Posture and Limb Detection for Pressure Ulcer Prevention

R. Yousefi, S. Ostadabbas, M. Faezipour, M. Nourani, L. Tamil
Quality of Life Technology Laboratory
The University of Texas at Dallas, Richardson, TX 75083
{rxy091020, sarahostad, miad.fz, nourani, tamil}@utdallas.edu

M. Pompeo, M.D.
Presbyterian Wound Care Clinic
Dallas, TX, 75231
healerone@aol.com

Abstract

Pressure ulcers have affected humans for ages and addressing the prevention of pressure ulcers is a prominent issue in our healthcare system. Once developed, the treatment is costly and it increases length of hospital stay. This is particularly true for patients with impaired sensation including diabetics, advanced age or prolonged immobility. In this work, we have developed a processing platform that unobtrusively records patient's bed posture and tracks different limbs along with associated statistical pressure data. The proposed algorithm has a training and test step. K Nearest Neighbor (kNN) algorithm is used to classify different postures. A cardboard body model is assigned to training samples for body limb detection.

Keywords: Pressure Ulcer, Posture Classification, Limb Detection, Pressure Mapping System.

I. Introduction

Pressure ulcer (PU) is a skin breakdown which develops over a bony prominence as a result of pressure as main factors and other factors like shear stress and friction [1]. In hospitalized patients, the prevalence ranges from about 3% to 11% (approximately 1.5-3.0 million patients in the United States). Groups known to have a high risk of developing pressure ulcer include bedridden patients , wheelchair-bound individuals, frail elderly [2] with no or limited mobility, as well as individuals with diabetes, poor nutrition, and chronic blood-flow diseases [3].

Pressure ulcers imposes an enormous burden on our health care system [4]. Once developed, PUs represent an acute health condition that results in increased costs and suffering over many months and even years. Pressure ulcers result in both an increased length of hospital stay and increased hospital costs [5]. The current cost to our health care system resulting from PUs is more than $1.2 billion annually [6]. Effective ulcer prevention and early detection will greatly reduce patient suffering/discomfort. Strong motivation for this work comes from the high cost of PU treatment and the growing shortage of trained health care providers. In 2000, the shortage of nurses was estimated at 6%. This shortage is expected to grow to 20% by 2015 and, if not addressed, to 29% by 2020.

We have developed a monitoring platform using commercial pressure mapping system that records patient's bed posture and tracks different limbs along with associated statistical pressure data. Turning the patient every two hours, as traditionally advised to hospital staff, is neither efficient nor practical. Our methodology allows care givers to schedule and reposition patient more effectively. It also allows continuous risk assessment and provides related information for a managed healing process.

The remaining of this paper is as follows:
A review of previous work is done in Section II. Our data collection platform is described in Section III. The proposed algorithm and associated experimental results for posture classification and body limb detection are discussed in Section Section IV. Section V contains concluding remarks.

II. Previous Work

To deal with pressure as the main contributing factor in PUs, different support surfaces have been introduced to distribute load over the contacted areas of the human body. Features added to support surface to do pressure redistribution includes air fluidized, alternating pressure, low air loss and multi-zoned surfaces. There has been always a need to evaluate the effectiveness and optimize usage of support surface technology and other resources to prevent PUs. Pressure sensors are good means to monitor pressure on different areas of the body on support surfaces. Adding processing capabilities to pressure sensors could help us extract more useful information for pressure ulcer management including patient's posture on the bed.

Pressure sensors have been used for bed posture detection in many research works. A low-cost sensor mat with minimum number of sensors with a feed-forward neural net was presented in [7] for detection and distinction of body position. Harada et al. have proposed a template-based human posture detection [8] and a pressure image-based human motion tracking system [9]. In [10], a bed robotic system was proposed for elderly and the disabled, and pressure sensors embedded in the mattress are used to estimate the pose of the patient. A bed posture detection method is developed in [11] using Bayesian classification for the elderly where statistical kurtosis and skewness measures are estimated as feature vector to represent the shape of pressure contour using the pressure values received from sensors. To achieve a better performance, a multimodal approach to human sleeping posture classification, using pressure sensor array and video camera as complementary modalities was proposed in [12]. A comparison of different sleeping posture classification using cost-effective pressure sensitive mattress was studied in [13].

III. Data Collection Platform

Force Sensing Array (FSA) [14] is used to collect pressure data on the bed. The FSA system is a flexible mat that contains 2048 (32×64) uniformly distributed sensors which cover the total contact area between the subject and the bed. Figure 1 shows the pressure mapping system which is used in this study.

Figure 1. Data Collection Platform [14].

The FSA system can measure interface pressure between 0 to 100 mmHg per sensor. The sensor mat is light, thin and flexible. The electronic interface samples the sensor mat in 0.6 second. Sensor values are considered as a gray scale pressure image and this image is passed to our data processing unit which is described in the next section.

IV. Algorithm

An overview of hierarchial limb detection technique is depicted in Figure 2. In this approach, first we classify patient's posture on the bed into 5 different postures which are shown in Figure 3, then, we fit a model to classified posture using an articulated human body model. The algorithm has two main steps which are training and test step. The upper path is the training phase and the lower path is the test phase.

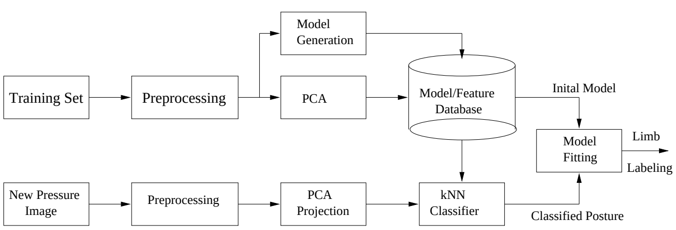

Figure 2. Overview of developed processing unit.

The goal in training phase is to generate required data set for both posture classification and limb detection in each posture. To do so, a database of projected training samples into lower dimension space and also a database of human model in different postures are prepared during training.

A. Posture Classification

To build the training set, a complete set of pressure maps are collected using mentioned data collection platform. The maps are collected for 6 different subjects in 5 different postures as shown in Figure 3. During training, all training images go in to preprocessing unit. Preprocessing unit extract the body segments of the image and improve quality of pressure images using binary image processing techniques. All the training images is scaled to a fixed size for PCA training and generation of feature database.

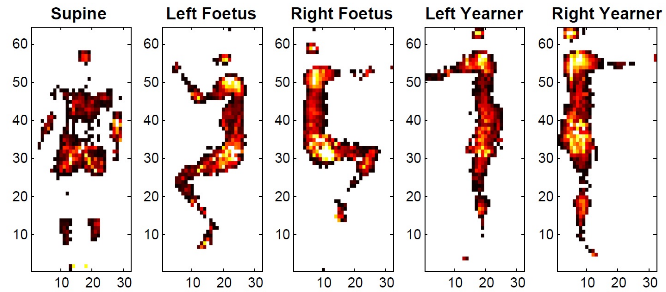

Figure 3. Pressure image of five postures considered in our experimentation.

PCA is a useful statistical technique that allows reduction of data dimensionality by projecting data from a correlated high dimension input space into an uncorrelated low dimension data space. Training phase of PCA accepts output of preprocessing and in summary, the following steps create the eigenspace:

- Creating data matrix
- Creating covariance matrix
- Computing eigenvalues and eigenvectors
- Picking up eigenvectors based on new space dimension

After eigenspace creation, all the training images are projected into the new low dimension space and feature database.

During test in bottom path of Figure 2, each new pressure frame goes into the same preprocessing unit. After preprocessing, it is projected into new low dimension space using eigenspace created in training phase. The distance between extracted features for new frame and every training instance is calculated using kNN classifier and k closest training examples are piceked up. New frame is assigned to the most common category by voting multiple neighbors to increase resistance to noise.

Table I summarize experimental results extracted for postures classification.

TABLE I
PCA Confusion Matrix(%)

	Right Foetus	Left Foetus	Right Yearner	Left Yearner	Supine
Right Foetus	99.2	0	9.3	0	0.1
Left Foetus	0	99.6	0	0.2	0.1
Right Yearner	0.7	0	90.7	0	0.3
Left Yearner	0	0.4	0	99.8	0.2
Supine	0.1	0	0	0	99.3
Overall performance			97.7		

Confusion matrix contains information of predicted and actual classes. Each column of this matrix represents instances in actual class while each row of this matrix represents the instances in a predicted class. For example, the entries of the first column of the above confusion matrix have the following meaning: 99.2% of actual Right Foetus instances are predicted correctly while 0.7% of actual Right Foetus instances are erroneously predicted as Right Yearner and 0.1% as Supine.

B. Limb Detection

Most pressure ulcers form over bony areas of the body such as sacrum, over the hip bones, heels, back of the head, heels and shoulder. Limb detection allows us to track at-risk regions of the body and assess those parts more accurately with associated pressure statistics. Figure 4 shows some of the high risk areas of body in different postures.

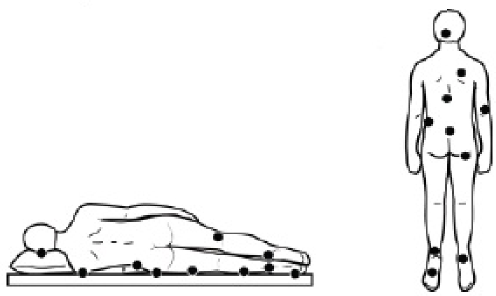

Figure 4. Common at-risk areas of body in different postures(form [16]).

Two different articulated human body models is developed for body limb detection which are shown in Figure 5 [15]. Figure 5-a is a parametric model with 12 sizing parameters for 6 patches and 5 angles for head, hands and legs. Figure 5-a is used to segment body limb in Foetus and yearner postures and Figure 5-b is used to segment body limbs in supine posture. During training phase a database of human body is generated. During test, kNN classifier chooses the most similar sample in database and associated body model of this sample is chosen to be an initial estimation of the model parameters for new test map.

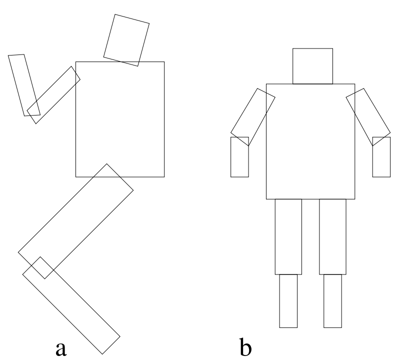

Figure 5. Articulated human body model (a) Foetus/Yearner (b) Supine.

The algorithm fits head and back area, legs and hand patches respectively by doing a hierarchial search around the initial parameters.

V. Conclusion

In this paper, a processing unit is developed to classify patent's bed posture and detect body limbs over time. Processing unit deploys a hierarchial approach to detect posture and body limb in each classified posture. Monitoring and keeping record of patient's bed posture and body limb over time with associated pressure time statistics help nurses to effectively schedule patient repositioning. The proposed algorithms extract body limb location over time which gives us information of patient mobility over time. As our future work, we are working on a mobility quantification technique that help nurses to have a record of patient mobility which is proven to be a relatively important factor in pressure ulcer development.

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