Pressure-Sensor System for Sleeping-Posture Classification

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Abstract

In this paper we present our research work on the classification of sleeping postures using pressure sensing. A densely pressure-sensor grid placed under the matrass is first used for the posture classification task that will serve next as a reference. Pressure data obtained from 21 subjects for 4 sleeping postures (supine, prone, left and right side) has been analysed to determine the optimal location and the number of pressure sensors for an efficient sleeping-posture classification system. Obtained settings are used to build the optimal system and a second experiment including 11 subjects has been carried out with the new system. The obtained results are very promising and show the potential and the interest of the proposed method compared to existing systems.

Introduction

Bedridden patients are confined to bed because of illness or infirmity. This category of people requires additional care to avoid the formation of pressure ulcers due to the long sleep on the same posture. The pressure applied to the skin causes a deprivation of blood on the pressed skin area. If the pressure remains too high on the same spot for a couple of hours, skin tissue gets damaged and even may die. Since the discomfort of these pressure ulcers for the patients is enormous and the costs for treatment are high, the prevention of pressure ulcers is important. Prevention starts with using special materials for mattresses and sheets. In addition the patient is turned every 2 hours which requires the presence of nurses. In order to reduce nursing costs fewer nurses need to take cares of more patients at the same time by noting the time of turning. In the last years a number of lawsuits have happen against mistakes in the treatment of bedridden patient. Therefore the automatic monitoring of the sleeping postures can be very helpful to avoid mistakes by providing, e.g., alarms in case the posture did not change for a long period. It allows also logging of sleeping data and tracing other sleep related issues.

The topic of posture classification based on pressure data has been mainly researched for applications related to sitting [4, 5, 6] and sleeping. In [1] 18 sitting postures have been classified using PCA. In [2] **Error! Reference source not found.**8 sleeping postures have been classified from pressure data based on kurtosis and skewness estimation. The alternative approach is to use a camera for posture classification [3]. Many drawbacks can be expected using computer vision approaches such as changes in viewing angle, lighting condition, clothing and covers.

Posture Classification System Design

The goal of this research is to develop an unobtrusive system that measures sleeping postures based on pressure sensors. Therefore we have used pressure sensor mats placed under the mattress on top of an additional thin mattress. This choice avoids the direct contact of the subject with the pressure sensors and therefore prevents any possible safety issue related to the presence of the sensors close to the subject body. In our current research we focus on the optimization of the number, location and size of pressure sensors in order to have an efficient system in term of posture classification accuracy and costs. First a dense grid of pressure sensors (42x192 sensors) is used to determine the optimal location and size of the pressure sensors. Then the obtained settings are used to build the optimal system. The system works as follows: first a feature vector is extracted from each pressure sensor frame. A classifier is trained using features labelled with the sleeping posture. A new feature vector is then fed to classifier to obtain the estimated sleeping posture. Different types of classifiers such as linear, quadratic, nearest neighbourhood and SVM have been tested with a collected dataset of 21 subjects. Figure 1 depicts an example of the 4 most frequent sleeping-postures.

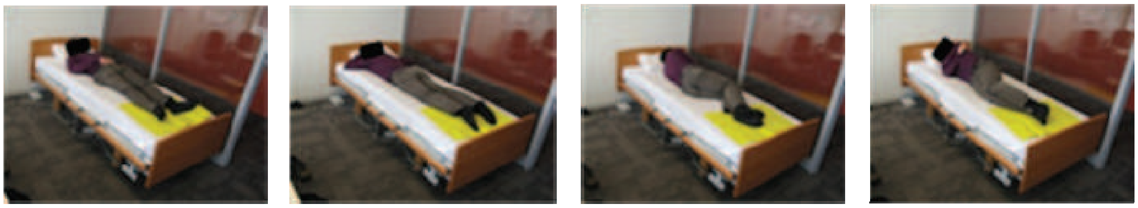

Figure 1. A subject during the recording of the 4 analysed postures: supine, prone, left and right side.

Experiments and Results

In the experiments four TekScan© pressure-sensor mats have been placed between a thin mattress, which is placed on the bed slats, and the mattress. A data frame that is recorded by the pressure system is a matrix of pressure values ranging from 0 to 255. The sampling rate was set to 1 frame every 3 seconds. In the first experiment the sleeping-posture data has been collected from 21 different subjects. Each subject was asked to lay-down for about 3 minutes on each of the four chosen posture, i.e., supine, prone, left-side and right-side and behave naturally for the chosen posture. For each subject and for each posture 240 frames are recorded to capture movement variability. Additionally a full night recordings for about 10 nights from 2 subjects were collected. It turned out that collected data is representative enough and similar to the full night recording in term of pressure values and patterns.

The feature extraction is as follows: firstly a coarse grid of bins is defined and secondly the pressure values are summed in each bin. Finally the resulting feature vector is normalized by the total pressure to account for weight differences between subjects. Different grids of bins have been tested and it turned out that 3x12 and 4x10 bins are good choices, see Figure 2. To deal with the differences of subject positions in the bed we compare the centre point of gravities and apply linear interpolation techniques.

Different classifiers have been tested [7] *for the* task from PRtools matlab toolbox. Table 1 shows the obtained error classification results for linear, quadratic, k-NN and SVM classifiers. Two training settings have been used. The first setting is subject-split where subjects included in the training are not included in testing. The second setting is measurement-split where postures of the same person can be in both training and testing. e.g., left posture used for training and supine posture of the same subject is used for testing. This difference in splitting did not show significant difference in terms of classification accuracy and showed that the classification does not require personalization to achieve high accuracy. This result shows that the system can be pre-trained in factory and therefore makes the deployment of the system easier and cheaper.

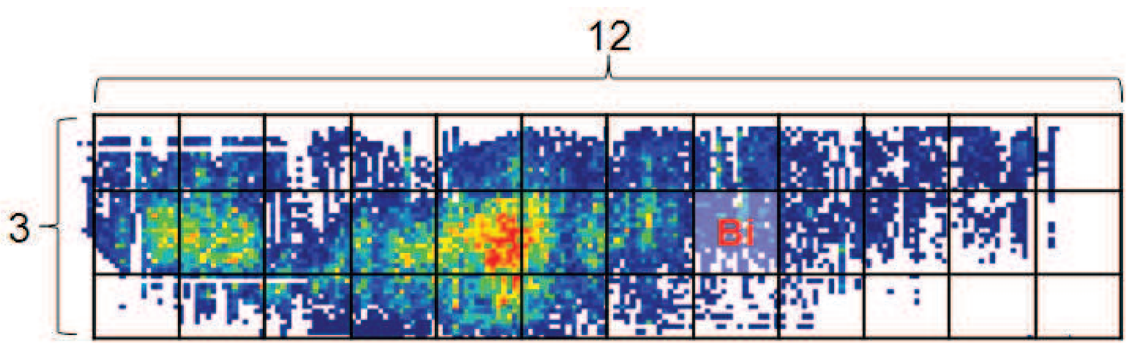

Figure 2. Pressure frame of left-side posture with the head on the left and the legs on the right. A grid of 3x12 is applied by summing the pressure in each cell.

Table 1. Mean and standard deviation of the sleep-posture classification error for two training conditions.

Classifier	Subject split	Measurement split
Linear	10.69%±6.8%	9.24%±3.02%
Quadratic	10.9%±8.1%	11.03%±2.66%
1-NN	6.66%±5.42%	5.31%±1.86%
SVM	2.91%±2.91%	2.90%±0.97%

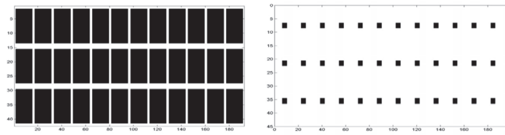

Figure 3. Pressure sensor size used in the first experiment (left) and second experiment (right).

In order to further reduce system requirements in terms of the number of pressure sensors, the size of the bins as in Figure 2 is reduced as illustrated in Figure 3. In this case the obtained feature vector of size 36 (3x12) is based on less pressure points since the overlaying mattress serves as a spatial low-pass filter, thus this bin-size reduction is allowed. To further optimize the sensor layout, different distances between sensors and different distances from the mattress border are tested.

The first experiment was based on the TekScan© pressure-sensor mats that are much narrower than the mattress. As a consequence a person may be positioned off the mat. To extent the width of the sensor area we have increased the number of rows from 3 to 4 and to end up with about the same number of bins we have decreased the number of columns from 12 to 10. As a consequence the length of the feature vector has increased from 36 to 40.

For each setting the feature vectors for all subjects are extracted and the train and testing cross-validation procedure is applied. Figure 4 shows the results. The left column shows the initial sensor configuration and middle column shows the final sensor configuration. The rows illustrate the distance offsets from the left border of the mattress. The right column shows the classification error as a function of distance between sensors. The optimal settings for a 4x10 sensor grid is a distance of 6 cm between sensors and a left offset of 20 cm from the left side (head side). This optimal settings lead to a classification error of 2.22% ± 2.7% (third row). The related confusion matrix is depicted in Table 2. Although the sensor size is reduced compared to the first experiment, position optimization allowed a good system performance.

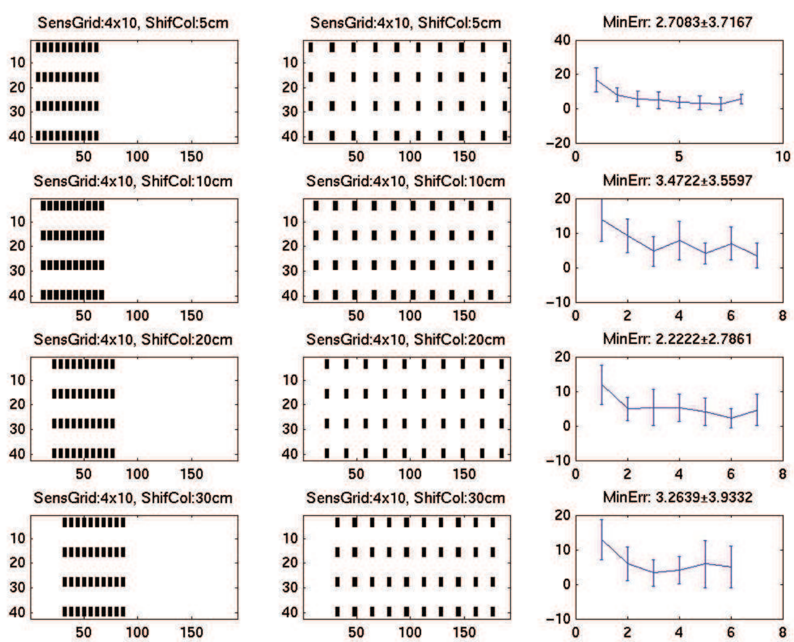

Figure 4. Sensor grid optimization by changing the distance between sensors.

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Table 2. Confusion matrix obtained using the optimized hardware system (sensor grid of 4x10).

	Supine	Prone	Left	Right
Supine	97.22%	2.22%	0%	0.55%
Prone	0.55%	95.55%	3.88%	0%
Left	0%	0.55%	98.33%	1.11%
Right	0%	0%	0%	100%

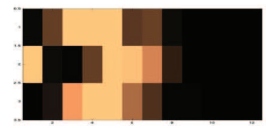

Figure 5. Optimal sensor location map. High intensity indicates that the sensor is important for posture classification.

It is not required to have the sensors lying on a rectangular grid and therefore it could be possible to further reduce the number of sensors needed. A forward feature selection algorithm is thus applied to identify the most important sensor location. Figure 5 shows the relevance of sensors that are most import for the sleep-posture classification. It can be seen clearly that the right part of sensor area (legs and feet) are much less important for posture classification.

Conclusions

In this paper we investigate the problem of sleep posture classification using pressure sensors placed under the mattress. The main application is the monitoring of bedridden subjects for pressure-ulcer prevention. The design steps of the system are described and the choice of sensor configuration is presented. The proposed system showed a promising performance (about 2% of classification error). As future work we plan to include temporal aspects to further improve the classification by avoiding abrupt change between postures.

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