors, was introduced and placed in the thoracic area. Combination of neural network and Bayesian Network for classification was used to create the AI model.

### *B. Camera-based Technology*

Vision technology is one of the devices that can determine sleep posture. Depth camera is one of popular devices that used in vision approach. Grimm et al. [8] proposed the technique to avoid fall when people sleep on bed by using depth camera. Disparity maps were converted to depth maps and bed aligned map to solve alignment problem into many grids. They used Convolutional Neural Network (CNNs) in 3 layers for classification human position on bed. Signal Processing was adopted with Depth Data. Data were record in 512x424@30 fps depth image. Camera position was set on top of a tripod and it is directly facing down on top of the subject. With the image processing technique, three features were extracted, which are FFT of whole 2D grayscale depth image, 2D cross-section scans of 3D depth data and Gabor feature. Finally, they propose 2D cross-section scans and its Fourier transform signals can be used for distinguishing different sleeping postures. However, the main problem of camera-based technology is privacy because we have to setup camera to record activities all night.

## III. METHODOLOGY

### *A. System Architecture*

The objective of this study was to develop an automated pressure sensing bed system which could provide sleep postures and estimate sleep quality. We developed both hardware and software systems in order to provide patient's assistance.

Intelligent sleep detection system, i-Sleep system, was proposed in this research for analyzing sleep behavior, as illustrated in Fig. 1. In system architecture, we used 48 FSR sensors on two form plates. Each sensor obtained the pressure data in different location by microcontroller and sent its data through cloud for collecting data into database. Machine learning model was trained by collected data from 35 volunteers. This model is used to predict the current sleep posture and store result of classification into database for processing sleep quality. Furthermore, web application was implemented for display real time sleep posture and summarize the sleep behavior for estimation of sleep quality.

### *B. Hardware design*

Pressure sensing sensor or i-Sleep was designed with 48 FSR sensors on 2 foam plates, as shown in Fig. 2. The first plate was 57 centimeters width and the second plate was 61 centimeters width. And both were 86 centimeters height. These pressure sensing sensors were stacked together, so that there was one piece of 118x86 centimeters i-Sleep sensor.

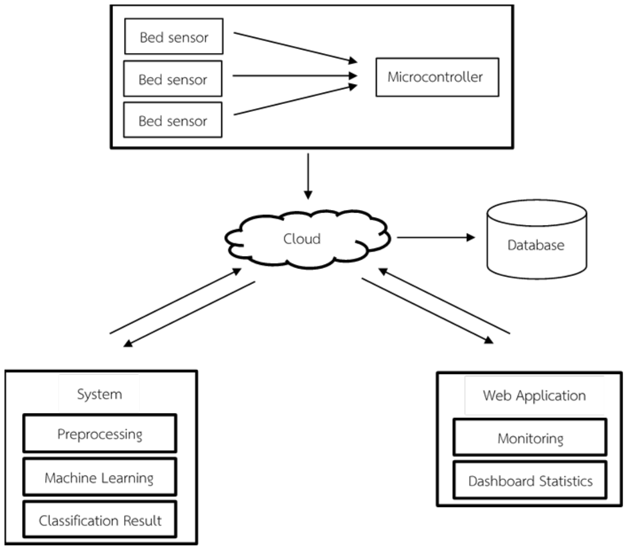


Fig. 1. Overview of i-Sleep system.

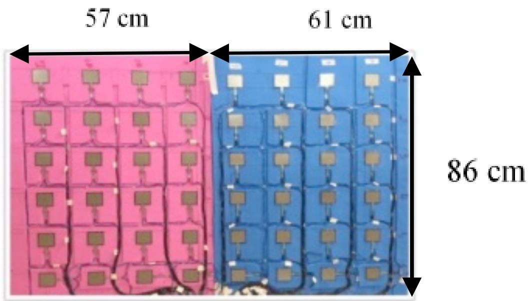


Fig. 2. i-Sleep sensor.

i-Sleep sensor was placed under the mattress. Thus, volunteers would not directly touch the i-Sleep sensor.

To obtain the data, ESP32, a low-cost, low-power system on a microcontroller with integrated Wi-Fi and dual-mode

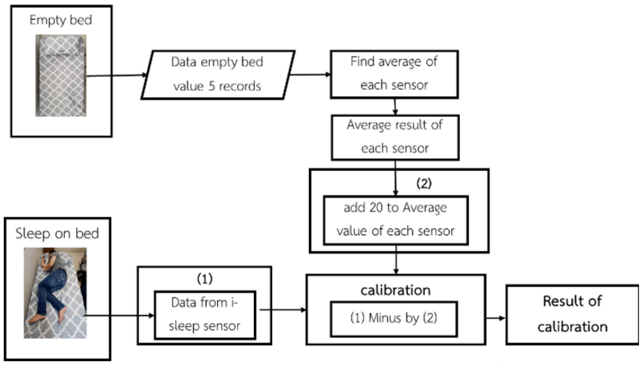


Fig. 3. Calibration method

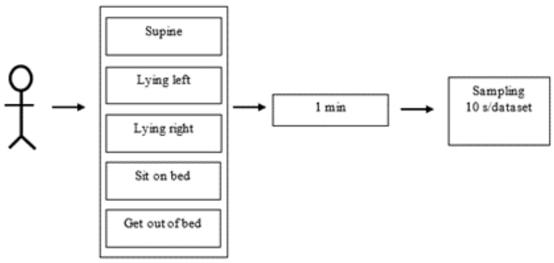


Fig. 4. Data preparation

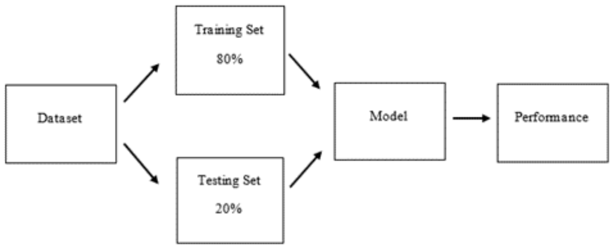


Fig. 5. Training set and testing set

Bluetooth was used. By putting this sensor in series electrically with a resistor of known value, where the total voltage across the whole circuit was 5V, applied force would cause the voltage going into the MCU to fall between 0-5V, which was the common operating range of many MCU's analog to digital converter (ADC). For a 12 bit ADC, the maximum voltage of 5 V corresponds to the digital value of 4095.

### C. *i-Sleep system*

In order to classify sleep posture, machine learning technique is adopted in i-Sleep system. We can divide into three parts as followed.

**Data preprocessing**

First a baseline value of each sensor had to be established, since each sensor's response characteristic is a little different from all the other due to the variation in constructing them. First, a total of five output values from each sensor was averaged and plus with some constant for protecting the error. After we got the threshold, new input data would be minus by threshold for setting zero for each sensor, as show in Fig. 3.

To create sleep posture classification model, we collected the pressure data from the participants with 5 sleep postures consist of lying supine, lying left, lying right, sitting on bed and getting out of bed. Participant was asked to perform each sleep posture in 1 minute. The sensors were read from every 10 seconds, as show in Fig. 4.

However, the dataset was not clean enough for training model. Missing value happened in some circumstance due to quality of sensor. Thus, we edited data in the dataset by using the average value fill in the lost data. Then, we split training set with 80% and testing set with 20%. In training set, data was used to build the machine learning model for analyzing and classifying sleep posture. In testing set, data was used to estimate performance of machine learning model, as shown in Fig. 5.

**Data categories**

The preprocessed data is categorized into three levels: raw data, normalized data, and color scale data.

- **Raw data** refers to the pressure data that collected from i-Sleep sensor after calibration and removed missing value. Range of raw data was between 0-4095.
- **Normalized data** refers to the data that used the normalization process. We used standardization, shown in equation (1), after collected the raw data from i-Sleep sensor. Due to the range of data was wide, each attribute might affect to the accuracy. Therefore, we tested the model by normalized the data for reducing the possibility of inconsistent data.

$$Z = \frac{x - \mu}{\sigma} \tag{1}$$

- **Color scale data**, we have purpose of separating the data that we need the smallest numbers of data set and equal numbers of data in each set. We divided data into four sets due to corresponding to our purpose and these sets might show significant results.

**Machine Learning**

It is a tool for prediction or classification the data. In this research, sleep posture classification model was created by using supervised learning technique. For the classical mahine learning classifiers [9], we considered 7 algorithms, including Gaussian Naive Bays, Bernoulli Naïve Bays, Neural Network, Support Vector Machine (SVM), Logistic Regression, Random Forest and K-Nearest Neighbors (KNN).

With the advantage of machine learning technique, the ambiguous pattern can be identified. For example weights of male and female are different. It can make variety pattern of pressure data although sleep with the same posture.

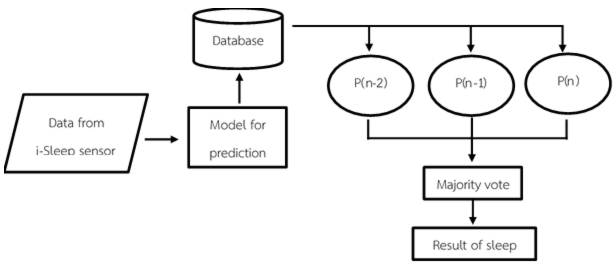


Fig. 6. Majority vote on web application

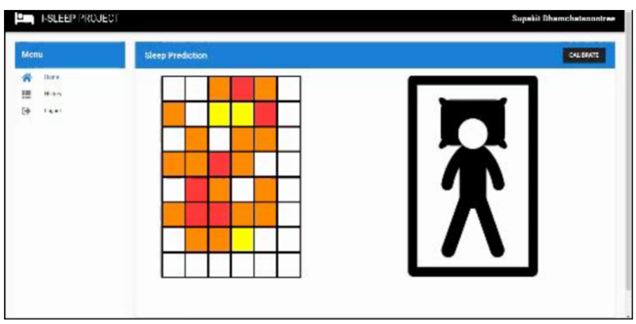


Fig. 7. Sleep prediction

Furthermore the pressure data is continuous value and each

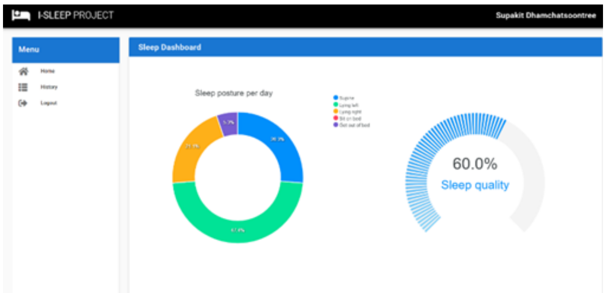


Fig. 8. Sleep dashboard

(a) (b) (c)

(d) (e)

Fig. 9. Sleep posture (a) Lying supine (b) Lying right (c) Lying left (d) Sitting on bed (e) Getting out of bed.

sleep posture is active in different zone. For example, when human sleep in supine posture, center of i-Sleep sensor will be activated, or left side of i-Sleep sensor will be activated when human sleep most to the left or lying left. However, each activated zone has different pattern. Thus it is difficult to use only rule-based to classify the sleep posture.

### D. *Web appplication*

After we received the classified sleep posture result, we will display on web application. The server was developed by Python and the data is collected into the mongoDB. For the web application, we have two main modules:

- Realtime sleep posture prediction: It retrieved three latest predition results from the database through API. Then, Majority vote, illustrated in Fig. 6, is used to determind the current sleep posture before showing on web application., as shown in Fig. 7.
- Sleep dashboard: We summarized the sleep posture in daily or monthly for analyzing sleep behavior and estimation of sleep quality. In sleep quality, we use Pittsburgh Sleep Quality Index (PSQI) as a guideline for calculate the sleep quality index, as show in Fig.8.

For the sleep quality index of this research, we calculated based on five components:

- Component 1: REM cycles
- Component 2: Sleep latency
- Component 3: Sleep duration
- Component 4: Sleep efficiency
- Component 5: Sleep disturbance

Finally, we add 5 component scores together for estimating sleep quality score. There are 3 levels in sleep quality score:

- 75% and above: Good sleep quality
- 50% to 75%: Fair sleep quality
- Less than 50%: Poor sleep quality

## IV. EXPERIMENT RESULTS

### A. *Experimental set-up*

The experiment was done by 30 volunteers, 15 males and 15 females. They were different in gender, height and weight. They were also diverse in term of body pattern and how they fall as sleep. The average height and weight of 30 people was 150-180 centimeters and 50-80 kilograms. Each of participate slept on the bed to collect the pressure data. Volunteers performed 6 postures, including lying supine, lying right, lying left, sitting on bed, changing posture and getting out of bed, which collected about 1 minute long per posture. However, if there is a failure during sending the data to cloud, the current pressure data will not be counted. The steps of collecting sleep posture data illustrate in Fig. 9.

### B. *Experimental results*

From the experimental setup, 1983 sleep posture records were collected, which could be divided to lying supine (388 records), lying right (379 records), lying left (377 records), sitting on bed (385 records), changing posture (99 records) and getting out of bed (355 records). We divided the data into 2 parts: 80% for Training set and 20% for Testing set. The results of the experiment are as follows:

**Raw data**

The data in Raw data format, in range between 0-4095, was tested with 7 algorithms, and the result of sleep posture classification is presented in Table 1. From the results, random forest, KNN, and logistic regression got the high accuracy with 95.2%, 94.9%, and 94.7% respectively.

**Standardized data**

Due to the range of the raw data is wide, we compared the 7 traditional machine learning algorithms with normalized data. Table II shows the result of sleep posture classification with normalized data. From the results of sleep posture classification with normalized data. All algorithms achieved high accuracy in prediction. However, SVM got the highest accuracy with 95.8%.

TABLE I. SLEEP POSTURE CLASSIFICATION RESULTS WITHRAW DATA

| Algorithm | Accuracy (%) |
|---|---|
| Gaussian Naïve Bayes | 84.3 |
| Bernoulli Naïve Bayes | 90.6 |
| Multi-Layer Perceptron (MLP) | 92.4 |
| Support Vector Machine (SVM) | 37 |
| Logistic Regression | 94.7 |
| **Random Forest** | **95.2** |
| K-Nearest Neighbors (KNN) | 94.9 |

TABLE II. SLEEP POSTURE CLASSIFICATION RESULTS WITH NORMALIZED DATA

| Algorithm | Accuracy (%) |
|---|---|
| Gaussian Naïve Bayes | 93.9 |
| Bernoulli Naïve Bayes | 93.1 |
| Multi-Layer Perceptron (MLP) | 94.5 |
| **Support Vector Machine (SVM)** | **95.8** |
| Logistic Regression | 94.5 |
| Random Forest | 95.2 |
| K-Nearest Neighbors (KNN) | 94.5 |

### Color scale data

Data in color scale data has the short-range value, which is between 0 and 3. Table III shows the result of classification when using color scale data. From the TABLE III, classification results are not significant different, except Gaussian Naïve Bayes and Bernoulli Naïve Bayes. In addition, we have tested the i-Sleep system with unseen data. We use 100 sleep posture records from extra two volunteers, and 20 records of each sleep posture were collected. Table IV describes the classification results of unseen data test in raw data format, color scale data format , and standardize data format.

From the TABLE IV, K-Nearest Neighbors achieved the highest accuracy in testing with unseen data in all data formats: raw data, normalized data, and color scale data with 91.1%, 86.7%, and 88.8% respectively. Finally, we select KNN classification for i-Sleep system because normalized datasets are appropriate for KNN. Moreover, KNN got high accuracy with unseen data test. In this research, k was set as odd value for protecting prediction result in the same class and then we set k is 5.

TABLE III. SLEEP POSTURE CLASSIFICATION RESULTS WITH COLOR SCALE DATA

| Algorithm | Accuracy (%) |
|---|---|
| Gaussian Naïve Bayes | 77.5 |
| Bernoulli Naïve Bayes | 89.1 |
| Multi-Layer Perceptron (MLP) | 95.7 |
| **Support Vector Machine (SVM)** | **95.9** |
| Logistic Regression | 93.9 |
| Random Forest | 95.7 |
| K-Nearest Neighbors (KNN) | 94.5 |

TABLE IV. SLEEP POSTURE CLASSIFICATION RESULTS WITH UNSEEN DATASET

| Algorithm | Accuracy (%) | | |
|---|---|---|---|
| | Raw data | Color scale data | Normalized data |
| Gaussian Naïve Bayes | 80.0 | 82.2 | 4.4 |
| Bernoulli Naïve Bayes | 80.2 | 82.2 | 77.7 |
| Multi-Layer Perceptron (MLP) | 80.0 | 77.7 | 75.7 |
| Support Vector Machine (SVM) | 37.7 | 62.2 | 62.2 |
| Logistic Regression | 71.1 | 82.2 | 75.7 |
| Random Forest | 80.0 | 77.1 | 77.7 |
| **K-Nearest Neighbors (KNN)** | **91.1** | **88.8** | **86.7** |

## V. CONCLUSION

In this work, we implemented i-Sleep for identifying sleep posture by using a pressure data. We designed 48 FSRs sensor, called i-Sleep sensor, for detecting pressure on the bed. Then, data was collected 30 participants from 15 males and 15 females. All data were categorized into raw data, standardized data and color scale data. Data was training in various models. From the experiment, when models were testing by unseen data, K-nearest neighbors algorithm achieved the highest performance with 91.1, 88.8, and 86.7 accuracy in raw data, normalized data, and color scale data respectively. Furthermore, the results of classification were shown on web application. User can find the sleep posture history and sleep quality of each day via web application.

For future work, we could reduce number of sensors, and develop modern technique into classification method such as convolution neural network, or deep learning.

## ACKNOWLEDGMENT

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