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# Textile-based pressure sensors for step detection: a preliminary assessment

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**Abstract.** This paper presents the development and performance assessment of textile-based sensor based on a three layer architecture for the step detection. Two different transducing elements (EeonTex™ LG-SLPA and velostat) and electrodes (Satatex Techniktex P-130 and Elitex yarns) were selected for the construction of the sensors. The performance of the resulting sensors was assessed based on a dynamometer cyclic compression/decompression test with different compressions loads and at different speeds. Additionally, a real-life experiment was conducted to evaluate the sensor response during walking. The results show that all sensors configurations have a non-linear resistance-force relation. The best sensor configuration for the step detection was the combination of EeonTex™ LG-SLPA as a transducing element and the Elitex yarns for the electrodes. In this configuration, the resistance magnitude varies in an order of hundreds of kohms between the stance and the swing phases.

## 1. Introduction

Position estimation based on the Pedestrian Dead Reckoning (PDR) technique suffer from cumulative error due to the drift on the inertial sensors measurements. Typically, to prevent the exponential growth of the error on the position estimation, the PDR-based systems apply the zero-velocity update (ZUPT) technique. This technique takes advantage of the human gait to minimize the drift impact and correct the position estimate. I.e., every time the foot is in touch with the ground (stance phase), the inertial sensors readings are considered drift and the pedestrian position is corrected based on the magnitude of those readings. However, the ZUPT technique relies on the definition of thresholds on sensors' readings (e.g., stance duration, acceleration and angular velocity magnitudes) [1]. These thresholds make the performance user- and motion-dependent, characteristics that are undesired in Indoor Positioning Systems (IPs) for emergency responders [2].

In this paper, we study the viability of embedding textile-based pressure sensors on a sock to detect the stance phase. To do that, different materials for both the electrodes and the sensing element were used and the performance of the resulting sensors was assessed based on two different experiments.

Besides improving the stance detection of the conventional ZUPT methods, the proposed solution is wearable, comfortable, easy-to-use, and cheaper than solutions with pressure sensors embedded on the insole [3].



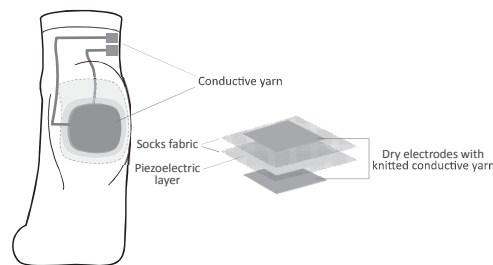
## 2. Materials and Methods

In this section, the assembly details and materials used for the construction of the pressure sensor prototypes as well as the equipment and experimental setup used/ designed to assess their performance are described.

### 2.1. Pressure Sensor Prototype

Figure 1 shows the sketch and the fabrication details of the pressure sensors developed. The sensors are produced in three layers: the top and bottom layer are made with conductive materials (fabric and yarn knitted on the sock), and the middle layer is a piezoresistive substrate. The sensing element is placed on the sock’s heel and conductive leads connect the sensor to the acquisition device (placed on the user’s ankle).

The dimensions of the sensing element and electrodes are 10x10 mm and 7.5x7.5 mm, respectively. The dimension of the electrodes is smaller than the sensing element to prevent any short-circuit between the two conductive layers.



**Figure 1.** A sketch of the three layer textile-based pressure sensor with the conductive leads embedded on a sock.

### 2.2. Configuration of the Sensors’ Prototypes

To assess the best combination of materials (electrodes and sensing element), three different sensor configurations were tested. They differ on the piezoresistive element (EeonTex™ LG-SLPA and velostat) and the conductive materials (Satatex Techniktex P-130 and a silver coated yarn from Elitex) used. Table 1 shows the materials used for the construction of each pressure sensor prototype, which are labeled as S1, S2 and S3.

**Table 1.** Description of the materials used for the construction of each pressure sensor prototype.

Sensor Label	Conductive Materials	Piezoresistive Sensing Element
S1	Elitex yarns	EeonTex™ LG-SLPA
S2	Satatex Techniktex P-130	EeonTex™ LG-SLPA
S3	Satatex Techniktex P-130	Velostat

### 2.3. Experimental Setups

Two types of experiments were conducted to assess the viability of using the pressure sensors for step detection. In the first experiment, a uniaxial dynamometer (Houndsfield, H100KS) and a digital multimeter (Agilent, 34410A) were used to characterize the electrical behavior of the pressure sensors during a 10 cycle compression/decompression test. This setting aims to study the sensor’s response, in terms of electrical resistance, when it is submitted to different pressures. Therefore, for each sensor configuration, three different compression cycles (2-136N, 2-173N, and 2-210N) were applied. These compression forces corresponds, based on the ratio between the heel and dynamometer probe areas, to a body weight of 55, 70, and 85 kg, respectively. The application of different compression forces aims

to study how the sensor respond to different body weights and if it possible to detect steps for all body weights and determine the wearer’s weight based on the sensor output. Additionally, three different speeds (5, 25, and 50 mm/min) were set to evaluate the dynamic sensor response and to assess if the sensor is able to detect steps at different walking speeds. For the dynamometer experiment, a total of 27 individual tests were performed, 9 per each sensor configuration.

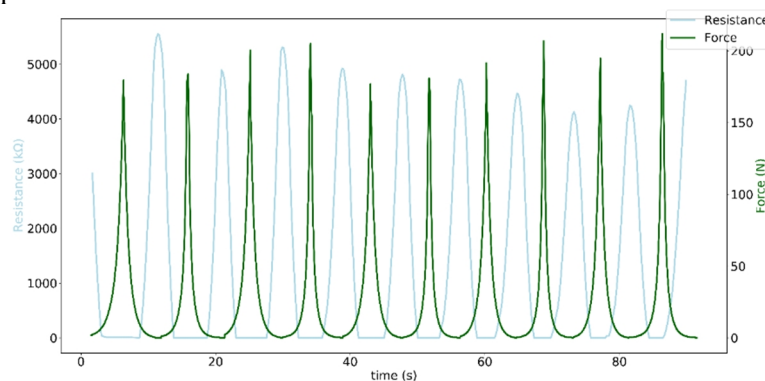
On the other hand, the second experiment consisted on asking a volunteer (male, 30 years old, 70kg) to wear a sock with the pressure sensor embedded, perform five consecutive steps and then stopped with the heel on the ground. This experiment was repeated five times for each sensor configuration and the sensor output was recorded using the same digital mutimeter (Agilent, 34410A). This experiment aims to evaluate the sensor response on a real scenario, since the dynamometer cannot replicate the velocities experienced during walking ( $\approx 1\text{m/s}$ ).

### 3. Results and Discussion

During the stance phase, the heel presses the piezoresistive material and the sensor’s resistance decrease. In the swing phase, the pressure between the heel and the footwear decreases and the resistance of the sensor increase. This resistance variation allows the step detection and higher its variation better the stance phase can be detected.

#### 3.1. Dynamometer Experiment

Figure 2 shows the typical response of the developed pressure sensors during a dynamometer compression cycle. As can be seen in the figure, the resistance-force relation is non-linear (resembles to an exponential function), which is in line with the findings of similar research [4,5]. Since the goal of this work is to detect steps, this behavior of the sensor is beneficial as it allows to easily detect the step, the difference on the sensors resistance between the stance and swing phases can be in the order of hundreds of kilo ohms (figure 2). As expected, when the sensor is compressed (stance phase) its resistance decrease and increases during the decompression phase (swing phase). Additionally, the sensor response during the 10 compression/decompression cycles is almost the same, meaning that the sensor output is repeatable.



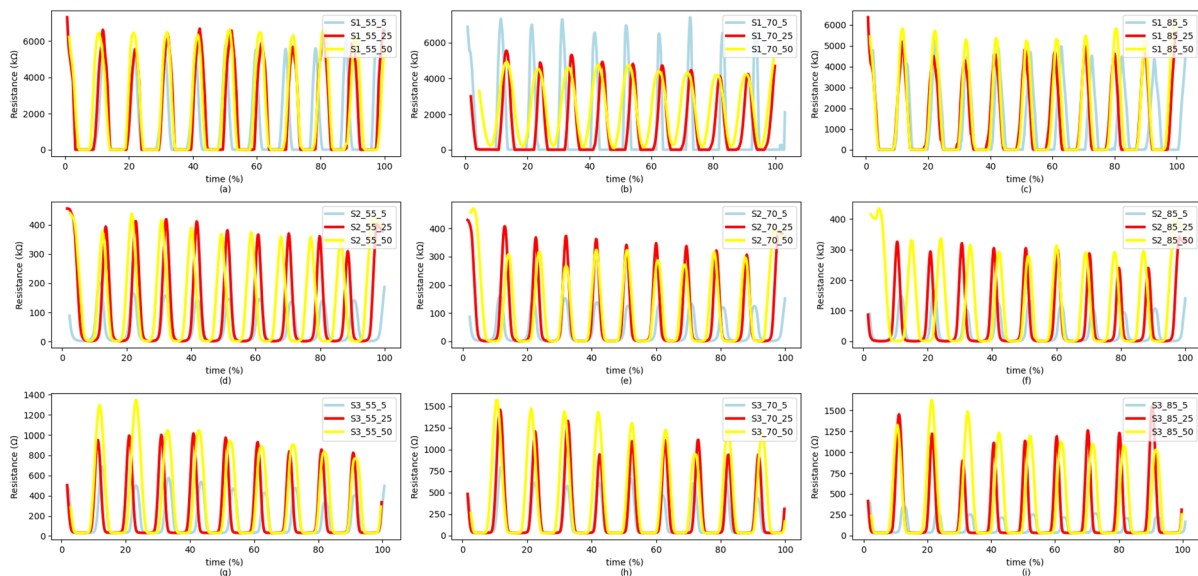
**Figure 2.** Example of a sensor output for the 10 cycles of compression/decompression for the dynamometer experiment. This graph illustrates the response of the S1 sensor configuration, for a simulated user weight of 70 kg (173 N) and a test velocity of 25 mm/min.

Figure 3 shows the resistance versus time percentage plots for all sensors configurations, weights and speeds. The time of the plots was converted to a percentage for an easier comparison between the experiments performed under different speeds.

Based on the results obtained, the S1 sensor configuration stand out as the best option to detect the steps as the resistance magnitude changes in the order of thousands of kilo ohms between the compression and decompression cycle. Whereas the sensor configuration S2 has a variation magnitude in the order of hundreds of kilo ohms and the S3 configuration in the order of hundreds of ohms. Additionally, unlike S2 and S3 configurations, the response of the S1 configuration is almost the same

for different speeds. For the S2 and S3 configurations the magnitude of the sensor response at lower speed is lower than for higher speeds. This phenomenon can be related with the limitations of the dynamometer. I.e., for higher speeds the applied force is higher than the threshold defined (e.g., see figure 2).

Although the resistance magnitude seems to decrease during the 10 compression/decompression cycles, it is not possible to state that the sensor is not repeatable since the dynamometer is not capable of applying the same force for each compression/decompression cycle. For lower velocities (5 mm/min) the sensors' magnitude is almost the same. Regarding the different forces applied, by analysing the graphs of figure 3 does not seem that they have a significant impact of the sensor output. However, more tests with better equipment should be conducted to assess if it is possible to determine the wearer's body weight based on the sensor output.

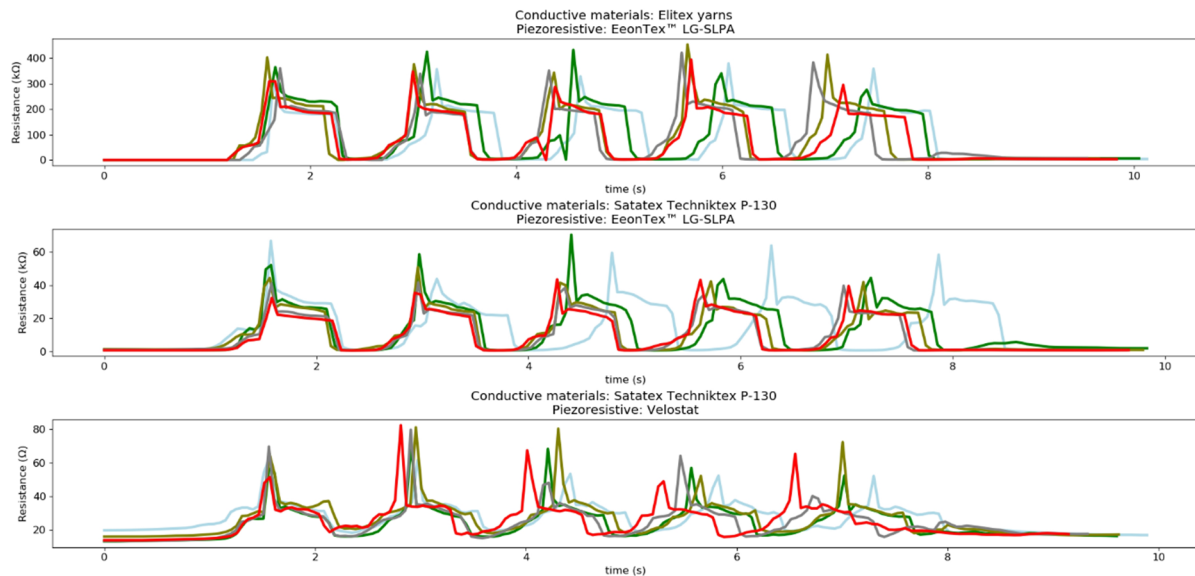


**Figure 3.** Resistance versus time percentage plots for the different sensors configurations, simulated users' weight, and test velocities.

### 3.2. Walking Experiment

Figure 4 shows the results of the tests for the walking experiment. As can be seen in the figure, the best results were obtained for the S1 configuration, followed by the S2 and S3 configurations. Compared with the results obtained from the dynamometer tests, it is possible to see that the resistance magnitude for all sensor configurations decreased significantly. This phenomenon can be explained by the existence of a continuous force applied to the sensor due to its placement between the heel and shoe. Nevertheless, the stance and the swing phases can be clearly distinguished, validating the use of these pressure sensors for step detection.

Additionally, we can see that a peak appears in the beginning of the swing phase. This peak refers to the heel off moment and can be explained by the diminution of the pressure applied by the heel on the sensor, which is later restored during the swing phase. Moreover, for all the sensor configurations, the resistance when the heel is pressing the sensor is very stable and its magnitude after the five steps is very close to the initial value. This means that the sensor is capable of providing reliable results for stance detection.



**Figure 4.** Resistance versus time plots for each sensor configuration while a volunteer performs five consecutive steps.

#### 4. Conclusions

In this paper, three types of textile-based pressure sensors were proposed and evaluated for the stance detection. These sensors were evaluated on a dynamometer compression/decompression cycle test and by a real-life experiment.

As demonstrated in this paper, the steps can be easily detected by means of a textile-based pressure sensor integrated on a sock. From the three configurations evaluated, the combination of Elitex yarns as conductive materials and EeonTex™ LG-SLPA as the piezoresistive element provided the best results. In this first assessment, many relevant aspects of sensor construction have been investigated and a detailed knowledge about the sensor behavior has been acquired.

As future work, the sensors will be fully characterized in a more advanced dynamometer and more sensor configurations will be tested. Namely, the creation of 3D structures with conductive yarn to replace the three layer architecture and simulate the piezoresistive behavior of the sensing elements used in this work. Additionally, the textile-based pressure sensor will be integrated into PDR system [6] to assess its viability in the drift control of the inertial sensors.

#### Acknowledgments

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