Data Labeling Scheme for Bed Position Classification

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Abstract. This study proposes a data labelling scheme for bed position classification task. The labelling scheme provides a set of bed position for the purpose of preventing the bed fall and bedsore injuries which seriously imperil the aging people health. Most of the elderly fall down when they attempt to get out of bed with unassisted bed exit. Also, there is a high possibility of rolling out of bed when an elderly lies close to the edge of the bed. In addition, a bedridden person, who cannot reposition by him/herself, has a high risk of bedsores. Repositioning in every two hours alleviates the prolonged pressure over on the body. We collected the data from a specific set of bed sensor and classified the signal into five positions on the bed, which are off-bed, sitting, lying center, lying left, and lying right. These five positions are the fundamental information for developing a model to capture the movement of the elderly on the bed. The precaution strategy is then able to be designed for the bed fall and bedsore prevention. The data of the five different positions are manually annotated by observing the synchronized video through a specially designed workbench. The combination of the positions of off-bed, sitting, and lying is used to detect a bed exit situation, and the combination of the positions in the lying state, i.e. lying center, lying left, and lying right, is used to detect the rolling out of bed situation. Moreover, to notify for reposition assisting in the bedridden, the three lying positions are used to calculate the time of the abiding position.

Keywords. Bed position classification, geriatric care, data labeling scheme

1. Introduction

Falls are the major trouble of elderly care in nursing homes. The possibility of this accident leading to death or disability for elder people is as high as 40.4% [1]. From the national statistical office of Thailand survey, 11.6% of elderly have an experience of falling down and 54.1% of them are hospitalized. The possibility of injury gets higher

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with higher age as the body becomes weaker [2]. 8.7% of elderly at a medical center in Taiwan have a tendency of falling again if they have fallen previously. 28.6% of them fell at the bedside [4]. Most of the elder people fall when they attempt to get out of bed or lie close to the edge of a bed.

On the other observation, lacking of reposition in bedridden people is a cause of bedsore due to the prolonged pressure over the body. The body movement in every two hours is widely accepted to alleviate the bedsore injuries.

To prevent accidents around the bed and bedsores, we have to constantly monitor the elderly activity on and around the bed. That means a large number of care workers is required to take care of an elderly. The demand for geriatric care is increasing in the ageing society. The nursing home care faces a shortage of care workers. The availability of the care workers today is only about 11.1% of the total elder population as reported by the National Statistical Office of Thailand [2]. It is leading to a heavier burden and inefficiency in elderly care services in the coming years of ageing society. Therefore, the monitoring system for elderly care becomes more and more necessary to reduce the workload of care workers.

Although wearable devices are widely introduced to monitor the body movement, it is uncomfortable for the elderly to use in their daily life [5-6]. This can result in discontinuous monitoring as when the elderly refrain from wearing the device. On the other hand, a non-contact sensor has been proven to be appropriate for continuous monitoring the activity and body movement on the bed. In this case, the system must be able to detect the body position on the bed in order to prevent the bed falls. There are some reports of using an ultrasonic sensor, air pressure sensor, and vibration sensor [7-9]. Though the aforementioned studies can determine whether the patient is in the bed or not, this is not enough to prevent a fall. To prevent falls, the system needs to detect the position of lying with respect to the edge of the bed. Some previous studies use commercial pressure mat systems to detect the bed position [11-14]. Although the studies have shown promising results in bed position classification, their approaches require quite a large number of sensors, which are not practical and are costly in actual practice. For this concern, one of the purposes of our study is to reduce the number of sensors and still keep a comparable performance.

This paper proposes a scheme for labeling the bed position to the signal data of the bed sensor. We collect the signal data from a specific set of bed position sensor and classify the signal into five body positions on the bed, which are off-bed, sitting, lying center, lying left, and lying right. These five positions are the fundamental information for constructing a training model for capturing the elderly body movement on the bed.

The paper is organized in the following sections. Section 2 and section 3 discuss the details of the sensing equipment and the data collection respectively. Section 4 describes our approach in labeling the signal data for the body position on the bed. Finally, section 5 concludes the design of the labeling scheme.

2. Equipment

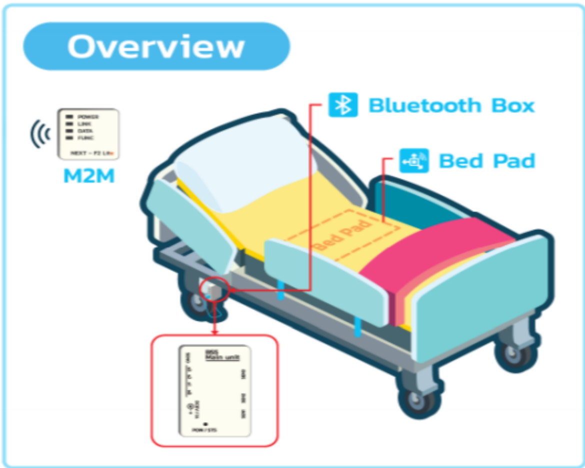

Figure 1. Composition of the bed sensor equipment provided in MIMAMORI system

In our data labeling scheme, the AIVS Co. Ltd. ready-made sensor pad, called MIMAMORI system is used to prepare the signal data set. This system is composed of an M2M box (router), a Bluetooth box, and a bed sensor pad as shown in Figure 1. The Bluetooth module box collects the signals from the bed sensor pad and packages the data to transfers to the M2M box (router) wirelessly. The M2M box (router) classifies the data to observe the target body movement which can be used to detect. This information can be used to display the notification.

2.1. Sensing Equipment

The bed sensor pad consists of a pair of two types of sensors i.e. two piezoelectric sensors and two force sensitive resistor (FSR) sensors. The force sensitive resistor (FSR) detects pressure and weight while piezoelectric sensor detects vibration. Each pair of the sensors is embedded on each side of the pad in the size of 180 mm × 600 mm as shown in Figure 2. The sensors are placed symmetrically in the middle of the pad. The pad is inserted under the bed mattress to avoid direct contact with the body.

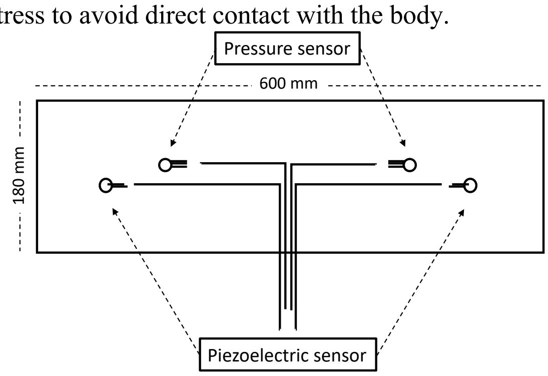

Figure 2. Sensor pad

Header	Signal Data					Ender
	Sensor ID	Piezo right	Weight right	Piezo left	Weight left	
8 byte	2 byte	8 byte	8 byte	8 byte	8 byte	3 byte

Figure 3. Data structure of signal data package

The Bluetooth module box is a data transmission device which packages the signal data, and wirelessly sends the packaged data to the M2M box (router). A package of the signal data has a sampling rate of 30Hz. One package is 45 bytes long. It contains of the header, signal data, and the ender. Figure 3 shows the structure of signal data package with 8 bytes of header, 34 bytes of signal data and 3 bytes of ender. The 34 bytes of the signal data are from the four sensors, which is composed of the first two bytes containing the sensor ID, and the next 8 bytes each containing data from each sensor i.e. the right piezoelectric signal, the right weight signal, the left piezoelectric signal, and the left weight signal, respectively. The magnitude of each sensor value is 256. The range of the value of the piezoelectric signal is between -127 to 128, and the range of the weight signal is between 0 to 256.

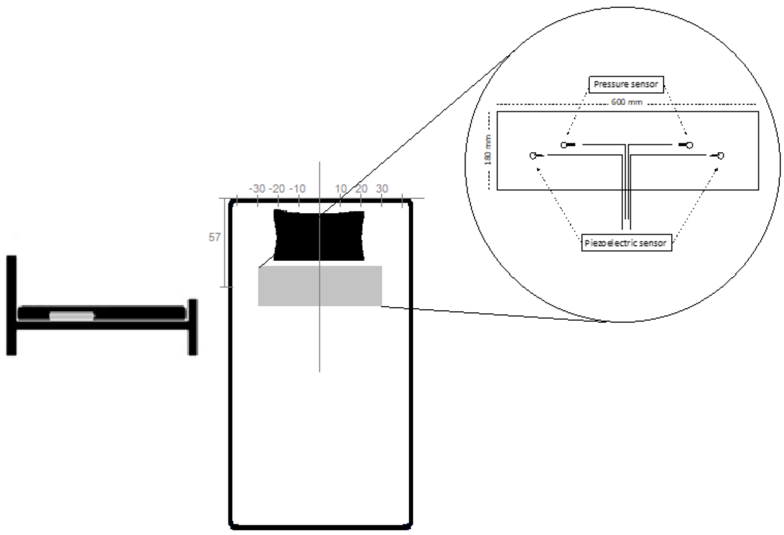

Figure 4. Placement of the bed sensor pad

2.2. Placement of the Bed Sensor Pad

The sensor pad is placed beneath the bed mattress in the transverse direction, about 57 cm from the top of the bed. This position is around the body back area of the supine posture. The average height of the head, i.e. vertical length between the tip of chin and the top of the head. For the Thai people, it is approximately 20 cm. The distance from neck to bust position is approximately 17cm on average [7]. From our observation, most people lie about 20 cm from the top of the bed. Therefore, the position at about 57 cm from the top of the bed is suitable for setting the sensor pad to align the center of the pad to the body back area. Horizontally, the center of the pad is placed to align with the center line of the bed, as shown in Figure 4.

By placing the bed sensor pad as shown in Figure 4, the acquired signal data from both sides of the pad can show the difference for detecting three different types of lying positions on the bed, such as lying center, lying left, and lying right. For example, in the case of lying center, the body applied pressures on both sides of the pad, so that both sides of weight signal are activated. In the case of lying left or lying right, sensors in the lying side are highly activated comparing to the other side. Sample signal patterns are shown in Figures 5 (c) – 5 (e).

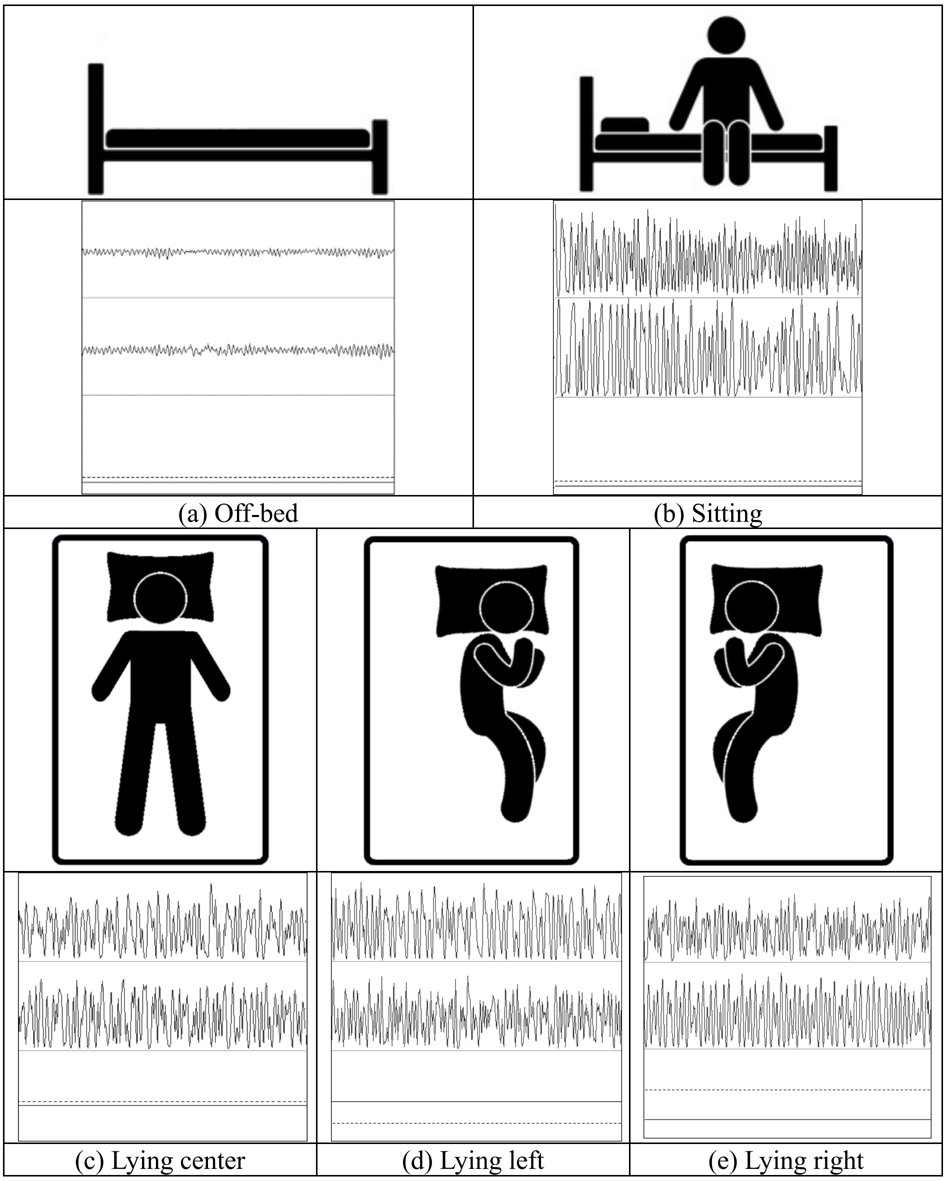

Figure 5. Correlation between signals and positions, where the first solid line is the signal of piezoelectric sensor on the left, the second solid line is the signal of piezoelectric sensor on the right, solid line is the signal of FSR weight sensor on the left, and dash line is the signal of FSR weight sensor on the right

Because of placing the sensor pad at upper part of the bed, the signals in sitting position can then be distinguished from the ones of lying positions. In the sitting position, the activation of the FSR sensors is low because there is no direct weight on the sensors. In addition, the signals from piezoelectric sensors are also used to identify whether somebody is on the bed or not. Figures 5 (a) – 5 (b) show the sensor signals of off-bed and sitting positions. Both sides of the FSR sensors are lightly activated in both positions. In the sitting position, the piezoelectric signals are lightly activated in contrast to the off-bed position which the signals from piezoelectric sensors can hardly be detected.

3. Data Collection

3.1. Target Participants

All patients who had age more than 50 years old, or had the Expanded Disability Status Scale (EDSS) more than 5, admitted at the Banphaeo hospital, and voluntarily participated in this study. The Expanded Disability Status Scale (EDSS) is the standard scale for assessing the body disability. The EDSS scale has a range between 0 to 10, in 0.5 increments. The higher level of EDSS represent a higher level of disability, EDSS level 0 for the normal status and EDSS level 10 for death status. For example, EDSS level 5 means the ability of ambulatory without aid or rest for about 200 meters; disability severe enough to preclude full daily activities. EDSS level 8 means the patient is restricted to bed or chair or perambulated in wheelchair, but may be able to be out of bed by himself/herself in much of the day; retains many self-care functions; generally, has effective use of arms. The 19 subjects between the age of 35-92 agree on the written informed consent to participate in this study. The experiment is approved by the Human Ethics Committee of Thammasat University.

Figure 6. John Kurtzke's Expanded Disability Status Scale (EDSS)

3.2. Procedure of Data Collection

The collected data includes the information of age, sensor signal, EDSS, and video file. Due to the privacy issue, the period during nurse intervention and nakedness are not permitted to record. The patient EDSS assessment is performed by nurses. We collect data from different five rooms equipped with different sets of sensors. Table 1 is the summary of the data collected from each subject. The room 1, 2, 3, 4, and 5 is occupied by 2, 3, 3, 6, and 5 subjects respectively. In case of EDSS score, there are 11 patients having EDSS level 0, 6 patients having EDSS level between 1-3, and 2 patients having EDSS level over 8. The 2,462 hours of data are collected. The average length of stay is 130 hours or 5.4 days.

Table 1. Summary of each subject dataset

Subject	Room	age	EDSS	Length of stay (h)
1	1	61	0	138
2	1	61	0	138
3	2	67	1	49
4	2	65	3	212
5	2	52	1	271
6	3	67	8	197
7	3	74	0	194
8	3	79	0	260
9	4	73	0	120
10	4	83	1.5	25
11	4	81	3	24
12	4	85	0	130
13	4	92	0	93
14	4	72	0	108
15	5	35	8.5	142
16	5	51	1.5	124
17	5	54	0	149
18	5	65	0	40
19	5	59	0	48
Total				**2462**

4. Labeling Scheme

4.1. Labeling Method

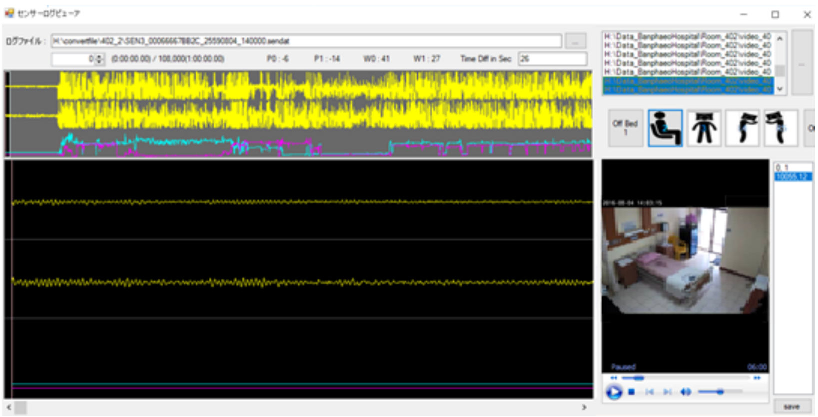

Figure 7. Screen shot of data labeling workbench

The labels are designed for the purpose of fall precaution. The elderly has a high risk of falling down when they are getting out of bed without assistance. Therefore, the precaution state can be signified by the positions of sitting and out of bed. For the rolling out of bed, the precaution state can be signified by the positions of lying left and lying right. The time of the abiding position is taken into account to prevent bedsores by accumulating the abiding position time.

The signal data is labeled by monitoring the synchronized video as shown in Figure 7. The annotator manually scans the signal data to identify the points when the subject was changing position. The point is then labeled as the beginning or end of the position.

The number is used to label the class of the bed position. The labels for five fundamental position classes and the class for other are described in the followings,

- "1": Off bed (the subject is not on the bed)
- "2": Sitting
- "3": Lying center (the subject is lying in the center of the bed)
- "4": Lying left (the subject is lying on the left side of the bed)
- "5": Lying right (the subject is lying on the right side of the bed)
- "9": Other (the positions other than the above five positions, or cannot be identified)

As a remark, lying left "4" and lying right "5" positions are defined when the subject is lying on either left or right side of the bed regardless of the lateral position of the subject. The signal data with either ambiguous positions or without video to confirmed are considered as other "9".

The state of changing is labeled with the combination of the starting position and the ending position. For example, the signal data is labeled as "35" when the subject is changing position of lying center to lying right. As a result, there are 14 intermediate position classes defined as shown in Table 2.

Table 2. Definition of labels for intermediate position classes

Label	**Description**	**Label**	**Description**
12	Off-bed to Sitting	35	Lying center to Lying right
21	Sitting to Off-bed	42	Lying left to Sitting
23	Sitting to Lying center	43	Lying left to Lying center
24	Sitting to Lying left	45	Lying left to Lying right
25	Sitting to Lying right	52	Lying right to Sitting
32	Lying center to Sitting	53	Lying right to Lying center
34	Lying center to Lying left	54	Lying right to Lying left

4.2. Database structure

Table 3 shows the format of the filename of the dataset. The format guideline is provided to couple the header file and the dataset file according to their filenames. The header file is a text file format containing the description of the dataset as shown in Figure 8. The header file provides the notation of the dataset together with the information of the subject and the particular equipment which can be varied. Both files are needed to understand the description of the dataset. The filename is composed of the recording date in the format of YYYYMMDD and appended by the subject ID, which is used the same to correspond the header file to the dataset file. For example, Bed_2019011_1_head.txt is the header file of the dataset recorded in 2019 January 1, and the subject ID is 1. The corresponding dataset filename is Bed_2019011_1.csv

Table 3. Format of filename

File name	Description
Bed_YYYYMMDD_ID_head.txt	Header file containing the information of labeled dataset
Bed_YYYYMMDD_ID.csv	Dataset file containing the labeled dataset in CSV format

The header file is a text file having the filename formatted as described in Table 3. The detail in the header file is described in the format shown in Figure 8.

```
<YYYYMMDD>, <subject ID>, <mac address>, sensor: [<sensor
notation>], class: [<class notation>], offset: [[<minimum
offset>], [<maximum offset>]], <total number of dataset>
```

Figure 8. Description of data in header file (Bed_YYYYMMDD_ID_head.txt)

The description in the header file is provided as shown in the followings,

- <YYYYMMDD> is the record date.
- <subject ID> is an integer referring to a unique subject ID.
- <mac address> is the Mac address of the device.
- sensor: [<sensor notation>] is the list of the sensor notation corresponding to the list of the signal data in the CSV file.
- class: [<class notation>] is the list of the class label with its notation. There are five fundamental position classes with one other class, and 14 intermediate position classes as described in Section 4.1.
- offset: [[<minimum offset>], [<maximum offset>]] is the list of offset value of the signal data.
    - [<minimum offset>] is the list of average value of the signals in the off-bed position, or offload position.
    - [<maximum offset>] is the list of average value of the signals in the lying center position, or full load position.

- <total number of dataset> is the total number of the dataset.

The offset values are listed the order of the defined sensors. Therefore, the offset values in Figure 9, offset: [[0.34, 0.2, -0.12, 0.8], [20.29, 45.2, 3.1, 48.9]], are listed in the order of sensor notation, sensor: [p0: right piezo, w0: right weight, p1: left piezo, w1: left weight]. Figure 9 shows an example of the header file.

```
20190111, 1, 00:06:66:67:BB:2C, sensor: [p0:
right piezo, w0: right weight, p1: left piezo,
w1: left weight], class: [1: off-bed, 2:
sitting, 3: lying center, 4: lying left, 5:
lying right], offset: [[0.34, 0.2, -0.12, 0.8],
[20.29, 45.2, 3.1, 48.9]], 63558
```

Figure 9. Example of header file (Bed_YYYYMMDD_ID_head.txt)

Together with the header file, the labeled dataset is provided in CSV file format with the same prefixed filename (named by using the header filename without "_head"). The value of <total number of dataset> is the total number of rows and one row for the column name. The first four columns of each row are the values of the four signals. The last column is the class label. Figure 10 show an example of the dataset file.

```
p0, w0, p1, w1, class
-6.0, 49.0, -8.0, 23.0, 1
-8.0, 49.0, -7.0, 23.0, 1
…,
-7.0, 49.0, -5.0, 23.0, 1
```

Figure 10. Example of dataset file (Bed_YYYYMMDD_ID.csv)

4.3. Statistics of Dataset

4.3.1. Size of Dataset

Table 4 shows the number of samples for each subject in each position. Most of the patients are apt to lie in the center of the bed, resulting 34.70% of all samples. Since the data sampling rate is 30 Hz, the data of lying center is as large as 71601361 lines or 662 hours 58 minutes and 48.67 seconds (number of lines divided by 30 times in 3600 seconds).

The period of time for one position is called *interval time slot*. Normally, one position in one interval time slot can last in more than one sample. Therefore, there can be many samples in the one interval time slot. For example, Figure 11 shows the signal in the sequence of off-bed, sitting, and lying center. This sequence has three interval time slots of three static positions with two intermediate positions ("12" for changing position of off-bed to sitting, and "23" for changing position of sitting to lying center). By extracting the period of time of each position, this labeled dataset can also be used to create the sleep model of the patient. This model can be used to detect the need for repositioning to countermeasure bedsores. According to the fact that the bedridden people need to be repositioned in every two hours to alleviate the prolonged pressure over the body.

Table 4. Number of samples for each position

Subject	# of samples				
	Off-bed	**Sitting**	**Center**	**Left**	**Right**
1	2618401	1491879	2905268	757209	2148593
2	943136	2103531	6070776	1172003	2409231
3	1435156	227720	600075	719441	365085
4	2677584	2472651	4567397	2013940	1096304
5	7024011	833605	8617848	3755907	1629044
6	2044640	1907768	4663568	3164236	6417095
7	756065	4277256	3330871	688585	5747187
8	5675452	4419305	12017232	1824036	1677805
9	868551	2642063	1918736	2509039	988665
10	916928	241962	591691	683150	36539
11	694178	186644	662649	24545	938290
12	1255697	2765764	3868646	1920577	1643054
13	2748068	576724	3856197	760989	1082126
14	4738695	447041	1438879	1680817	1127646
15	262945	951783	6988659	2507394	2400420
16	2489310	398169	3768076	2994610	1889510
17	1132205	3646007	3938122	1064024	393030
18	2097682	669110	740740	8951	9224
19	2684058	527960	1055931	99761	563666
Total	**43062762**	**30786942**	**71601361**	**28349214**	**32562514**
Percent	**20.87**	**14.92**	**34.70**	**13.74**	**15.78**

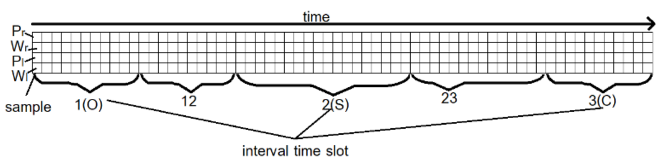

Figure 11. Structure of dataset

Table 5 shows the number of the interval time slots of each subject, which can be interpreted as the number of positions. For example, in the dataset, subject 1 stays in the position of lying left for 18 times.

Table 5. Number of positions for each subject

Subject	# of positions				
	Off-bed	Sitting	Middle	Left	Right
1	29	116	40	17	56
2	39	253	285	132	174
3	33	62	13	21	17
4	51	148	134	86	62
5	33	118	76	60	55
6	5	32	181	119	173
7	19	135	73	40	123
8	64	124	71	46	19
9	75	218	193	125	70
10	9	18	14	9	2
11	19	32	18	2	19
12	29	150	130	71	112
13	34	67	60	24	33
14	21	42	19	15	21
15	17	60	55	44	46
16	60	141	63	71	54
17	55	138	101	37	24
18	11	26	14	1	0
19	14	37	29	5	12
Total	**617**	**1917**	**1569**	**925**	**1072**

4.3.2. Probabilities of positions

Table 6 shows the probability of state transition of the 19 subjects estimated from the dataset. The values in the table are the probability values of changing position in the row to the position in the column. The probabilities of changing position are estimated by Bayes theorem and conditional probability as shown in Eq. (1) [10].

$$P(P_i|P_{i-1}) = \frac{P(P_{i-1}\ and\ P_i)}{P(P_{i-1})} \quad (1)$$

where P_i is the current position and P_{i-1} is the previous position. The probability of changing position from off-bed (O) to lying (C, L, R) position rarely occurs with 0.01-0.02 of the probability. It can be interpreted that the patient almost always becomes sitting (S) before going into bed. It is almost impossible that the patient jumps into the bed without changing position to sitting (S) or getting any assist before going into the bed. This is why the probability of changing position from off-bed (O) to sitting (S) is as high as 0.96.

Table 6. Probabilities of position changing

P_{i-1}	P_i				
	O	**S**	**C**	**L**	**R**
O	0	0.96	0.02	0.01	0.01
S	0.34	0	0.44	0.12	0.10
C	0	0.36	0	0.26	0.38
L	0.01	0.28	0.58	0	0.13
R	0.01	0.32	0.59	0.08	0

The probability can be depicted in the state transition diagram labeled with the transition probabilities, shown in Figure 12.

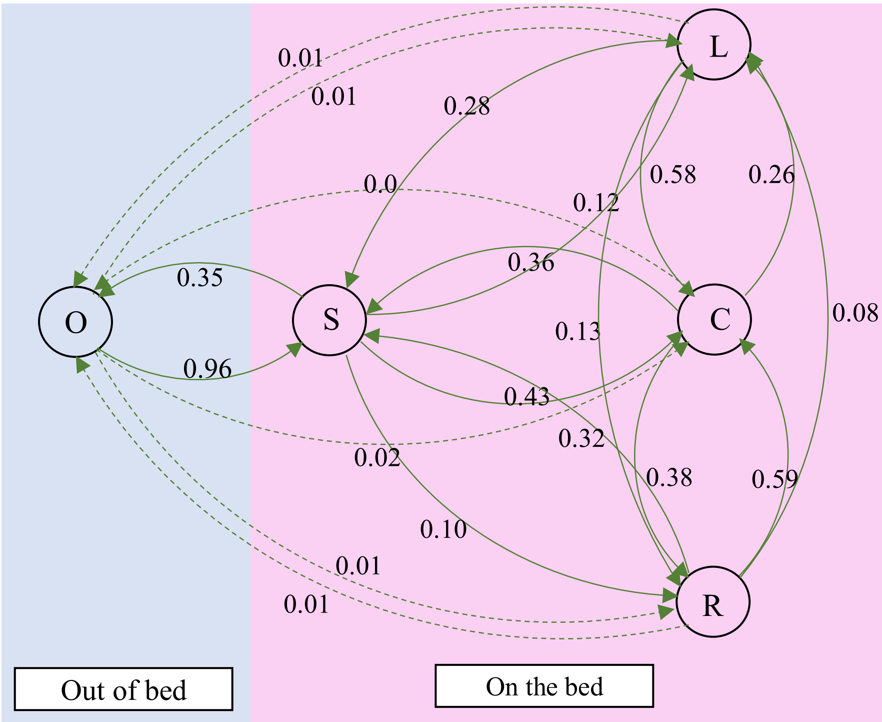

Figure 12. State transition with labeled probability

On the other hand, the probabilities of changing position from lying (C, L, R) to off-bed (O) position are also as low as 0-0.01. The probability of changing position from lying center (C) to off-bed (O) is 0. Therefore, we can conclude that rolling out of bed can happen only from edge of the bed. However, our dataset has no data of rolling out of bed. In addition, the rapidly changing positions such as lying left (L) to lying right (R), and lying right (R) to lying left (L) have the probability of 0.13 and 0.8 respectively. It shows that the elder patients move their body slowly due to the weakness of muscles. They have to move to lying center (C) before moving further.

To capture more history context of the previous positions, the previous two consecutive positions can be taken into account. So, the conditional probability is extended to $P(P_i|P_{i-1}, P_{i-2})$ or called position tri-gram. The result of the probability is shown in Table 7.

Table 7. Probabilities of position tri-gram

P_{i-2}	P_{i-1}	P_i				
		O	**S**	**M**	**L**	**R**
O	**S**	0.22	0.00	0.42	0.20	0.15
S	**O**	0.03	0.95	0.01	0.01	0.00
S	**M**	0.01	0.49	0.03	0.24	0.23
S	**L**	0.00	0.51	0.25	0.04	0.20
S	**R**	0.01	0.60	0.26	0.08	0.05
M	**O**	0.25	0.00	0.75	0.00	0.00
M	**S**	0.37	0.02	0.44	0.09	0.09
M	**L**	0.01	0.19	0.64	0.02	0.14
M	**R**	0.00	0.17	0.70	0.11	0.02
L	**O**	0.00	0.75	0.25	0.00	0.00
L	**S**	0.47	0.02	0.22	0.23	0.07
L	**M**	0.01	0.26	0.03	0.45	0.25
L	**R**	0.01	0.26	0.26	0.45	0.02
R	**O**	0.33	0.67	0.00	0.00	0.00
R	**S**	0.29	0.04	0.26	0.12	0.29
R	**M**	0.01	0.22	0.02	0.17	0.58
R	**L**	0.03	0.21	0.26	0.02	0.47

5. Conclusion

To release a bed sensor dataset, the bed position label has been designed and the data labeling scheme for bed position classification is proposed. In this study, a set of position labels are designed for using in the task of detecting the bed position to prevent bed falls. Off-bed (O) and sitting (S) are important positions for detecting the possibility of bed exit which have high probability of leading to bed falls. The dataset is collected from a particular set of sensors efficiently designed to detect body movement on bed. However, the signal patterns can be modeled for using with any other combination based on FSR and piezoelectric sensors. Moreover, the dataset can also be used to capture and study about the sleeping behavior especially of the elderly. The combination of lying positions (C, L, R) can also be used to detect the rolling out of bed when moving forward to the edge of the bed is detected. As a result, the five fundamental positions i.e. off-bed, sitting, lying center, lying left, and lying right are defined together with the expression of intermediate positions. Based on the dataset, the table of conditional probability and the state transition diagram are also estimated for both position bi-gram and tri-gram models. The dataset and the labeling scheme are significantly utilized to study the elderly sleeping behavior and moving pattern for bed fall and bedsore prevention.

Acknowledgement

The sensor pad and IP camera were supported by AIVS Co., Ltd. The video and patient data were recorded under the consent of the patients and acknowledgement of Banphaeo Hospital. We are very thankful to Mr. Shuichi Yoshitake, chairman of AIVS, for his strong support in the equipment utilization under the Japanese International Cooperation Agency (JICA) grants for SME development support, and the director together with the staff of Banphaeo Hospital for the overall supports in data collection.

The authors gratefully acknowledge the financial support provided by Thammasat University Research fund under the NRCT, Contract No. 25/2561, for the project of "Digital platform for sustainable digital economy development", based on the RUN Digital Cluster collaboration scheme.

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