

# Evaluating Pressure Ulcer Development in Wheelchair-Bound Population Using Sitting Posture Identification

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Received February 2013

## ABSTRACT

Pressure ulcers are a common complication among wheelchair-bound population. They are resulted from prolonged exposure to high pressure, which restricts blood flow and leads to tissue necrosis. In this work, a continuous pressure monitoring system is developed for pressure ulcer prevention. The system consists of 64 pressure sensors on a  $40 \times 50$  cm<sup>2</sup> sheet. Real time pressure data and corresponding maps are displayed on a computer simultaneously. Furthermore, a posture detection procedure is proposed for sitting posture identification. Having information about the patient's postural history, caregivers are capable of a better decision about repositioning and treating the patient.

**Keywords:** Interface Pressure Monitoring; Pressure Ulcer; Sitting Posture

## 1. Introduction

Sitting-acquired pressure ulcers are a common complication among wheelchair-bound population. It is reported in literature that 36% to 50% of pressure sores are attributed to sitting in a wheelchair [1]. Pressure ulcers are resulted from prolonged exposure to high pressure, which restricts blood flow and prevents blood from bringing oxygen and nutrients to underlying tissues. Hence, continuous measuring and monitoring of interface pressure is the most useful approach for preventing pressure ulcers, which are considered both a health and economic problem as they cause excessive expenditures by increasing the length of treatment up to several times [2]. In spite of so many attempts for improving ulcer prevention techniques, high incidence of pressure ulcers is observed and more effective prevention methods are required [3-5].

The relationship between pressure intensity and duration is explored by Reswick and Roger [6]. High pressures are tolerable for short times only and will lead to tissue necrosis if they are unrelieved [7]. However, low pressures are damaging if sustained for a lengthy period of time [8]. Meffre, *et al.* [9] designed a particular type of seat for wheelchair-bound patients using electro-pneumatic pressure sensors. These kinds of pressure sensors are more expensive than capacitive and resistive sensors and slower in data acquisition. Yip, *et al.* [10] presented

a flexible pressure monitoring system. The prototype consists of 99 capacitive pressure sensors on a  $17 \times 22$  cm<sup>2</sup> sheet. Yang, *et al.* [11] designed and evaluated an air-alternating wheelchair seat. They used resistive pressure sensors for measuring interface pressure. Drennan and Southard [12] presented a system consisting of pressure sensitive pads. The system produces alarms if the pressure intensity is more than the threshold adjusted by the user.

In this paper, we present a system for continuous monitoring of interface pressure. Furthermore, a procedure for identifying different postures of sitting is proposed. A wheelchair-bound patient may develop pressure ulcer if he has no sensation in his buttock. Sore development may happen faster if the patient's trunk is tilted to one side for a long period of time. In this work, we simulated different sitting postures of a wheelchair-bound patient. Having information about the patient's postural history, let caregivers decide better about repositioning and treating the patient.

The remainder of this paper is structured as follows: Section 2 describes the system design, including sensors array setup as well as, circuit and software design. In Section 3, we present the proposed procedure for sitting posture identification. The proposed method is verified by a particular statistical test. Conclusions are given in Section 4.

## 2. Methodology

### 2.1. Hardware Design of the System

In this work pressure sensing is carried out by Interlink Electronics force sensing resistors (FSR-part no. 400), which exhibit a decrease in resistance with an increase in the force applied to the active surface. By measuring the resistance, the applied force can be extracted and hence the corresponding pressure value can be calculated. To have a more precise measurement of force, each sensor was calibrated before it was used. An array of sensors is required for sensing pressure over a large area. We used 64 pressure sensors to cover an area of  $30 \times 40 \text{ cm}^2$ . Each row of the array consists of 8 pressure sensors as illustrated in **Figure 1**. All sensors are fixed on a Plexiglas sheet of size  $40 \times 50 \text{ cm}^2$ . A PCB of the same size was designed for wiring the sensors and is fixed under the Plexiglas sheet.

Measuring the resistances of FSR sensors is carried out by an Atmel ATMEGA16 microcontroller analog-to-digital converter. The same microcontroller controls multiplexers to select one resistive sensor at any time according to a particular sequence. The entire array of the resistive sensors is scanned every 320 ms with a sampling rate of 3 Hz.

A simplified schematic of the resistive sensors array and the related electronic circuitry is shown in **Figure 2**. Current source, designed by LM324 operational amplifier and 2N3906 transistor, sources a current of  $100 \mu\text{A}$  to the selected resistor and the ADC measures the corresponding value of voltage proportional to the resistance value. Each sensor is placed in a serial connection with a

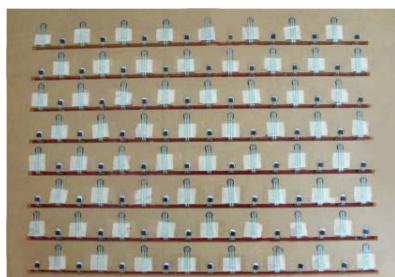


Figure 1. Pressure sensors array.

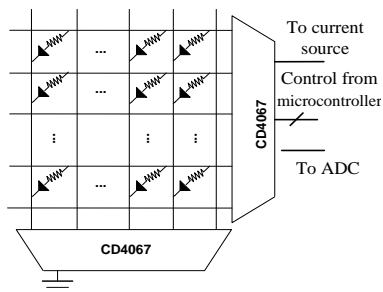


Figure 2. Schematic of resistive sensors array.

diode to prevent current flows into other sensors and as a result creating undesirable routs. The designed PCB, illustrated in **Figure 3**, interfaces the electronics and the sensors sheet.

### 2.2. Software Design of the System

Digitized data of sensors are transmitted from the microcontroller to a computer via a USB interface using FT232 chip. A GUI (Graphical User Interface) is developed in MATLAB to report pressure maps in real time, retrieve previous maps and risks and set alarms. Post processing of the obtained data is carried out in MATLAB. Measured values of pressure of each sensor in the array are saved in matrices at each sampling interval. In the GUI, there is an option for the user to define two thresholds for pressure intensity and duration. An alarm can be created by the software if the pressure intensity of one sensor is larger than the adjusted threshold and the duration of that pressure is more than the time threshold. This event is considered as a risky situation.

The GUI is designed in a way that we can see the last risks and their occurrence times. This would also provide useful information regarding patient's postural history. A sample pressure map of a person sitting on the setup is shown in **Figure 4**. The GUI stores the pressure in units of mmHg for each sensor and MATLAB post processing is used to generate this pressure map.

## 3. Sitting Posture Identification

### 3.1. Experiment and Results

As it was mentioned before, developing sores may happen faster in a wheelchair-bound patient if he involunta-

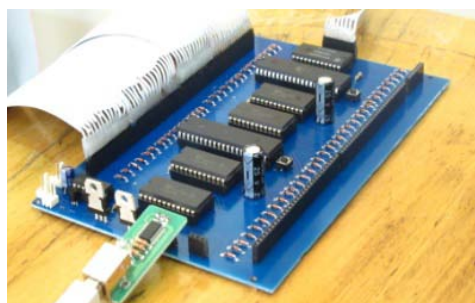


Figure 3. PCB used for the electronics.

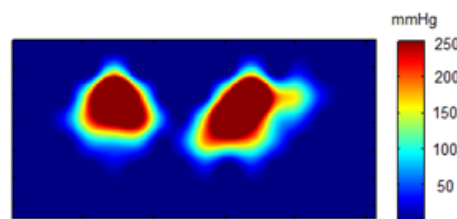


Figure 4. Pressure map of sitting volunteer.

rily leans to one side for a long period of time. In this work, we simulated different sitting postures of a wheelchair-bound patient. We had healthy volunteers in the experiment and we defined four different postures for them. These defined postures were assumed to simulate sitting postures of a wheelchair-bound patient.

In the first defined posture, our subject sat straight on the designed pressure sensitive seat with bent knees. This was assumed to simulate proper sitting of a patient in a wheelchair. In the second and third postures, the subject sat with legs crossed, right on left and left on right respectively. This was supposed to simulate the postures during which a patient leans to his left and right sides. In the last defined posture, the subject sat with legs stretched. **Figure 5** presents produced pressure maps for different sitting postures of the volunteer.

### 3.2. Proposed Method for Identifying Sitting Postures

Statistical parameters are used for detecting different sitting postures. Values of mean, standard deviation, skewness and kurtosis were calculated for each of the produced maps shown in **Figure 5**. We used pressure map matrices to calculate these parameters. Skewness and kurtosis coefficients, related to each matrix, were calculated from the probabilistic distribution of pressure values in the middle rows of the matrix. Fitted distributions corresponding to each of pressure maps of **Figure 5** are shown in **Figure 6**. As demonstrated, the result of distribution fitting for posture 1 and 4 are close to stan-

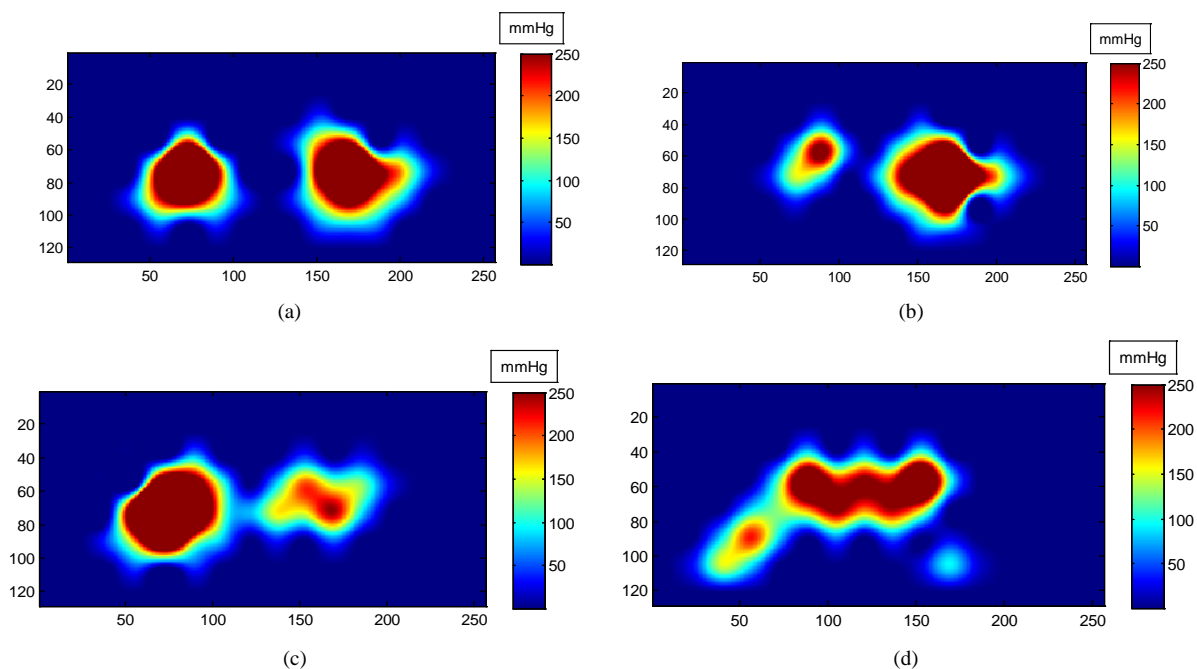
dard normal distribution and therefore the corresponding skewness values will be close to zero. Fitted distributions for postures 2 and 3 result in negative and positive skewness coefficients, respectively.

Now, we can present a method for detecting different sitting postures according to the calculated parameters. Skewness with negative sign (not close to zero) is an indicator of the second posture. Skewness with positive sign (not close to zero) is related to the third posture. The first and last defined postures are identified by skewness values close to zero (negative or positive). In addition, we can distinguish the first posture from the last one using mean values, since the mean pressure value of the total array in first posture is larger than that of the last posture.

### 3.3. Verifying the Proposed Method

One way analysis of variance (ANOVA) was used to verify the proposed method for identifying sitting postures. The sitting posture identification experiment, described in section 3.1, was performed for 5 volunteers (3 times for each subject), resulting in 15 different tests for each of the four defined postures. We calculated mean, standard deviation, skewness and kurtosis parameters for these fifteen pressure matrices.

**Figure 7** to **Figure 10** represent the obtained box plots for each parameter using MATLAB. Each column is related to one of the four defined postures. As it can be seen in **Figure 7**, there is no overlap between mean values of posture 1 and posture 4. Therefore the mean val-



**Figure 5.** Different sitting postures, (a) sitting straight with bent knees; (b) sitting straight with crossed legs, right on left; (c) sitting straight with crossed legs, left on right; (d) sitting with stretched legs.

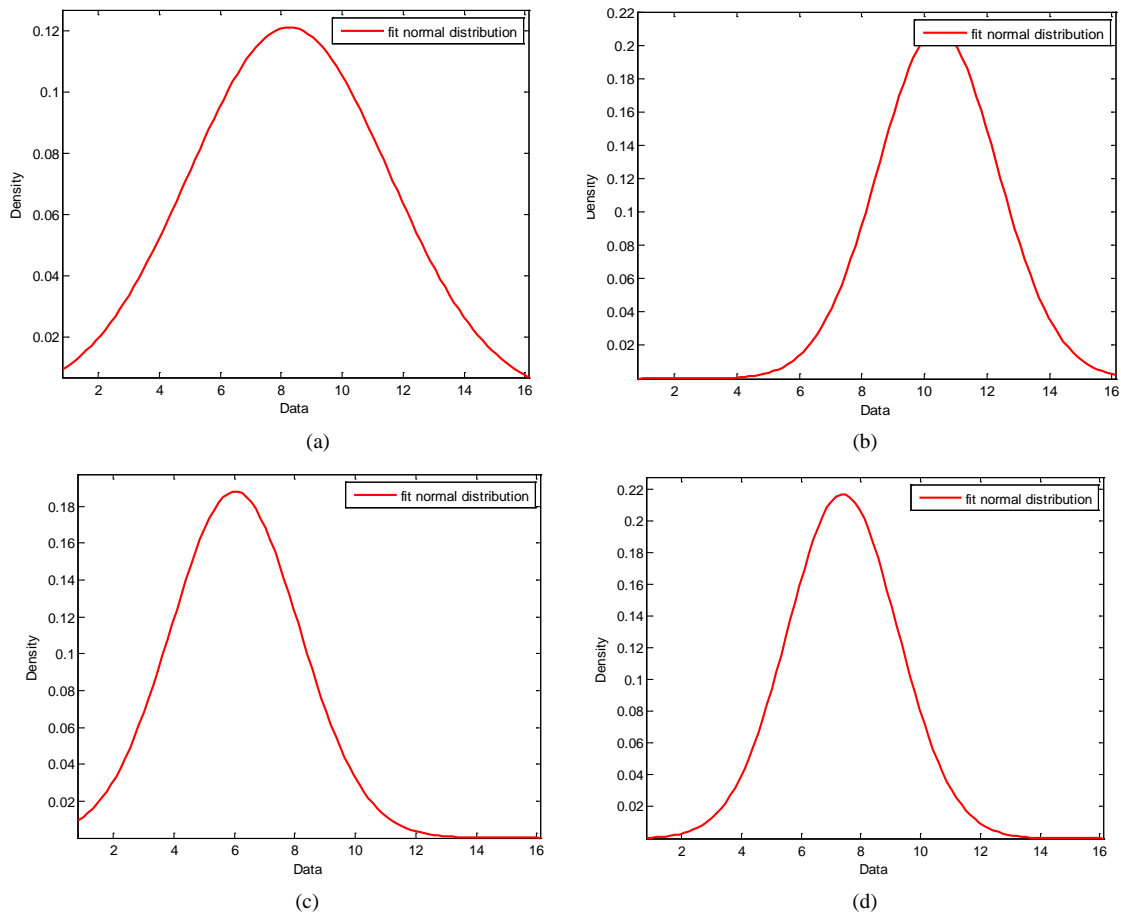


Figure 6. Fitted distributions for each posture of Figure 5 respectively.

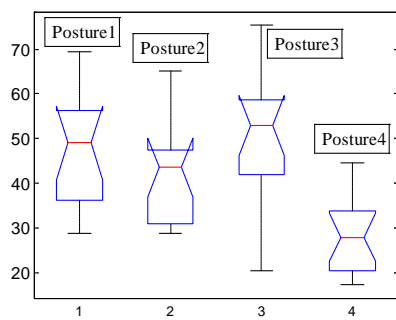


Figure 7. Box plots for mean values.

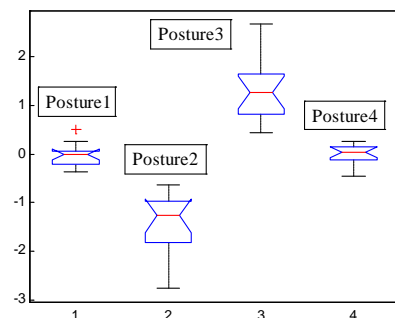


Figure 9. Box plots for skewness values.

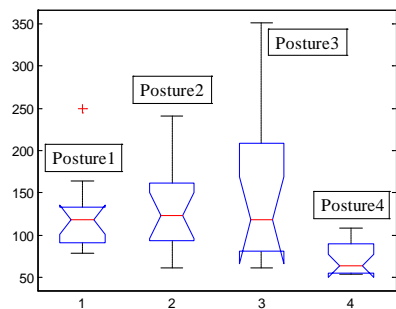


Figure 8. Box plots for standard deviation values.

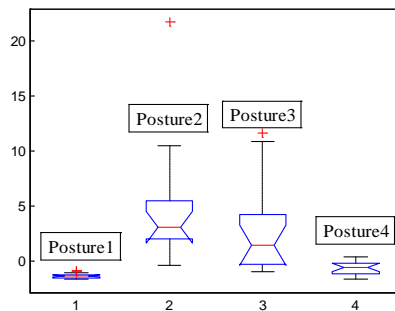


Figure 10. Box plots for kurtosis values.

ues can be used for distinguishing these two postures. **Figure 8** shows that the values of standard deviation vary from posture 1 to posture 4. According to **Figure 9** skewness values of posture 2 have negative signs, and skewness values of posture 3 have positive signs while those of postures 1 and 4 are close to zero (negative or positive). So these three groups (posture 2, posture 3, posture 1 and 4) can be distinguished by the skewness coefficient. Finally, **Figure 10** shows that kurtosis coefficients of posture 2 and 3 are generally larger than those of postures 1 and 4. This sounds reasonable, since fitted normal distributions of postures 1 and 4 are similar to standard normal distribution, while those of postures 2 and 3 generally have higher peaks.

#### 4. Conclusions

A continuous-time pressure monitoring system is presented. Due to its useful information about patient's movement history, feasibility for simultaneous monitoring of pressure and alarming options, it is proposed that this system can be utilized for pressure ulcer prevention. Sitting posture identification is possible using the presented system. A method for detecting different sitting postures has been proposed and verified. It is suggested that preventing pressure ulcers in wheelchair-bound patients can be performed using the sitting posture detection method.

Spatial resolution of the designed system can be improved in future works by increasing the number of pressure sensors. The presented pressure monitoring system can be expanded to be used in mattresses of bedridden patients.

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