Embedded Textile Sensing System for Pressure Mapping and Monitoring for the Prevention of Pressure Ulcers

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Abstract: Despite improvements in medical industry and consequent modernization of the biomedical devices and healthcare, pressure ulcers prevalence remains high particularly in hospitalized patients that present little or no mobility. This kind of skin injury affects the patients' quality of life and their caregivers, and on the other hand, increases directly or indirectly the healthcare costs. Thus, the monitoring and early identification of the risk factors that lead to the development of pressure ulcers is important to decide what are the appropriate preventive measures. The present work aims to present a new concept of a pressure sensing and monitoring system, able to detect the pressure exerted on the surface. In this case, the system consists of a sensing matrix made from a kind of commercial piezoresistive sensors embedded in a textile substrate. The solution presented can be used together with an actuation system, which will reply in order to allow the pressure relief according to the feedback from the pressure monitoring system.

1 INTRODUCTION

People with severe motor limitations have, in most of the cases, a decrease of sensitivity in the body´s areas in contact with support surfaces. In addition, their limited mobility doesn't allow them to frequently change position autonomously. As a result of these complications, the people tend to become bedridden which, consequently, may result in development of pressure ulcers, also known as decubitus ulcers (Rocha *et al.*, 2008). According to the European Pressure Ulcer Advisory Panel (EPUAP), National Pressure Ulcer Advisory Panel (NPUAP) and Pan Pacific Pressure Injury Alliance (PPPIA), a pressure ulcer is a localized injury of the skin and/or underlying tissue, usually over a bony prominence, as a result of pressure, or pressure in combination with shear (National Pressure Ulcer Advisory Panel, 2007), (*Superfícies de apoio na prevenção das úlceras de pressão*, no date). Although there are several risk factors which may trigger the development of pressure ulcers, the critical determinants include the intensity and duration of pressure, and the tolerance of skin and its support structures to pressure (Murray *et al.*, 2001), (Rocha *et al.*, 2006), (Lyder and Ayello, 2008). Usually, a pressure ulcer occurs when soft tissues are compressed between bony prominences and an external surface for a prolonged period of time. Pressure leads to the injury when it is higher than blood pressure within capillaries (a threshold of 32 mmHg is widely indicated as the point at which intracapillary pressure is overcome), resulting in capillary collapse and, consequently, insufficient sanguineous irrigation (Murray *et al.*, 2001), (Rocha *et al.*, 2008), (Lyder and Ayello, 2008), (Dealey, 2012), (Menoita *et al.*, 2012). The development of a pressure ulcer can occur in a short period of time (within 2 to 6 hours), which makes it necessary to adopt timely preventive measures, namely, identify patients with higher risk and/or more vulnerable to the development of pressure ulcers (Lyder and Ayello, 2008).

The common preventive strategies widely used in these cases, as a fundamental complement in the pressure ulcers treatment, include the use of pressure reduction devices or support surfaces. Among this kind of devices there are the static devices that provide a constant pressure redistribution, increasing the contact surface with the skin and reducing the force exerted per unit of area; and dynamic devices

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which offer a cyclically variable pressure (Rocha *et al.*, 2006). Static devices include mattresses, covers, cushions, wheelchair cushions and positioning supports made from viscoelastic materials, memory foam, gel or water and air. In the other hand, dynamic devices comprise alternating and low-air-loss mattresses, air fluidized beds, air cells with alternating insufflation, dynamic flotation systems and continuous low pressure devices, among others (Rocha and Miranda, 2006), (Fulton and Monro, 2009), (McInnes *et al.*, 2011), (Call and Black, 2015). Despite the benefits of these devices in preventing pressure ulcers, they also feature some limitations, operate preprogrammed and alternately, providing the same pressure redistribution, not effectively removing body pressure from high pressure points and not adapt to different pressure and risk situations.

Currently, the market has been focusing on new solutions which incorporate monitoring or sensing systems, allowing the measurement of the pressure exerted between the patient and contact surface. Basically, these systems supply mapping the pressure distribution in order to identify areas of the body that are under elevated pressures (Sensor Products Inc., no date), (*Mattress Retail & Design | XSENSOR Technology Corporation*, no date). However, these devices only allow the measurement or detection of pressure, not providing the relief or redistribution of the pressure, furthermore, its use in pressure ulcers prevention has not been reported.

The present work is part of a research project, designed ActiveRest, which has as main objective the development of a new concept of a smart textile mattress guard that through a body pressure mapping system in combination with an intelligent actuation system, will relieve the pressure on the user, preventing the development of a pressure ulcer. In addition, the ActiveRest project seeks to create a solution that integrates three development stages, as represented in the diagram of the Figure 1.

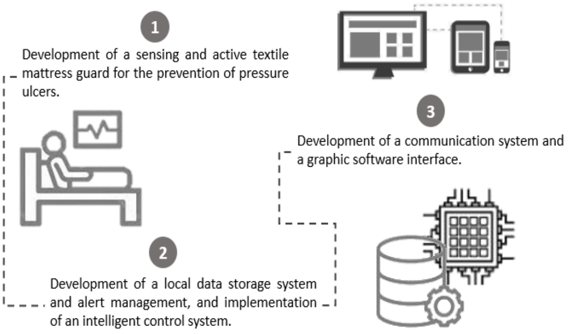

Figure 1: Main objectives of the ActiveRest project.

This paper presents the work carried out in the design and development of a pressure sensing matrix, based on the selection of flexible and adaptable materials, in order to create a system that allows pressure monitoring through the mapping of body pressure.

2 FORCE SENSING RESISTORS

Currently, on the market and in scientific literature there are numerous kinds of transducers that convert force into an electric quantity. In this case, force sensors can integrate sensors involving a variation of an electrical property (resistance, capacitance, or impedance), sensors generating a charge displacement (piezoelectric), among others that use different physical quantities (light, magnetic field, etc.) (Giovanelli and Farella, 2016).

A promising type of pressure sensor (the terms force and pressure are used as synonyms, considering that force is pressure over a known area), and widely used in several applications, is force sensing resistors (FSR), sometimes called piezoresistive sensors. Piezoresistive/force sensing resistors present some advantages in relation to other force sensors, namely, can be fabricated using flexible materials, which make them able to adapt to the place where they are inserted; are very robust against noise and the conditioning electronics is simple. Moreover, the unit costs are relatively low (Giovanelli and Farella, 2016), (*Overview | Force Sensitive Resistor (FSR) | Adafruit Learning System*, no date).

This study is focused on a type of commercial force sensing resistor, FSR 402 model of Interlink Electronics (Figure 2) with 14,7 mm diameter active area (*FSR 402*, no date). It is a robust polymer thick film (PTF) sensor that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. This sensor is fairly low cost and easy to use.

Figure 2: FSR 402 model of Interlink Electronics with 14,7 mm diameter.

2.1 FSR Study and Calibration

The experimental setup implemented to study and characterize the accuracy of the sensor's response is represented in Figure 3. In this case, on the sensor's surface different weights values (150, 300, 450, 600 and 750 g) were placed, and a bench multimeter was used to measure the sensor's resistive value, which changes according to the applied force. The multimeter was connected to a computer that stores the data that result of the pressure sensor reading. In order to ensure that the weight was uniformly distributed over the sensor´s sensing area, two types of materials with different stiffness and texture were tested, namely an acrylic circle and a felt circle, with a slightly lower diameter than the sensor sensing area (14 mm), as shown in Figure 4. These materials were used as spacers between the contact area of the sensor with the weight.

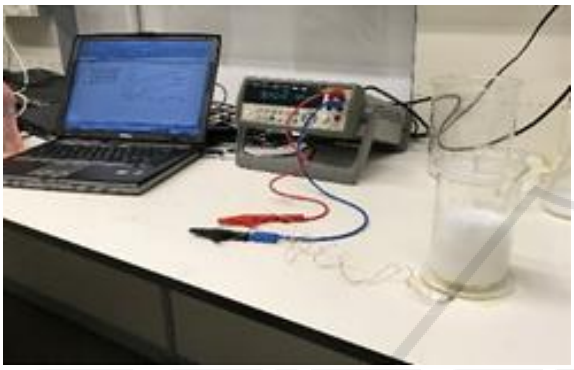

Figure 3: Experimental setup used to study of the FSR sensor response.

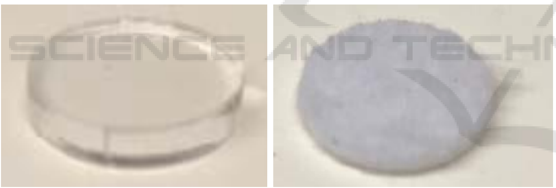

Figure 4: Acrylic and felt circles, respectively, used as spacers between the FSR sensor and the weight.

2.1.1 Results Analysis

Initially the sensor’s response was analysed in regards to the sensibility and response time, using the acrylic spacer. Figure 5 shows the graphical representation of the results obtained in the sensitivity study. The graph represents the relationship between the sensor conductance as a function of the pressure applied when placed on the sensor the different weights mentioned above.

As regards the study of the sensor’s response time, it is represented by the graph in Figure 6. In this case, a defined weight was used and the sensor´s response was measured over a period of time, verifying if the sensor reading remains constant on each sampling.

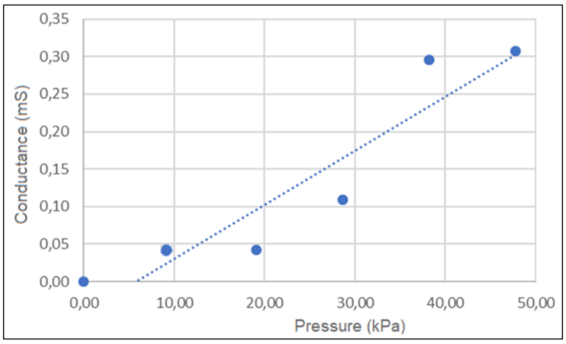

Figure 5: Sensitivity study of FSR sensor using an acrylic spacer between the sensor and the weight.

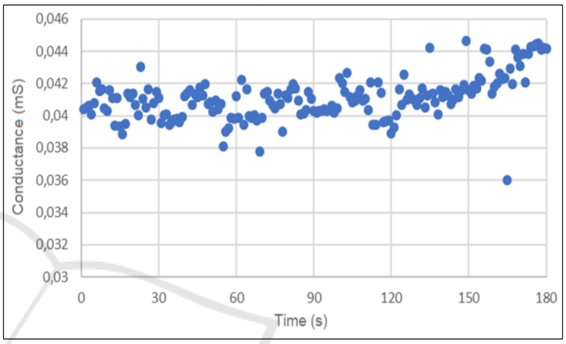

Figure 6: Response time study of FSR sensor using an acrylic spacer between the sensor and the weight.

According to the results obtained in both studies, for the acrylic spacer, it can be observed some inaccuracy in the results, so that the sensor´s response does not vary uniformly. As an alternative to acrylic, another material with lower stiffness was analysed, that is the felt spacer. Figures 7 and 8 represent the graphs with the results obtained using this material, for the study of the sensitivity and the response time of the sensor, respectively.

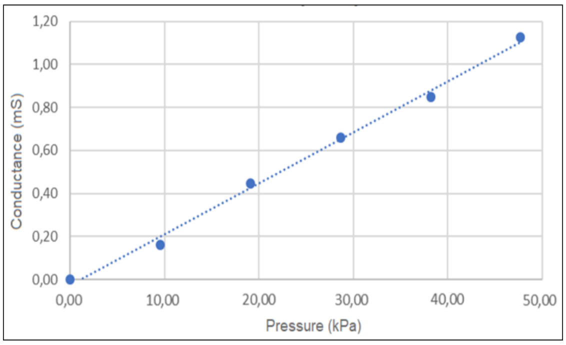

Figure 7: Sensitivity study of FSR sensor using a felt spacer between the sensor and the weight.

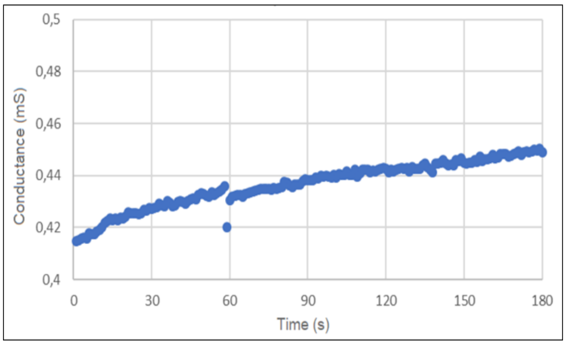

Figure 8: Response time study of FSR sensor using a felt spacer between the sensor and the weight.

Regarding the results obtained using a felt spacer, the sensor showed better results and greater sensitivity. From the graphic analysis, it was possible to observe that commercial piezoresistive sensors are quite accurate and have a short response time, which is about 1 minute. This improvement can be related with a more uniform and adequate distribution of the force over the sensor's contact area, minimizing some errors associated with inconsistencies in the force distribution, which can arise from substrate stiffness.

In order to analyse the consistency and stability of the sensor readings, as well as the variability of the implemented measurement system, the sensor's repeatability study was also performed. To this end, different measurement series were carried out, in a total of three repetitions. The results obtained with this procedure are shown in graphical representation of the Figure 9. From the graph it is observed that the sensor's response varied slightly throughout the tests, however the different is minimal, which shows good results in the repeatability of the sensor's response.

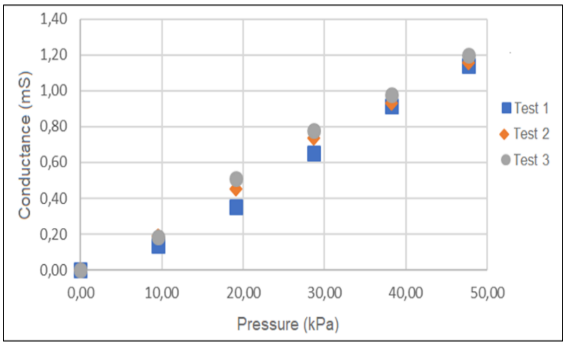

Figure 9: Repeatability study of FSR sensor over three tests, using a felt spacer.

3 APPLICATION OF FSR IN REAL SOLUTIONS FOR PRESSURE MONITORING

3.1 Implemented System Overview

The behaviour of piezoresistive commercial sensors on pressure monitoring applications, when used together with a commercial dynamic pressure mattress (INVACARE LIBER L803/ESKAL L839), was studied. For this analysis a calibrated weight of 10 kg was used and placed onto a surface of wood in order to distribute the force applied through several air cells (Figure 10). The FSR sensor was fixed and centred to an air cell at the mattress bottom (Figure 11). For this analysis two tests were performed, first using the felt spacers between the sensor and the air cell, and then without de felt spacer. Each test was repeated 2 times and lasted approximately 30 minutes to ensure that both operating cycles (filling and emptying) of the mattress were studied.

Figure 10: Calibrated weight of 10 kg placed on the air cells of the dynamic mattress.

Figure 11: FSR sensor fixed to an air cell of the mattress.

3.1.1 Results Analysis

The results obtained with and without the felt spacer represented in the graph of the Figure 12. Analysing the different curves, it is observed that the sensor presents better results when the felt spacer is used, presented a greater sensitivity. Furthermore, it is also possible to verify the sensor´s capability to detect the pressure exerted by the weight placed on the mattress taking into account the alternation of the filling cycles, featuring a similar behaviour over the time. On the other hand, due to technical difficulties in reproducibility of the experimental conditions, it was not possible to draw any conclusions about sensor’s accuracy.

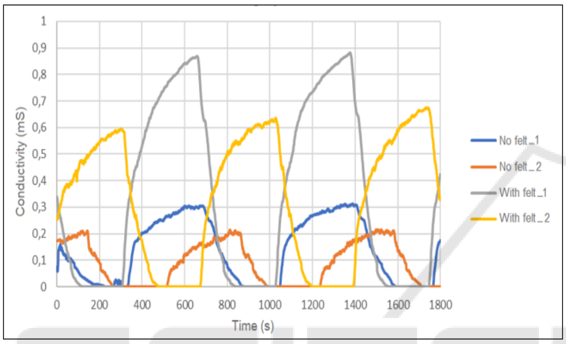

Figure 12: Sensitivity study of FSR sensor placed on a commercial dynamic mattress with a fixed weight of 10 kg. The tests were performed with and without the felt spacer.

4 PRESSURE SENSING MATRIX

4.1 Textile Sensing Matrix Design

In order to create a system capable to detect and measure the pressure exerted on a surface, for example the body pressure exerted between the patient and the mattress, a matrix composed of 96 piezoresistive sensors was constructed. Each sensor was previously calibrated and characterized based on the experimental procedure as described before. From the sensor’s calibration process were determined the calibration parameters by linear regression. As support for the sensing matrix, a textile substrate was used, on which the 96 sensors were arranged in 12 rows and 8 columns and fixed by a sewing process. The felt spacers were fixed to the sensor’s contact area using an adhesive tape and the connections between the sensors were made using coated conductor wire (0.7 mm diameter, 50 torsions per meter, 0.694 Ω electric resistance and electric insulation of PFA). Figure 13 shows the constructed textile matrix, and its respective connections between the piezoresistive sensors.

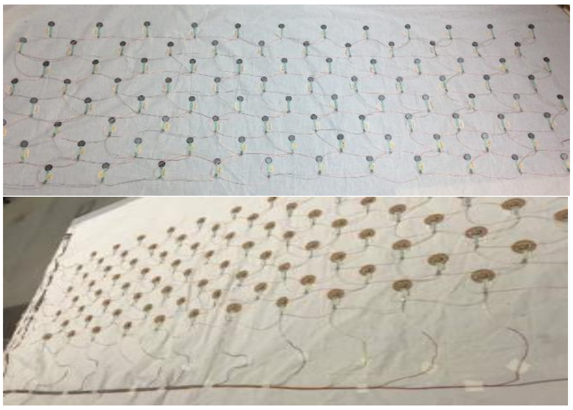

Figure 13: Sensing matrix (12x8) from commercial pressure sensors of Interlink Electronics.

4.2 Body Pressure Mapping

Tests with the sensing matrix were carried out using the dynamic mattress of INVACARE. The matrix was positioned under the mattress, so that each sensor corresponds to an air cell. The pressure exerted on the dynamic mattress surface resulted from the bodyweight distribution of a person with 79 kg laid along the mattress. This experimental procedure was adopted in order to measure the pressure variation detected by each sensor during the operation cycles of the alternating pressure device. The acquisition and display software was developed using Labview, and the implemented program provides the serial communication with the data acquisition board, and the display of the pressure values mapped to a color scale. This procedure can be observed in Figure 14.

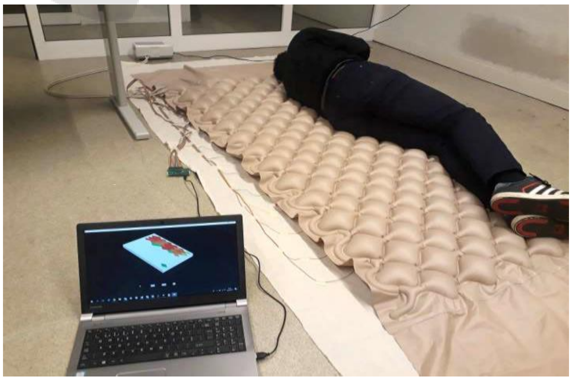

Figure 14: Body pressure mapping using the piezoresistive sensor matrix developed and the acquisition software.

5 CONCLUSIONS

This paper presents the work carried out in the design and development of piezoresistive sensor matrix used to detect and monitor the pressure. The characterization and calibration procedures of the FSR sensor was presented, as well as, tests in pressure measurement applications, where the influence of the use of different spacers material (acrylic and felt) with different stiffness was analysed. In this case, it was observed that the use of a spacer material, with low rigidity, namely the felt spacer, coupled to the commercial FSR sensor was found to greatly improve the accuracy of pressure measurement. The sensor's response using the felt spacers showed greater sensitivity.

From the graph of Figure 12 it is possible to see that the sensor starts to respond from a conductivity of approximately 0,05 mS which, by data from graphic representation of Figure 7, correspond to a pressure values below 5 kPa. With this, it is observed that the piezoresistive sensor can detect in the pressure range where the value of the capillary tension inside the tissues (32 mmHg, corresponding to about 4 kPa) is inserted, from which the pressure begins to cause lesions on the skin, especially in regions of vulnerable bone prominence. Thus, according to the study developed around the use of commercial piezoresistive sensors in pressure detection and mapping systems, it was found that this kind of sensors allows the pressure measurement, including when used with other pressure ulcer prevention systems. The developed sensing matrix was able to read pressure variations, presenting a satisfactory performance, which proves its usefulness in body pressure monitoring applications.

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