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A Pressure Distribution Measurement System for Supporting Areas of Wheelchair Users

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Abstract— **Pressure ulcers are skin injuries caused by long term exposition to high pressures on support points that interrupt blood circulation reducing the transport of oxygen and nutrients to the cells. They mainly affect people with poor mobility that stay in seating position for long periods of time. In spite of the diversity of commercial prototypes of cushions, ulcers caused by pressure are still a problem for wheelchair users. This work describes the design of a measurement system of pressure distribution in sedentary position. The aim of the system is to record the pressure concentration in order to obtain specific information about the supporting areas, and with these data used as feedback, eventually to determine an efficient random stimulation sequence to provide, in the future, a system to prevent these referred injuries. The proposed system consists of a 12 air-cell division cushion. Each cell has a pressure sensor and an input for electro valves to inflate and deflate. The recording and control of the valves is carried out through a graphical interface designed in LabVIEW®. A calibration procedure for the designed cushion was made by comparing the greatest load values pressure with a commercial platform, similar results were obtained.**

I. INTRODUCTION

Pressure ulcers are injuries on the skin and adjacent tissues caused by long term pressure or friction between two rigid planes, one that belong to the subject and the other external to him (Figure 1). This normally occurs on the bony prominences due to the excessive pressure that concentrates on weight points that are in contact with the skin surface [1]. The normal pressure of the tissue is between 12mmHg and 32mmHg, pressures greater than these might alter blood circulation and oxygenation, thus reducing nutrients transport to the cells and causing necrosis [2], [3].

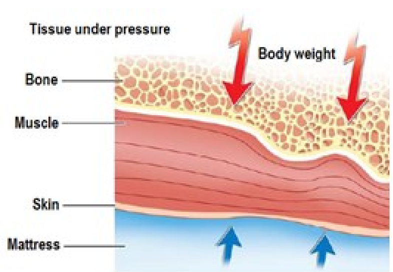

Figure 1. Tissue under pressure. *(From Preventing Pressure Ulcers: Clinical Practice Guideline. Washington, DC, US Department of Health and Human Services, AHCPR publication 92-0047 May 1992.)* .

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Most of them occur on the low part of the body; 65% on the pelvic area, 30% on the inferior limbs and the rest on other parts of the body [3].

Pressure ulcers are considered an important health problem due to the enormous economical and sanitary repercussions that they imply [4]. Therefore ulcer prevention is better than correction. Small ulcers have significant consequences not only for the suffering of the subjects but also for the treatment costs [5]. An adequate prevention of pressure ulcers concentrate in reducing the amount of pressure and the exposure time. This can be achieved though repositioning of the subject, rising body parts and also using support surfaces that are designed to handle the support of the tissues [6].

Wheelchair cushions have been prescribed to relieve pressure in support areas and to prevent ulcers. The development of an efficient seat for the control of weight distribution is an important problem in the rehabilitation engineering area. There are different commercial cushions; most of them are made of foam, gel, air or a combination of them [7]. An adequate seat should distribute the pressure, must be comfortable and should promote a correct posture also [8], [9], [10]. Despite the diversity of cushions that have been reported, the body prominences are still a problem to wheelchair users.

Reported devices consist of two systems, one that measures pressures and another that distributes them. This work presents the design of a cushion with individual air cells with pressure sensors for each section in order to have a real assessment of the pressure distribution. It is considered that having the direct information on each air cell, used as feedback, will make possible having a better control of specific stimulation on the points where the pressure concentration is centered. This paper is focused on the characterization of the pressure measurement.

II. SYSTEM DEVELOPMENT

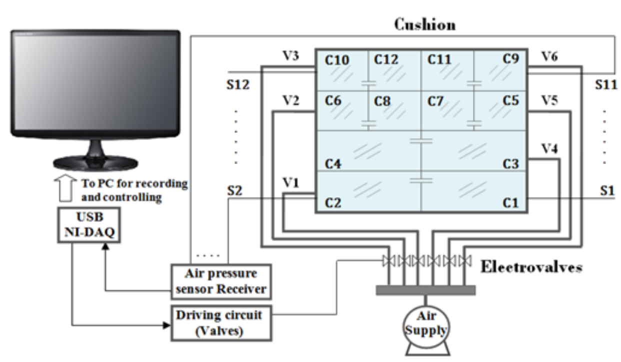


Figure 2. Block diagram of pressure measurement system.

Figure 2 shows the block diagram of the proposed system. It consists of a cushion made of vinyl, 12 air pressure sensors MPXV5050, 12 micro electro valves, one air micro pump, excitation circuits and a National Instruments board USB-6009, to acquire the data in a computer to carry out the recording and control through a graphical interface in LabVIEW.

A. Component selection

1) Cushion Development:

It has been demonstrated that there is a major pressure concentration on the ischial tuberosities areas, and they are more susceptible to develop pressure ulcers [11]. Therefore, a cushion with 12 air cells was developed and divided as follows: 8 for the ischial tuberosities and 4 for the thighs. The cushion was made of flexible material, vinyl, due to its malleability. Each cell was vulcanized with heat and two flexible tubes were connected on each of them. One tube was connected to an air pressure sensor and the other one was used to control inflating and deflating.

The cushion dimensions are 45 cm x 50 cm that corresponds to the typical size of an adult cushion. Each of the cells for the ischial tuberosities areas is 10.5 cm x 11cm, and the cells for the zone thighs are 11 cm x 21.5 cm. Figure 3 shows the developed prototype.

2) Sensor:

In order to measure the pressure distributions on the support surfaces an MPXV5050 from *Freescale*® was selected. Twelve of these sensors were used to measure the internal pressures on each air cell. The sensor is analog and linear, operates in the range from 0 to 375 mmHg and it is supplied with 3.3 V. The transfer function given by the manufacturer is shown in equation 1.

$$Vout = Vs^* (0.018 * P + 0.04) \quad (1)$$

where: P is the pressure, Vout is the output voltage and Vs is the supply voltage (3.3 V).

3) Electro valves:

For the inflating/deflating mechanism the following features were considered: small size, fast commutation response, minimum or null air leaking. The MHA1-M4H-3/2G-0,6-HC valve from FESTO® was selected. It measures 2 cm x 1 cm, has a nominal flow rate of 10 l/min, commutation frequency of 20 Hz at 5 V power supply with an electrical power consumption of 1W, which is appropriated in terms of compatibility with the acquisition board used. Six of this electro valves are used to inflate the air cells and another six in parallel to control deflation. The array of electro valves is shown in figure 4.

4) Air pump

As we required a small and light weight cushion, we used a micro air pump as an air source, the D2028 AIR-PRO®. This provides a nominal flow rate of 12 l/min to the six electro valves that inflate the cushion air cells. It operates at 12 V.

Figure 3. Designed cushion prototype with the sensors connected

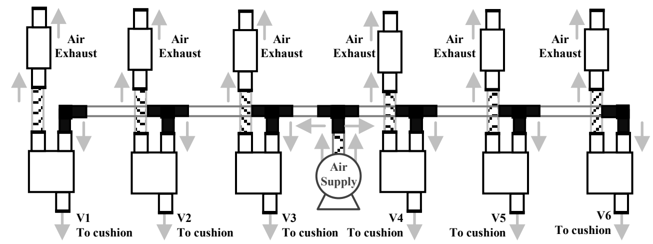


Figure 4. Valves array for inflating/deflating.

5) Data acquisition

The communication between the computer and the sensors was accomplished by the NI-USB6009 data acquisition card (National Instruments®, USA) which employs the USB port of the computer. The inputs were configured with a sample frequency of 1.25 kHz. The 8 analog ports were used. As the system employs 12 sensors, three multiplexers were used to enhance the acquisition capability. Additionally, 12 digital output ports were configured for the electro valves control.

The acquisition card has an ADC with a 13-bit resolution in single-ended mode. Hence, the system has a total resolution of 0.045 mmHg, enough to observe minimal changes on the pressure recordings.

6) Graphical interface for recordings and control purposes

The purpose of the graphical interface is thought to generate a feedback based on the pressure mapping given by the sensors placed on the support surface. Depending on these results, load redistribution will be able on the areas of greatest weight support. For this interface, a function was programmed to convert the sensor signal into pressure values (mmHg) considering (1).

The electro valves were controlled by PWM at a 10 Hz rate for the inflating/deflating sequence with a pulse width proportional to the value of the pressure sensors by the graphical interface. This interface allows the control of 12 electro valves, 6 of them are directly connected to the air-cells, and the other 6 are in parallel to control the exhaust air. The 6 inflating electro valves are connected to all sections of the developed air cushion. Each section is composed by 2 cells as shown on figure 5.

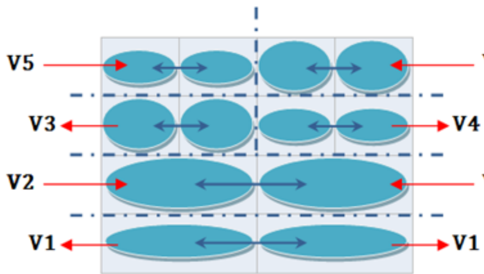


Figure 5. Air cushion sections for control inflating mechanism by the electro valves.

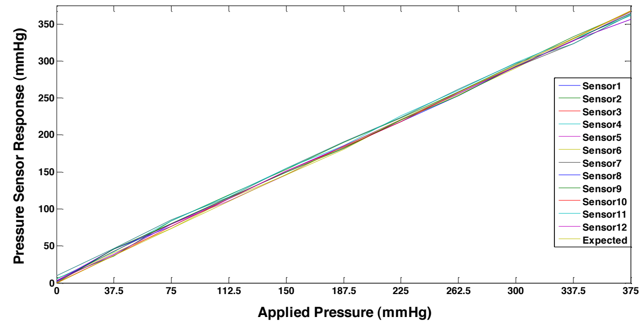


Figure 6. Pressure sensors response after signal processing.

III. Results and Discussion

A. Pressure sensors response

For the sensors calibrating procedure each one of these devices was provided with a controlled pressure in 37.5mmHg intervals up to 375 mmHg high limit by employing a manometer and a manual valve. The voltage responses from the sensors were acquired with a National Instruments® data acquisition card and by using a small graphical interface designed in LabVIEW®. The recordings were saved in an .xls format (Excel®). Afterwards, the results graphically demonstrated the linearity offered by the manufacturer, it was proven using the transfer function as shown on figure 6.

B. Air Cushion Calibration

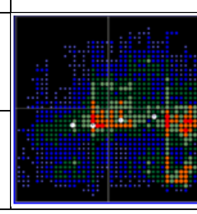
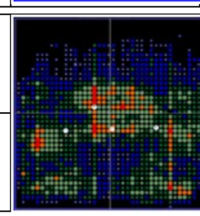
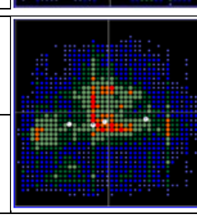
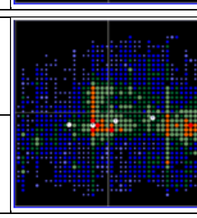
The air cushion designed to find the pressure values delivered as well as the pressure distribution area was characterized. A 2200 pressure sensor commercial platform and its software were employed to validate the pressure distribution area provided by the cushion. This platform does not quantify the amount of pressure, but it gives a mapping of the load distribution data. Therefore, it was used to prove that the greatest pressures are located within the same area of the developed cushion.

The characterization procedure was as follows: the cushion was located over the commercial platform, 4 healthy subjects of different physical complexions and heights were selected, they were asked to sit upright on the air cushion on a symmetrical position. Then, data were recorded and stored in a table by the graphical interface designed in LabVIEW®, at the same time the image given by the software platform was captured in order to compare with recording pressure sensors.

The obtained results are shown in Table 1, the measured pressure by the 12 air cells are presented. This table also reflects that the greatest pressure points on the 2200 sensor commercial platform corresponding to the areas of greatest pressure distribution on the developed system.

As seen on Table 1, the greatest support areas are the ischial zones. According to the scheme on figure 2, cells C7 and C8 have the peak pressure concentrations. This test was made for qualitative purposes to compare the developed system response with the pressure mapping shown by a commercial system.

TABLE I. Comparative Table of the Pressure Distribution Obtained with the Developed System and the Commercial Platform

Subject Data		**Pressure distribution**					Max
		Commercial platform	***Developed system (mmHg)***				
W	85 kg		9.81	10.17	10.26	9.85	
			51.41	63.57	82.05	51.89	
H	1.65 m		72.89		73.06		
			74.33		73.76		
W	72 kg		19.41	19.38	19.84	19.41	
			48.93	63.14	58.85	48.93	
H	1.69 m		65.59		65.14		
			69.85		69.62		
W	57 kg		10.98	11.21	11.23	9.85	
			32.42	58.93	60.80	51.89	
H	1.55 m		59.85		61.18		
			48.45		48.58		
W	79 kg		36.18	36.75	36.68	36.45	
			66.34	68.79	81.47	66.73	
H	1.7 m		56.06		56.47		Min
			41.09		41.06		

W=Weight H=Height

IV. CONCLUSION

In this work, the design of a pressure distribution measurement system with the aim of recording the pressure concentrations of a subject in the seating position was presented. The data could be used as a reference for the designing of a pressure redistribution control system for avoiding pressure ulcers.

The main contribution in respect to other systems that require a measurement system and a pressure redistribution system such as the alternating commercial cushion is that this proposal offers a punctual measurement of the pressure in each air cell and therefore, the load concentration point measurements. This information is used as feedback in order to provide a pressure re-distribution.

This represents a great advantage because the system is useful for assessing pressure redistribution as well as for investigation purposes to develop an intelligent control mechanism to redistribute pressure and avoid pressure sores.

This proposal is intended to be used in wheelchairs and chairs since it can be moved wherever the users need.

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