E-Textile Capacitive Electrodes: Fabric or Thread

Designing an E-Textile Cushion for Sitting Posture Detection

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Figure 1: Seat cushion prototypes with three electrode types: conductive fabric, conductive thread as spiral and as perimeter

ABSTRACT

Back pain is one of the most common illnesses in Western civilizations. Office work and lack of motion can lead to deterioration over time. Many people already use seat cushions to improve their posture during work or leisure. In this work, we present an E-Textile cushion. This seat cushion is equipped with capacitive proximity sensors that track the proximity and motion of the sitting user and distinguish up to 7 postures. Giving a user immediate feedback on the posture can facilitate more healthy behavior. We evaluated a number of different electrode setups, materials, and classification methods, leading to a maximum accuracy of 97.1%.

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CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing theory, concepts and paradigms**; **Ambient intelligence**;

KEYWORDS

Posture Detection; Smart Furniture; E-Textiles

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1 INTRODUCTION

Office workers often spend most of their working time seated in front of a screen. Many of them experience back pain, stiffness leading to long-term problems, impacting their quality of life. It is the most common form of chronic pain and is experienced as being the sixth biggest in terms of overall burden [7]. There are already mechanical methods to help prevent back pain such as ergonomic chairs, cushions, or stretching and exercises. Giving a user immediate feedback on his behavior is helpful [2], changing it, however, is not easy. The trend towards quantified self, where sensors eliminate the need for active monitoring shows that feedback from personalized data is very useful and acts as motivating force [8]. Capacitive proximity sensors are a valid approach in building smart furniture, as they sense the human body through non-conductive material. The sitting comfort of chairs is due to the soft, textile cushions. In this work, we evaluate conductive textiles attached to capacitive proximity sensors to detect some of the sitting postures, identified by the Global Posture Study [16]. To give design guidelines and define a minimal set of required material and sensors, we tested different sensor and textile electrode setups. We have built three prototypes with different textile electrode properties and tested their performance by detecting specified postures such as sitting upright, leaning back (the draw), leaning forward (the strunch), sitting left and right (the smart lean). To test the performance we evaluated the prototypes with a number of users, comparing single user vs. multi-user classification performance with various machine learning methods. The gathered data allows us to compare the performance of different materials and shapes.

2 RELATED WORK

Most smart furniture chairs integrate sensors into different parts of the chair. Common approaches use pressure sensors, capacitive proximity sensors or electrocardiogram electrodes [3–5, 9, 11, 13]. Example applications track sitting poses, vital signs and support the user by tracking breathing and heart rate or seating behavior, improving sitting posture or triggering exercises during work. Systems where only the seat area is equipped with sensors vary in the number of sensors from 16 to about 2000. Tekscan and Sensimat are two commercial systems. Tekscan has developed Body Pressure Measurement System, a pressure sensing array which finds its application in beds, car seats or chairs [17]. Sensimat integrates 6 pressure sensors into a wheelchair cushion supporting the user in sitting correctly [14]. Xu et al. and Meyer et al. use E-textiles as capacitive pressure arrays to detect sitting postures [12, 18].

Our contributions that go beyond previous work include exploring E-textile capacitive proximity sensing electrode shape, placement, and material implemented in three prototypes used in single and multi-user sitting posture evaluation.

Figure 2: First prototypes of the E-Textile cushion

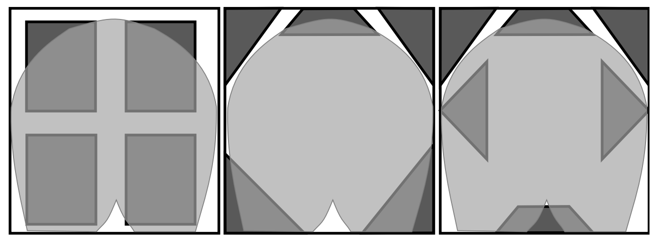

Figure 3: Surface of the sitting area covered when sitting on cushion layouts with 4, 5 and 6 capacitive sensing electrodes

3 SYSTEM DESIGN

We present the process of designing an E-Textile capacitive cushion. Throughout the different cushion prototype versions, the hardware setup remains the same.

For fast prototyping purposes, we use the OpenCapSense board capacitive proximity sensing and processing unit [6]. The board forwards the sensor values via Bluetooth to a smartphone. The data is logged and can be evaluated against a trained classifier. The according application estimates the sitting posture and shows the user how much time she has spent in a given sitting posture.

What differentiates the prototypes, is the different setup of the cushions. For the first prototype a wedge cushion and for the second a more thick, soft cushion was used. Both were chosen such that sensors, processing board, and battery could be fully integrated into the cushion, see Figure 2. During this very initial prototypes, four textile electrodes were chosen as a basic setup. These cover most of the surface of the cushion. However, the variations in shape, placement, and number of sensors could be improved. The experiments lead to the third cushion prototype which is for ease of prototyping reasons a thin, flexible cover of the sitting area of a chair.

Analysis of electrode shape and placement

We want to investigate the influence of shape, placement, and number of electrodes. When a user is sitting on the chair, most of the surface of the sitting area is covered, leading to an adjustment of the electrode layout, see Figure 3. For capacitive proximity sensing the relevant areas are those, where the sensor values change significantly during changes in sitting postures. To analyze this we created prototypical electrode patches, inspired by the form of the areas not covered while sitting. We experimented with the placement and number of the patches. Resulting in two designs of 5 and 6 electrodes, chosen to detect as many sitting postures as possible. After evaluating them, the design with 5 electrodes proved to perform better.

Analysis of textile electrode material

From the shape and placement analysis we chose through experimentation an evaluation of different sensor layouts that the sensor layout with 5 electrodes performs best. In a second step we focus on the electrode itself.

Textile electrodes can be made of different materials. We used conductive fabric and conductive thread [1, 15]. We evaluate both materials individually. We have created three different electrodes: one made of conductive fabric, one where the shape perimeter is made of conductive thread and one where the shape is filled by a spiral of conductive thread, see Figure 4. The placebo electrode is an electrode with no conductive material connected to the sensor, just the connecting wire. For each electrode, we conducted measurements to measure the spatial resolution, derived as the inverse of the noise range at specific distances. We measured the capacitance change by repeating the measurements three times and collecting 100 samples per height level, in 1 cm steps up to 30 cm. The measurement device with the evaluated electrode and the measurement electrode connected to a moving spacer are depicted in Figure 4. By computing the noise range at each distance Figure 5 shows that the electrodes made of conductive thread perform better overall, showing smaller noise range variations.

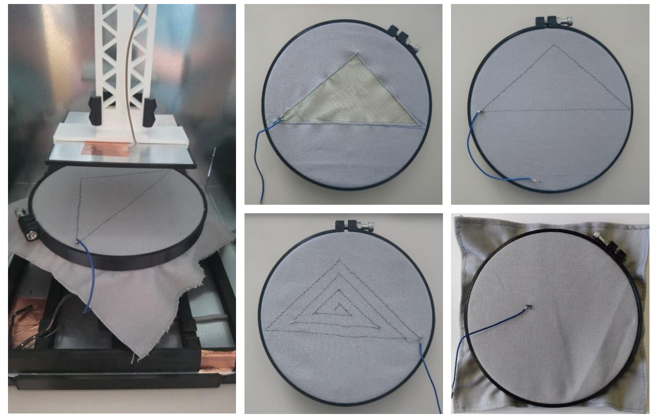

Figure 4: Measurement device and compared electrode types: fabric, perimeter, spiral and placebo

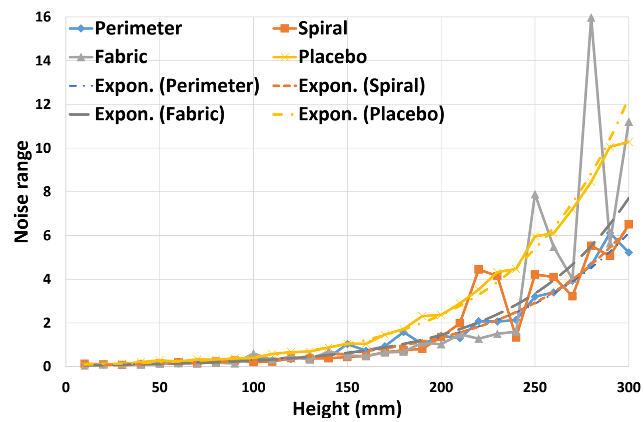

Figure 5: Noise range comparison of electrode types

4 EVALUATION

We aim at confirming the results obtained in Section 3 with regards to electrode layout and material through the evaluation of prototypes built following the design decisions. We integrated the three electrode types and the layout identified as best performing in prototype seat covers, as shown in Figure 1. We evaluate these with a multi- and single-user evaluation. For the evaluation we asked 20 participants (10 male, 10 female) to execute five postures: sitting upright, leaning back, leaning forward, sitting left and right. For each posture we also gathered data for the empty chair and standing in front of it, resulting in a total of seven classes. For each posture, we gathered 100 samples for 10 seconds. For the single-user evaluation, one participant repeated the evaluation five times.

The data were evaluated using a leave-one-subject-out cross-validation with 15 different classifiers and three additional parameter variations of SVM, using the WEKA machine learning toolkit [10]. From the multi-user data set we present the results of five test persons, comparable to the amount of data of the single user data amount.

The mean and best classification results of both evaluations are shown in Table 1. We observe that the higher density of the conductive surface of the conductive fabric electrodes does not provide better results as one could have expected. Compared to conductive fabric, electrodes made of conductive threads outperform conductive fabric. However, the spiral layout of the electrode made of conductive thread performs on mean slightly better than just using conductive thread for the electrode perimeter. In contrast, the highest accuracy is reached by the electrodes with their perimeter made of conductive thread. This can lead to less costly applications that have favorable results.

Table 1: Evaluation results per electrode type

		fabric		spiral		perimeter	
		mean	max.	mean	max.	mean	max.
multi-user	accuracy	51.8	62.1	58.9	72.6	56.4	**78.6**
	f-measure	43.8	55.8	51.3	67.7	49.2	73.4
single-user	accuracy	81.3	91.4	89.6	97.1	88.9	**97.1**
	f-measure	76.8	89.1	86.7	96.2	86.3	96.2

The change in classification results when generalizing from single to 20 users is more significant than anticipated. This is most likely due to interpersonal variation of posture execution and properties of the body.

Among the evaluated classifiers the WEKA implementation of K-nearest neighbors (IBk), Logistic Regression Trees (LMT), Naive Bayes Multinomial and Support Vector Machine (SMO, SMO with RBF kernel) perform best and result in the maximum classification results. Considering the overall mean performance per classifier Naive Bayes Multinomial performs best closely followed by Multilayer Perceptron and K-nearest neighbors (IBk).

5 CONCLUSIONS

We have designed a cushion for detecting sitting postures by using capacitive proximity sensing. The electrodes were made of conductive textile materials such as conductive fabric and conductive thread. For this, we have experimented and evaluated different electrode layouts and electrode materials. We confirm the electrode performance measurement outcomes by building different prototypes and which we evaluated with data collected from 20 users. Our prototypes made of conductive thread electrodes reached the highest single and multi-user accuracies of 97.1% and 78.6%. This indicates that the appropriate choice of material and classifier can lead to high accuracies, but are reduced when considering more users. Future systems should account for that using calibration routines.

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