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Original Article

Design and Evaluation of a Pressure and Temperature Monitoring System for Pressure Ulcer Prevention

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Abstract

Introduction
Pressure ulcers are tissue damages resulting from blood flow restriction, which occurs when the tissue is exposed to high pressure for a long period of time. These painful sores are common in patients and elderly, who spend extended periods of time in bed or wheelchair. In this study, a continuous pressure and temperature monitoring system was developed for pressure ulcer prevention.
Materials and Methods
The monitoring system consists of 64 pressure and 64 temperature sensors on a 40×50 cm2 sheet. Pressure and temperature data and the corresponding maps were displayed on a computer in real-time. Risk assessment could be performed by monitoring and recording absolute pressure and temperature values, as well as deviations over time. Furthermore, a posture detection procedure was proposed for sitting posture identification. Information about the patient's movement history may help caregivers make informed decisions about the patient's repositioning and ulcer prevention strategies.
Results
Steady temporal behaviour of the designed system and repeatability of the measurements were evaluated using several particular tests. The results illustrated that the system could be utilized for continuous monitoring of interface pressure and temperature for pressure ulcer prevention. Furthermore, the proposed method for detecting sitting posture was verified using a statistical analysis.
Conclusion
A continuous time pressure and temperature monitoring system was presented in this study. This system may be suited for pressure ulcer prevention given its feasibility for simultaneous monitoring of pressure and temperature and alarming options. Furthermore, a method for detecting different sitting postures was proposed and verified. Pressure ulcers in wheelchair-bound patients may be prevented using this sitting posture detection method.
Keywords: Interface Pressure and Temperature Monitoring, Pressure Ulcer, Sitting Posture Identification.

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1. Introduction

Pressure ulcers are tissue damages resulting from prolonged exposure to high pressure. Pressure applied over an extended period of time can restrict blood flow and lead to tissue breakdown. Pressure ulcers may occur in any location that experiences uninterrupted pressure for long periods of time; however, they are more commonly observed in wheelchair users and bed-bound individuals [1].

Pressure ulcer treatment may create financial burdens for caregivers, communities, and healthcare systems. Pressure ulcer is associated with high health care costs, given the extended length of hospital stay. The estimated cost of managing a full-thickness pressure ulcer is $70,000. In the U.S., the annual cost for pressure ulcer management is estimated at $11 billion [2].

Today, in spite of tremendous efforts for the improvement of ulcer prevention strategies, incidence of pressure ulcers is high and more effective prevention methods are required [3-5]. In 1950, the simplest method for pressure ulcer prevention was presented by a British nurse, who repositioned immobile patients every two hours [6].

Today, there are different types of pressure-reducing devices. Static systems reduce interface pressure by distributing the load over a larger area and dynamic support surfaces dispense alternating currents of air to different points of the contact surface. However, these methods may not be effective in practice. The repositioning method does not guarantee pressure relief in the area under pressure. Static devices are not a stand-alone solution, and patients may still develop pressure sores if there is not enough care. Furthermore, dynamic surfaces cannot be feasible on a large scale given the associated excess costs; hence, novel technologies for pressure ulcer prevention are required [12].

Recent approaches to pressure ulcer prevention are based on interface pressure measurement. In fact, it is the only way we can estimate the pressure applied to each body tissue, and thus prevent pressure increase and sore development. In this regard, Reswick and Roger investigated the relationship between pressure and time [7]. High pressure is tolerable for only short time periods, and if unrelieved, may lead to tissue necrosis [8]. On the other hand, low pressure can be damaging if left unrelieved for a long period of time [9]. In this regard, Sakai et al. continuously monitored interface pressure distribution in patients under intensive care [10]. The results provided an insight into the relationship between intensity and duration of applied pressure for pressure ulcer prevention. The limitation of their study was considering the upper limit of measurable pressure (209 mmHg).

Meffre, et al., by using electro-pneumatic sensors for measuring interface pressure, designed a particular type of seat for wheelchair users [11]. These pressure sensors are more expensive than capacitive and resistive sensors and slower in data acquisition. Also, Yip et al. presented a flexible pressure monitoring system [12]. The prototype consisted of 99 capacitive pressure sensors on a 17×22 cm2 sheet, and a high variability was reported in the behaviour of the sensors.

Yang et al. designed and evaluated an air-alternating wheelchair seat. They used resistive pressure sensors for measuring the interface pressure [13]. Drennan and Southard presented a system consisting of pressure-sensitive pads, which generated an alarm if the pressure intensity exceeded the threshold adjusted by the user [14]. In addition, Dai et al. proposed a system for monitoring wheelchair users' pressure-relief behaviours. The system utilized piezo-resistive sensors beneath a wheelchair cushion to monitor the pressure [17]. Also, a bluetooth-enabled fabric-based pressure sensor array was proposed by Chung et al. as a simple tool for continuous monitoring of pressure ulcer risk. [18]

Marenzi, et al., by using a capacitive sensor matrix, designed a system for analyzing interface pressure data and continuous monitoring of the centre of pressure of a seated person [19]. Also, Lee, et al. developed a seat-adjustable power wheelchair [20].

In this study, we present a system for continuous monitoring of interface pressure and temperature. According to the National Pressure Ulcer Advisory Panel, temperature is identified as an indicator for pressure ulcer development and can help identify risky positions. Both increased and decreased skin temperature can be used for indicating pressure ulcer development [15]. Therefore, by including temperature sensors, we developed a system and simultaneously monitored pressure and temperature at different points.

Furthermore, a procedure for identifying different sitting postures was proposed. Sitting-acquired pressure ulcers are a common complication among long-term wheelchair users. Approximately 36-50% of pressure sores are attributed to sitting in a wheelchair [16]. Wheelchair users may develop pressure ulcers, particularly when the sensation is lost in the buttock. Moreover, sore development may accelerate if the patient's upper body is tilted to one side for a long period of time. In this study, we simulated different sitting postures of a wheelchair user. The results indicated that information about the patient's movement history may help caregivers choose effective interventions in a timely manner.

In section 2 of this study, pressure and temperature sensing approaches are described. System design, sensor array setup, circuit design, and software design are explained in the same section. In section 3, we present the experimental results and describe the design and implementation of system evaluation. Furthermore, a particular procedure for sitting posture identification is proposed and verified. Finally, section 4 presents the discussion, and in section 5, the conclusion is provided.

2. Materials and Methods

2.1 Pressure and Temperature Sensing

In this study, force-sensing resistors (FSR-part no. 400, Interlink Electronics, USA) were used for pressure sensing. These resistors exhibit a decrease in resistance when an increase is observed 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.

The force vs. resistance characteristic diagram of FSR, presented in the article, provides an overview of FSR typical response behaviour.

For more accurate force measurement, we calibrated each sensor by applying specific values of force and measuring the corresponding resistance values. The resistance vs. force characteristic of a sample sensor, resulting from calibration, is shown in Fig. 1; the other sensors showed almost the same behaviours.

The DS18B20 digital thermometer (Dallas Semiconductor, USA) was used as a temperature sensor. The DS18B20 communicates over a 1-wire bus, and requires only one data line (and ground) for communication with a central microprocessor.

2.2 Sensor Array Setup

In order to sense pressure and temperature changes over a large area, an array of sensors is required. We used an array of 8×16 sensors to cover an area of 30×40 cm2. Each row of the array consisted of 8 pressure and 8 temperature sensors, as illustrated in Fig. 2. Therefore, the setup included 64 pressure and 64 temperature sensors, all fixed on a Plexiglass sheet of size 40×50 cm2. A printed circuit board (PCB) of the same size was designed for wiring the sensors and was attached under the Plexiglass sheet.

2.3 Circuit Design

The resistance measurement of FSR sensors was carried out by an ATMEGA16 microcontroller (Atmel, USA) analogue-to-digital converter (ADC). This microcontroller controlled multiplexers to select one resistive sensor at a time according to a particular sequence. The entire array of resistive sensors was scanned every 320 ms with a sampling rate of 3 Hz.

A simplified schematic diagram of the resistive sensor array and the related electronic circuits is shown in Fig. 3. The current source, designed by LM324 operational amplifier (Philips Semiconductor, USA) and 2N3906 transistor (STMicroelectronics, USA), provided a current of 100µA to the selected resistor, and the ADC measured the corresponding value of voltage proportional to the resistance value. Each sensor was placed in a serial connection with a diode to prevent current flows into other sensors, which could result in undesirable routing.

The digitized temperature was acquired by another Atmel ATMEGA16 microcontroller. This microcontroller controlled multiplexers to select each row of temperature sensors in an appropriate order. A simplified schematic diagram of temperature sensors and electronics is shown in Fig. 4. Also, Fig. 5 illustrates a schematic diagram of the designed wheelchair with embedded sensors.

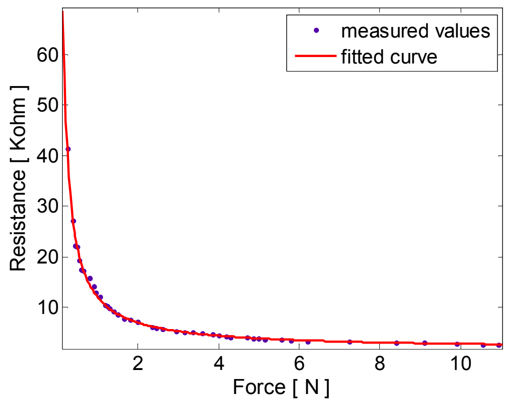


Figure 1. Resistance vs. force characteristic of a sample FSR; dots: measured values, solid line: fitted curve

Figure 2. Array of pressure and temperature sensors

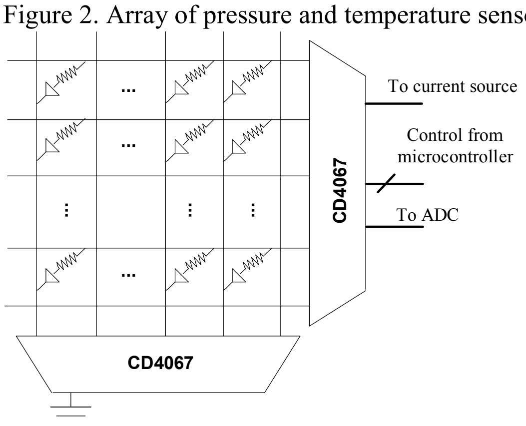


Figure 3. Resistive sensor array

Figure 4. Temperature sensor arrangement

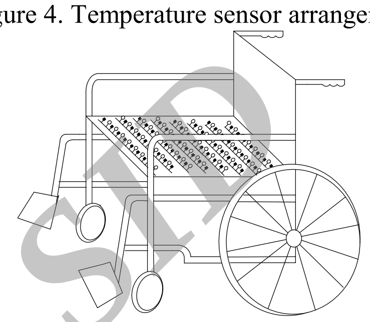


Figure 5. An illustration of the wheelchair with embedded sensors

2.4 Software Design

Digital data of sensors was transmitted from the microcontrollers to a computer via two USB interfaces, using FT232 chips. A Graphical User Interface (GUI) was developed in MATLAB software (R2012b) to report real-time pressure and temperature maps, retrieve previous maps and risks, and generate the alarms.

Further analysis of the retrieved data was carried out in MATLAB. Measured values of pressure and temperature of each sensor in the array were stored in matrices at each sampling interval. In the GUI, there was an option for the user to define two thresholds for pressure intensity and duration. An alarm was generated by the software if the pressure intensity of one sensor exceeded the adjusted threshold and the pressure duration was longer than the time threshold; this event was considered as a risky condition.

The temperature map corresponding to the same risky condition was checked to determine whether there was any significant temperature change in areas experiencing excessive pressure. The temperature changes could be used for identifying pressure ulcer development.

The GUI was designed in a way that we could see the latest risks and the time of their occurrence. This would, in fact, provide useful information regarding the patient's movement history. A sample pressure map of a person sitting on the setup is shown in Fig. 6. The GUI stored the pressure in units of mmHg for each sensor and data analysis was performed to generate this pressure map. The temperature map of the sitting volunteer, after post-processing, is given in Fig. 7.

3. Results

3.1 Time-dependant Behaviour of the System

In order to evaluate the behaviour of the system through time, a volunteer sat on the developed system for 30 minutes. Pressure and temperature matrices were stored in MATLAB software during this period. Time-dependant behaviour of specified pressure sensors is presented in Fig. 8 as pressure (mmHg) vs. time (s) graphs. By using interpolation, we obtained pressure-time graphs corresponding to the locations on which temperature sensors were placed. These graphs included the volunteer's sitting and standing-up instants, as well.

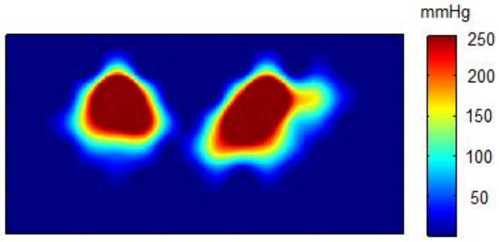


Figure 6. Pressure map of the sitting volunteer

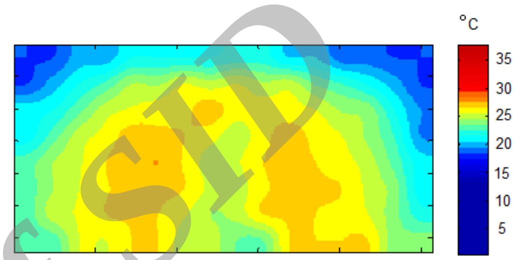


Figure 7. Temperature map of the sitting volunteer after post-processing

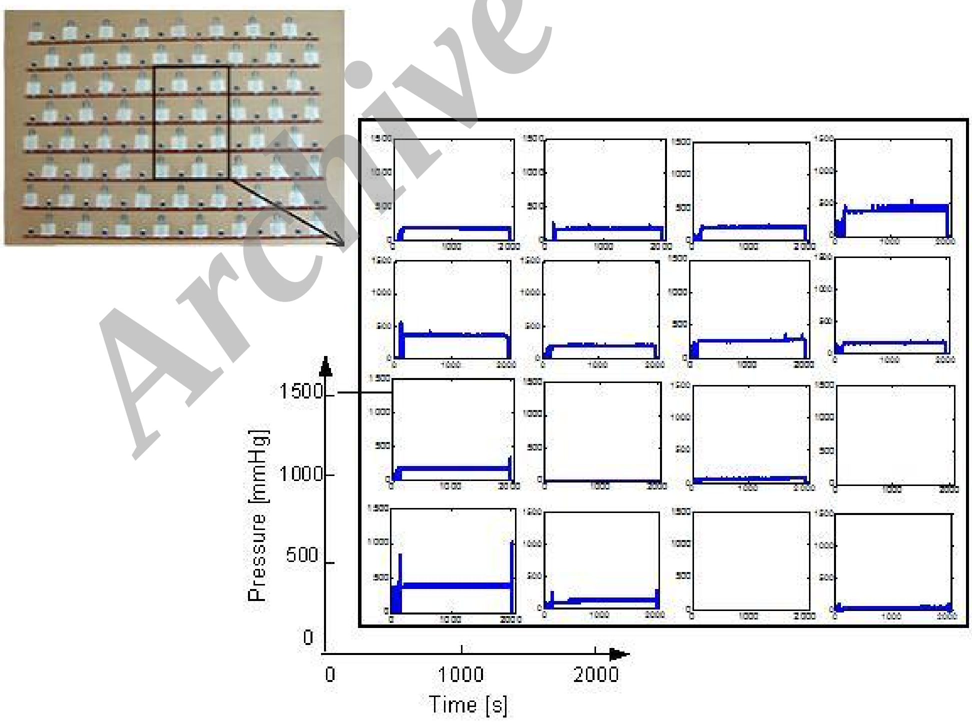


Figure 8. Pressure [mmHg] vs. time [s] characteristics of specified sensors during the test period. Pressure values corresponding to the locations on which temperature sensors were placed, were obtained using interpolation.

Early abrupt pressure changes observed in Fig. 8 are due to preliminary repositioning of the subject. Small deviations in the recorded values during prolonged test sessions may be the result of subject's smooth movements on the setup. Temperature vs. time characteristics of the specified temperature sensors are presented in Fig. 9. By using interpolation, we obtained temperature-time graphs corresponding to the locations on which pressure sensors were placed. A gradual rise in the recorded temperature values was observed in contact locations.

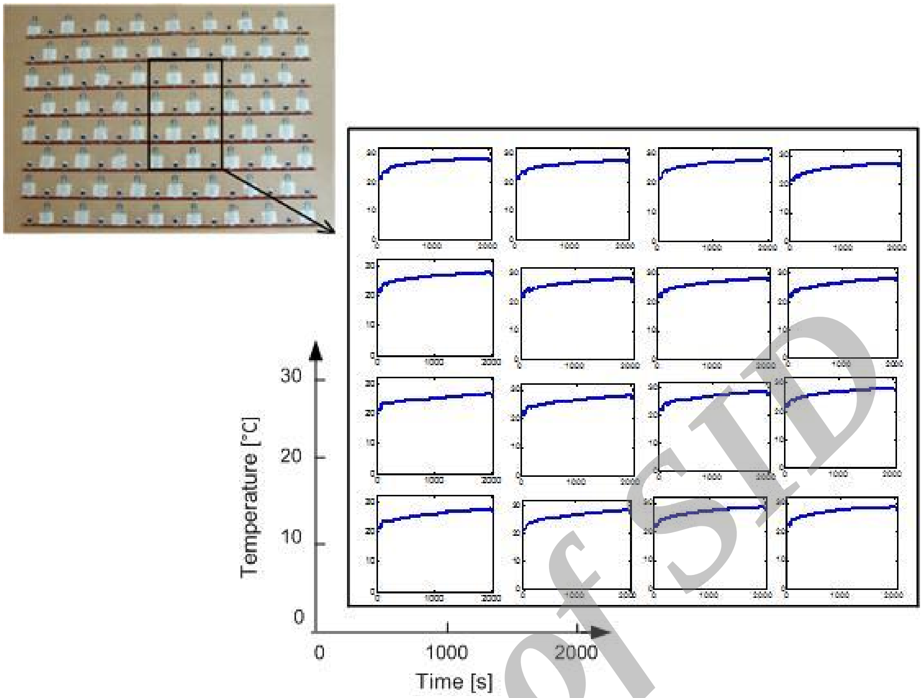


Figure 9. Temperature [°C] vs. time [s] characteristics of specified sensors during the test period. Temperature values corresponding to the locations on which pressure sensors were placed, were obtained using interpolation.

3.2 Repeatability of the Measurements

A test procedure was designed to evaluate the repeatability of pressure measurements. In identical test conditions, a particular amount of force was applied to each of the pressure sensors (and the corresponding measured force was recorded. This procedure was repeated ten times for each of the sensors, and therefore, ten force values were obtained for each sensor. Fig. 10 illustrates the measured values of force and mean and standard deviation of these values for the first four sensors of the setup.

Acceptable repeatability of measurements was concluded regarding the calculated values of mean and standard deviation for each sensor measurement. Small variations in the measurements of different sensors may be due to fabrication differences.

3.3 Sitting Posture Identification

Sore development may happen faster in a wheelchair user if he/she involuntarily leans to one side for a long period of time. In this study, we aimed to simulate different sitting postures of a wheelchair-bound patient. We evaluated healthy volunteers in the experiment and defined four different postures for them. These defined postures were used to simulate sitting postures of a wheelchair-bound patient.

In the first defined posture, the subject sat straight on the designed pressure-sensitive seat with bent knees. This was assumed to simulate the proper sitting of a patient in a wheelchair. In the second and third postures, the subject sat while crossing the right leg over left and crossing the left over right, respectively. These postures were used to simulate the postures during which a patient leans to his left and right sides, respectively. Finally, in the last defined posture, the subject sat with both legs stretched. Fig. 11 presents the produced pressure maps of different sitting postures of the volunteer.

3.4 Proposed Method for Identifying Sitting Postures

The sitting posture identification phase, described in section 3.3, was performed for 5 volunteers (3 times for each subject), resulting in 15 different tests for each of the four defined postures. To differentiate the four sitting postures, statistical parameters including mean, standard deviation, skewness, and kurtosis were calculated for each of the produced maps shown in Fig. 11. Pressure map matrices were used to calculate these parameters.

Skewness and kurtosis coefficients, related to each matrix, were calculated based on the probability distribution of pressure values in the middle rows of the matrix.

Fitted distributions corresponding to each pressure map of Fig. 11 are shown in Fig. 12. As demonstrated, the results of distribution fitting for postures 1 and 4 were close to standard normal distribution, and therefore, the corresponding skewness values would be close to zero. Fitted distributions for postures 2 and 3 resulted in negative and positive skewness values, respectively.

One way analysis of variance (ANOVA) was used to verify the feasibility of the calculated statistics for differentiating sitting postures. Figures 13 to 16 represent the obtained box plots for each parameter using MATLAB software. Each column is related to one of the four defined postures. As shown in Fig. 13, there is no overlap between mean values of postures 1 and 4. Therefore, the mean values can be used for distinguishing these two postures.

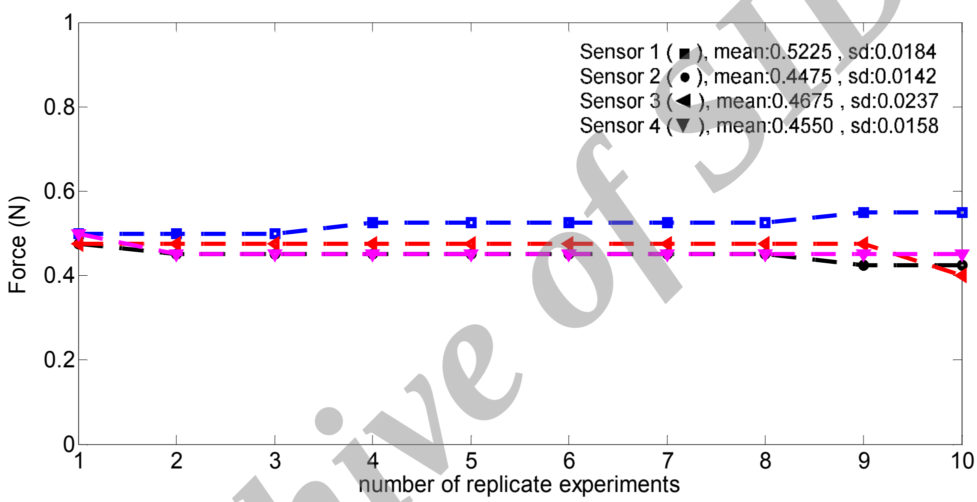


Figure 10. The measured values of force and means and standard deviations for the first four sensors

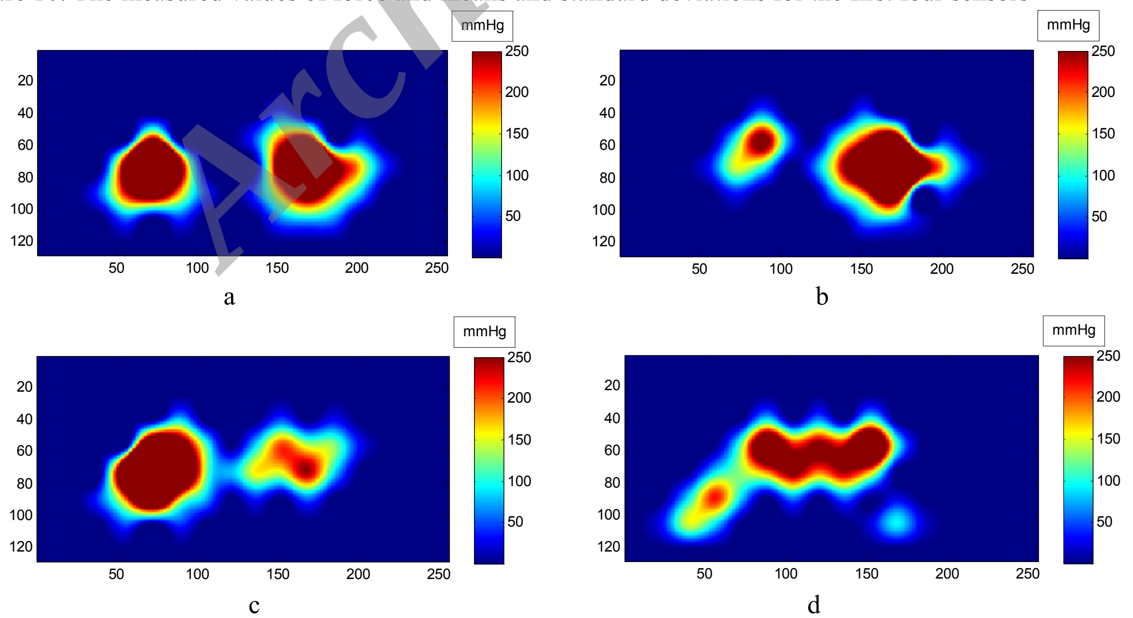
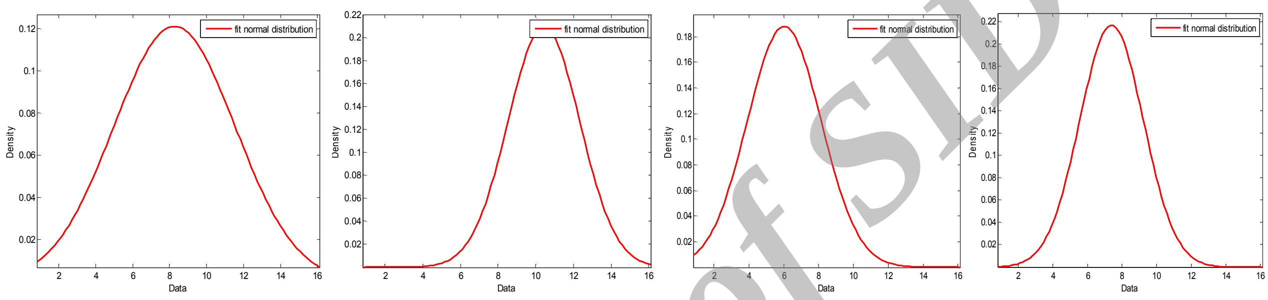


Figure 11. Different sitting postures of the sitting person; a. sitting straight with bent knees; b. sitting straight while crossing the right leg over the left leg; c. sitting straight while crossing the left leg over the right; and d. sitting with both legs stretched

Fig. 14 shows that the standard deviations vary from posture 1 to posture 4. According to Fig. 15, skewness values of posture 2 are negative, and skewness values of posture 3 are positive, while those of postures 1 and 4 are close to zero (negative or positive). Therefore, these three groups of postures (posture 2, posture 3, and postures 1 & 4) can be distinguished by the skewness coefficient. Finally, Fig. 16 shows that kurtosis coefficients of postures 2 and 3 are generally larger than those of postures 1 and 4. As shown in Fig. 12, fitted normal distributions of postures 1 and 4 are similar to the standard normal distribution, while those of postures 2 and 3 generally have higher peaks.

Posture separation was evaluated using ANOVA and multiple comparison tests. As it can be seen from the results presented in Table 1, postures 1 and 4 can be distinguished from each other, using the mean parameter and based on the mean difference and 95% confidence interval. Also, postures 2 and 3 can be distinguished from each other and from postures 1 and 4, using the skewness parameter and based on the mean difference and 95% confidence interval.



a b c d

Figure 12. Fitted distributions for each posture of Fig. 11, respectively

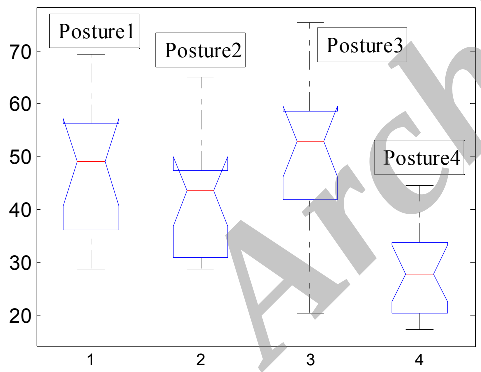


Figure 13. Box plots for mean values

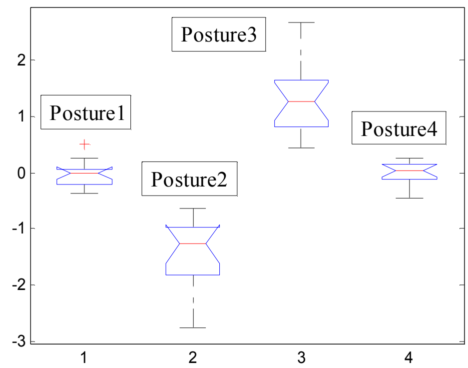


Figure 15. Box plots for skewness values

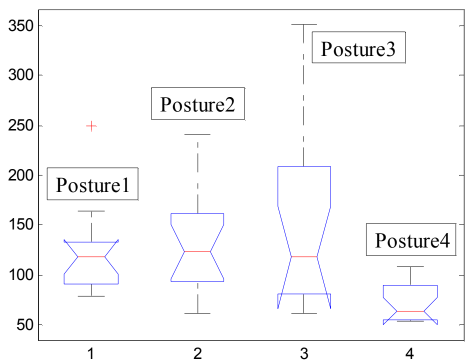


Figure 14. Box plots for standard deviation values

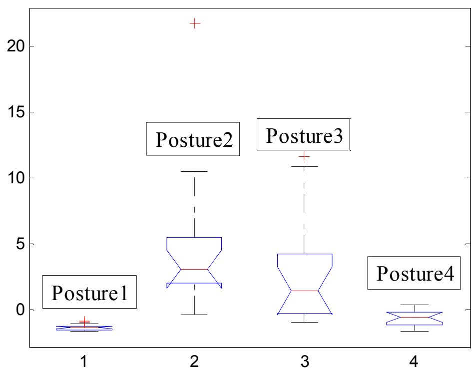


Figure 16. Box plots for kurtosis values

4. Discussion

Interface pressure has been taken into account in previously developed monitoring systems for pressure ulcer risk assessment. Since the interface temperature can be also considered as an indicator for predicting pressure ulcer development [15], we suggested that simultaneous monitoring of interface pressure and temperature might provide a better insight into the condition of tissue, subjected to unrelieved pressure.

By observing the temperature map corresponding to the risky position under pressure (a position in which excessive pressure is applied to the tissue for a long period of time), we can decide whether there is any significant temperature change in areas experiencing excessive pressure. The temperature changes can be used for identifying pressure ulcer development. Therefore, the developed system may provide a more suitable monitoring strategy for effective pressure ulcer prevention. Implementation of this system requires that risky positions be well defined by a professional therapist for each individual.

Steady temporal behaviour of the designed system and repeatability of the measurements were evaluated using tests, described in section 3. The results illustrated that the system could be utilized for continuous monitoring of interface pressure and temperature for pressure ulcer prevention.

A significant portion of pressure sores are developed in wheelchair-bound patients. Sore development may happen faster if the patient's body is tilted to one side. Hence, identifying the different sitting postures of a patient and including this information in alarm setting of the system may be helpful. In this study, a method for detecting sitting posture was proposed and verified.

Considering the ethical considerations, this experimental study was performed on healthy volunteers and in laboratory environment. Although it is reasonable to believe that the assumed postures simulate healthy and unhealthy sitting postures in wheelchair-bound patients, thorough field studies on immobilized subjects are required to evaluate the proposed statistics for differentiating sitting postures and generalizing the results to wheelchair-bound population.

In the developed GUI, we have provided an option for generating alarm messages when the pressure intensity and duration values exceed the pre-defined values. However, these threshold values were set based on the experiments performed on healthy individuals. Considering the differences in tissue properties of healthy and immobilized subjects (e.g. we cannot expect equal damage or similar duration of sore development), the threshold values for alarm generation need to be adjusted, based on tests performed on wheelchair-bound patients.

In this work, the FSR sensor was selected from different types of pressure sensors, given specific considerations. The force sensitivity was optimized for use in human touch control application and the sensor best fit the geometry of our system. In addition, it needed a relatively simple electronic interface and the required precision was achieved after calibration. DS18B20 temperature sensor was chosen given the specified merits. Unlike LM35 or other temperature sensors, the use of this sensor does not involve calibration, noise elimination, or voltage regulation. This sensor covers a range of -55° to +125°C. One of the most important advantages of the sensor was the networking capability, which allowed the placement of many such sensors on the same line and facilitated all temperature measurements through one pin of the microcontroller.

For more precision, the measuring system can be implemented using other types of pressure sensors and the number of sensors can be increased in order to obtain more accurate pressure and temperature maps.

Table1: Posture separation evaluated using ANOVA and multiple comparison tests.

Posture	Mean*	Standard Deviation	Skewness	Kurtosis
	($p=7.03 \times 10^{-5}$)	($p = 0.0035$)	$p = (2.55 \times 10^{-20})$	$p = (1.65 \times 10^{-5})$
1/2	3.88(-7.98, 15.76)	-4.07(-57.32, 49.16)	1.49(1.01, 1.98)	-6.01(-9.43, -2.59)
1/3	-2.55(-14.43, 9.31)	-25.55(-78.8, 27.68)	-1.34(-1.83, -0.86)	-4.60(-8.02, -1.18)
1/4	18.51(6.63, 30.38)	50.20(-3.04,103.45)	-0.01(-0.49, 0.47)	-0.70(-4.12, 2.71)
2/3	-6.44(-18.32, 5.42)	-21.47(-74.72,31.76)	-2.84(-3.33, -2.36)	1.40(-2.01, 4.82)
2/4	14.62(2.74, 26.49)	54.28(1.03, 107.53)	-1.50(-1.99, -1.02)	5.30(1.88, 8.72)
3/4	21.06(9.19, 32.94)	75.76(22.51, 129.01)	1.33(0.85, 1.82)	3.90(0.48, 7.32)

*p<0.05

5. Conclusion

A continuous time pressure and temperature monitoring system was presented in this study. This system may be suited for pressure ulcer prevention given its feasibility for simultaneous monitoring of pressure and temperature and alarming options. It also provides helpful information about the patient’s movement history and differentiates sitting postures. A method for detecting different sitting postures was proposed and verified. Pressure ulcers in wheelchair-bound patients may be prevented using this sitting posture detection method. Spatial resolution of the designed system can be improved in future studies by increasing the number of pressure and temperature sensors. The use of the presented pressure and temperature monitoring system can be extended to sensor-embedded mattresses for bed-ridden patients.

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References

1. Bouten C, Oomens C, Colin D, Bader D. The aetiopathology of pressure ulcers: A hierarchical approach. In: Bader D, Bouten C, Colin D, Oomens C, editors. Pressure ulcerresearch: Current and future perspectives. Berlin: Springer-Verlog; 2005. p.1.
2. Reddy M, Gill SS, Rochon PA. Preventing pressure ulcers: a systematic review. JAMA. 2006 Aug 23;296(8):974-84.
3. Ferrarin M, Andreoni G, Pedotti A. Comparative biomechanical evaluation of different wheelchair seat cushions. J Rehabil Res Dev. 2000 May-Jun;37(3):315-24.
4. Brienza DM, Chung KC, Brubaker CE, Wang J, Karg TE, Lin CT. A system for the analysis of seat support surfaces using surface shape control and simultaneous measurement of applied pressures. IEEE Trans Rehabil Eng. 1996 Jun;4(2):103-13.
5. Defloor T, Grypdonck MH. Do pressure relief cushions really relieve pressure? West J Nurs Res. 2000 Apr;22(3):335-50.
6. Elliot J. How one nurse helped stop killer bedsores. BBC News [Internet]. Retrieved June. 2009;11:2009. Available from: http://news.bbc.co.uk/2/hi/health/7952519.stm
7. Reswick J, Rogers J. Experience at Rancho Los Amigos Hospital with devices and techniques to prevent pressure sores. Bedsore biomechanics. 1976:301-10.

8. Swain I. The measurement of interface pressure. Pressure Ulcer Research: Springer; 2005. p. 51-71.
9. Npuap.org [Internet]. European Pressure Ulcer Advisory Panel (EPUAP) and National Pressure Ulcer Advisory Panel (NPUAP). Pressure Ulcer Prevention, Quick Reference Guide; 2009. Available from: http://www.npuap.org/wp-content/uploads/2012/02/Final_Quick_Prevention_for_web_2010.pdf
10. Sakai K, Sanada H, Matsui N, Nakagami G, Sugama J, Komiyama C, et al. Continuous monitoring of interface pressure distribution in intensive care patients for pressure ulcer prevention. J Adv Nurs. 2009 Apr;65(4):809-17.
11. Meffre R, Gehin C, Dittmar A. MAPI: active interface pressure sensor integrated into a seat. Conf Proc IEEE Eng Med Biol Soc. 2007;2007:1358-61.
12. Yip M, Da He D, Winokur E, Balderrama AG, Sheridan R, Ma H. A flexible pressure monitoring system for pressure ulcer prevention. Conf Proc IEEE Eng Med Biol Soc. 2009;2009:1212-5.
13. Yuxiang Y, Jian W, Zonghai G, Yi Z, editors. Design and preliminary evaluation of an air-alternating wheelchair seating system for pressure ulcer prevention. Bioinformatics and Biomedical Technology (ICBBT), 2010 International Conference on; 2010 16-18 April 2010.
14. Drennan DB, Southard DW, inventors. System and method of reducing risk and/or severity of pressure ulcers. US Patent US2010/0268122 A1. 2010 Oct 21.
15. Sprigle S, Linden M, McKenna D, Davis K, Riordan B. Clinical skin temperature measurement to predict incipient pressure ulcers. Adv Skin Wound Care. 2001 May-Jun;14(3):133-7.
16. Geyer MJ, Brienza DM, Karg P, Trefler E, Kelsey S. A randomized control trial to evaluate pressure-reducing seat cushions for elderly wheelchair users. Adv Skin Wound Care. 2001 May-Jun;14(3):120-9; quiz 31-2.
17. Dai R, Sonenblum SE, Sprigle S. A robust wheelchair pressure relief monitoring system. Conf Proc IEEE Eng Med Biol Soc. 2012;2012:6107-10.
18. Chung P, Rowe A, Etemadi M, Lee H, Roy S. Fabric-based pressure sensor array for decubitus ulcer monitoring. Conf Proc IEEE Eng Med Biol Soc. 2013;2013:6506-9.
19. Marenzi E, Bertolotti GM, Cristiani A. Design and Development of a Monitoring System for the Interface Pressure Measurement of Seated People. Instrumentation and Measurement, IEEE Transactions on. 2013;62(3):570-7.
20. Wei-chen L, Jyun-An Y, Chung-Hsien K, editors. Development of a seat-adjustable power wheelchair. System Science and Engineering (ICSSE), 2011 International Conference on; 2011 8-10 June 2011.