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Design and Fabrication of a Capacitance Based Wearable Pressure Sensor Using E-textiles

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Abstract

This paper addresses the methods used for the design and fabrication of a capacitance based wearable pressure sensor fabricated using neoprene and (SAC) plated Nylon Fabric. The experimental set up for the pressure sensor is comprised of a shielded grid of sensing modules, a 555 timer based transduction circuitry, and an Arduino board measuring the frequency of signal to a corresponding pressure. The fundamental design parameters addressed during the development of the pressure sensor presented in this paper are based on size, simplicity, cost, adaptability, and scalability. The design approach adopted in this paper results in a sensor module that is less obtrusive, has a thinner and flexible profile, and its sensitivity is easily scalable for 'smart' product applications across industries associated to sports performance, ergonomics, rehabilitation, etc.

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Keywords: E-textiles; Capacitance; Wearable Technology; Pressure; Sensor.

1. Introduction

Etextiles are the result of the convergence of electronics and textile technologies. Etextiles can be used in a wide range of applications from healthcare to sports, fashion, industrial and military activities. They can be used to develop unobtrusive solutions to common issues encountered daily. Pressure sensors are a key application of etextile technology, which embedment is relatively new for consumer products, particularly in the sports, orthotics, and rehabilitation products industries.

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Because of their high potential and ubiquitous applications, the development of pressure sensors made from conductive fabrics is an area of active research [1]. The main operating principle utilised in etextile pressure sensors is to detect and measure changes in some intrinsic electrical property of the sensor material and design such as resistance, capacitance, or piezoelectric characteristics.

A wide array of etextile based pressure sensor products are available commercially; these textile based pressure sensors can be applied to provide robust and cost-effective alternatives to conventional solutions [2-6]. Pressure Profile Systems, Inc. specialises in capacitance based pressure sensing products for a wide range of industries [7]. Wenyao et al. implemented a resistance based pressure sensor using etextiles to develop a sitting posture monitoring device [6]. Wood et al. developed a capacitive pressure sensor based in the AD7754 analogue to digital converter (ADC) [5]. Their design is comprised of layers of silver coated conductive yarn embroidered either side of a compressible spacer. This paper addresses the methods used for the design and fabrication of a capacitance based wearable pressure sensor. The fundamental design parameters addressed during the development of the pressure sensor presented in this paper are based on size, simplicity, cost, adaptability, and scalability. The design approach adopted in this paper results in a sensor module that is less obtrusive, has a thinner and flexible profile, and its sensitivity is easily scalable according to the application requirements. This significantly broadens the potential for 'smart' product applications across industries associated to sports performance, ergonomics, rehabilitation, etc. where design customisation to individual user requirements of performance and quantitative evaluation is currently highly desirable [8-14].

2. Methodology

2.1. Sensor Design Fundamentals

The fundamental design for the pressure sensor is based on a material layer configuration. A single sensor module is considered to initially define the important design parameters of the sensor, to then consider the possibility of scalability to a sensor modules grid for different application requirements. Taking the later into account, each sensor module consists of a capacitor realised by sandwiching a compressible dielectric material, such as neoprene, between two layers of conductive fabric. Figure 1 shows a schematic of a basic sensor module. The modular design approach means that the basic sensor module can be scaled to an arbitrary sized pressure sensor made by connecting and (or) fabricating several sensor modules in a grid or array.

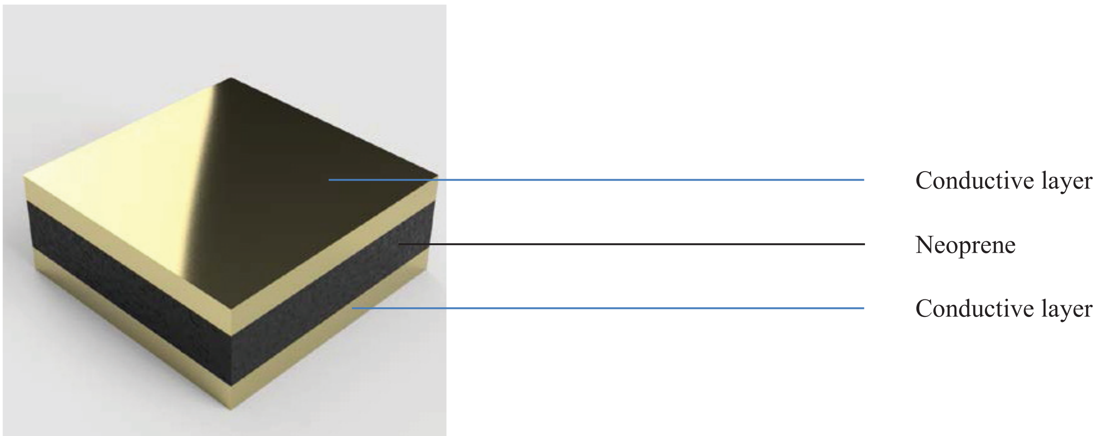

Figure 1 Transducer module configuration

The etextile used in the fabrication of the pressure sensor is Zell; a Tin/Copper over Silver (Sn/Cu/Ag)-(SAC) plated Nylon Fabric manufactured by Shieldex-U.S. The fabric was chosen for its high conductivity and ruggedness. Table 1 shows some properties of the material adapted from the manufacturer's data sheet.

Table 1. Zell Technical Data Sheet. Adapted from [15]

Property	Value
Surface Resistance	< 0.02 Ohms/square
Shielding Effectiveness	Average 85 db from 30Mhz to 10Ghz
Abrasion Resistance	500,000 Cycles
Temperature Range	-40°C to 90°C
Total Thickness	.003” (0.1mm) nominal
Number of Splices	1/100M nominal

2.2. Operating Principle

The capacitance of a capacitor is directly proportional to the area of the conducting surfaces and inversely proportional to the distance between the plates as shown in Equation 1.

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \tag{1}$$

Where, C is the capacitance, ϵ_0 is the permittivity of free pace, ϵ_r is the dielectric permittivity (neoprene in this case) and d is the distance between the capacitor plates. For this setup, the dielectric permittivity and permittivity of free space, as well as the area of each module is constant. This implies that the capacitance of each sensor module is dependent only on the distance between the conductive surfaces. From Equation 1, to get non-trivial capacitance values, the effective area (A) should be significantly greater than the distance between the capacitor plates (d).

Pressure on one of the conductive surfaces of a pressure sensor cell will cause a change in the distance between the conductive surfaces, which will lead to a change in the capacitance of the cell.

2.3. Experimental design for the Transducer Operation

The frequency of the signal produced by the transduction circuit is proportional to the capacitance of the sensor module being measured. As mentioned earlier, applying pressure to one or both surfaces of the sensing module changes its capacitance. This implies that the frequency of the transducer is proportional to the pressure applied to the sensing module.

The experimental set up for the pressure sensor is comprised of a shielded grid of sensing modules, a 555 timer based transduction circuitry, and an Arduino board.

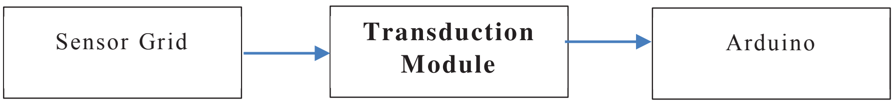

Figure 2 Block Diagram of the Pressure sensor

The Arduino board measures the frequency of the signal and computes the corresponding pressure applied to the sensor module.

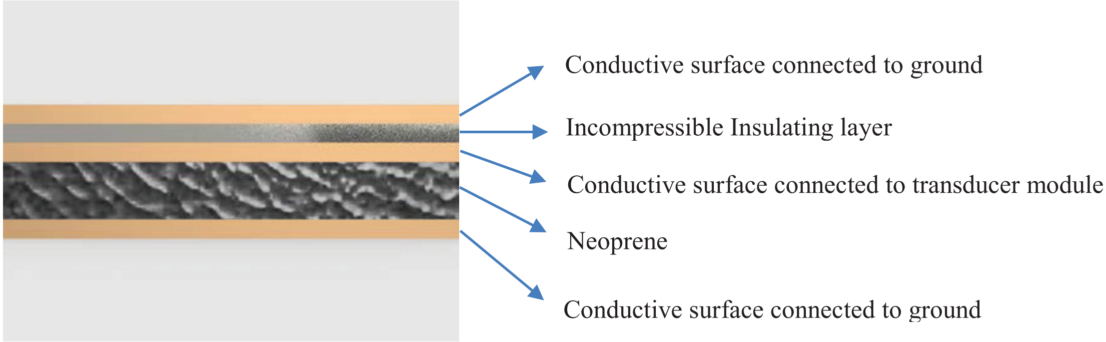

Figure 3 Experimental Setup

To minimize noise due to electromagnetic and electrostatic disturbance, the sensor module is shielded with a layer of Zell fabric connected to ground. The electromagnetic shield is separated from the sensor module by an incompressible insulating fabric layer. To avoid errors due to ground loops, the electromagnetic shield, transduction module, sensor cells and Arduino are connected to a common ground.

The output of the transduction module is a square wave, which negates the need for an analogue to digital converter. This eliminates analogue to digital sampling errors.

Sensor and shield module have a combined thickness of 2.4mm. Each sensing cell area is 400mm^2 and the neoprene thickness is 2mm thick. Each layer of conductive fabric and insulation is 0.1mm thick. This design profile specifications were chosen in order to produce a sensor that can be incorporated unobtrusively into potential orthopedic, medical and sports consumer product applications.

3. Results

3.1. Pressure Calibration

Pressure is directly proportional to force and inversely proportional to area. For calibration purposes, it is important that the force to be measured by each cell is distributed evenly within the boundary of the sensing surface. This is one of the factors that determined the sensing surface area.

The sensor was calibrated using standard masses. Three sets of ten iterations were recorded for each mass measured during the calibration process. The resultant frequencies were averaged for each mass. The neoprene was tested for plastic deformation after each mass was measured. Plastic deformation occurred at 1,650g for the specified sensor design.

Figure 4 shows the frequency (Hz) - mass (g) plot obtained for the sensor calibration. Curve fitting and system identification techniques were employed to smooth the curve and derive a transfer function for the sensor. Figure 5 shows the smoothed curve and the original curve.

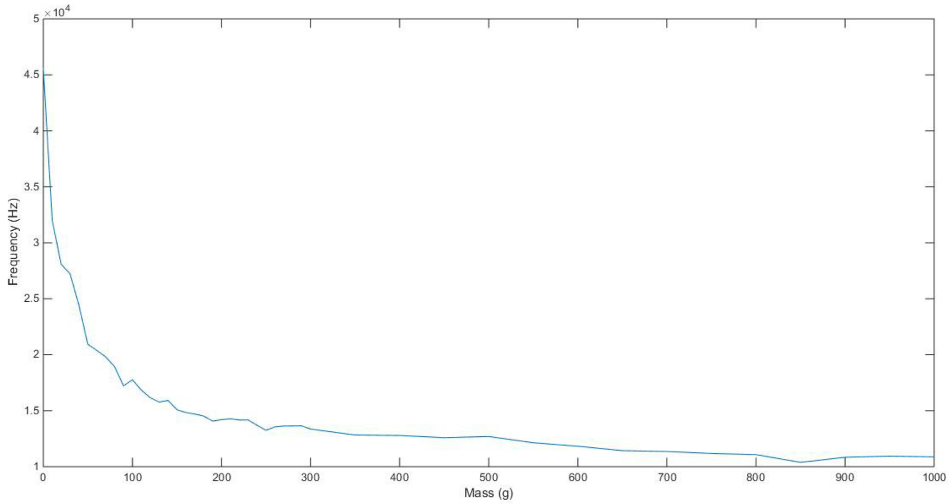

Figure 4 Frequency (Hz)-Mass (g) plot

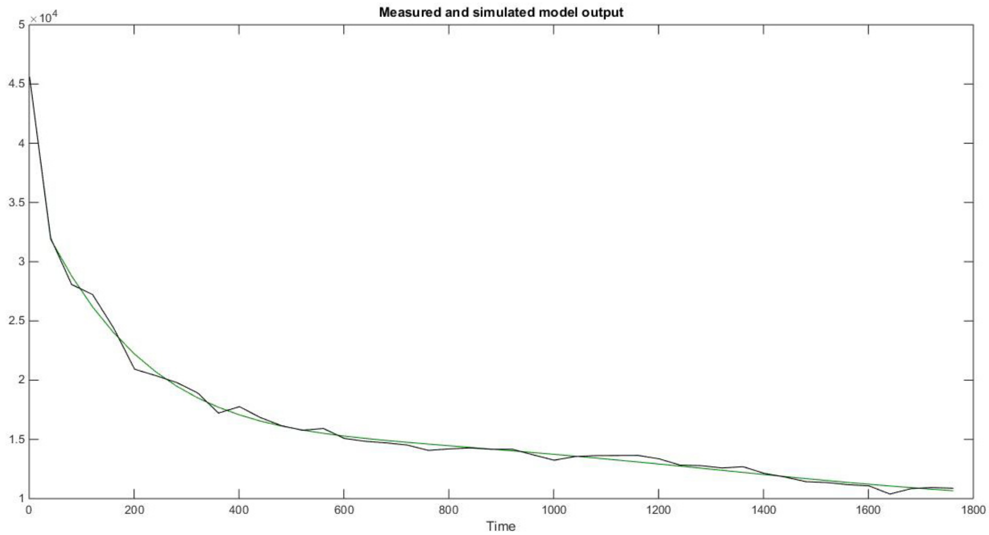

Figure 5 Smoothed sensor curve.

4. Conclusions

The design of this wearable sensor is sensitive to a maximum of 1.65kg equivalent pressure over a 400mm^2 sensor with a flexible wearable profile of 2.4mm thickness. From literature, forces exerted by flexion, extension and rotation movements of upper human joints can range between 2N-60N [16].Further investigations will be carried out to optimize the design and fabrication of the pressure sensor. It will cover scaling the sensitivity of the sensor for a wide range of applications. Further investigations will also focus on reducing the overall sensor thickness as well as determining the optimal resolution, grid-module configuration and transducer circuitry. This will enable the development of pressure sensors integrated into sporting and medical garments.

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