INTELLIGENT CHAIR SENSOR-ACTUATOR
A Novel Sensor Type for Seated Posture Detection and Correction

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Abstract: In order to build an intelligent chair capable of posture guidance and correction we propose a new sensor/actuator pressure cell capable of measuring applied pressure and conformation change, which will allow posture evaluation, guidance and correction. We developed and applied the pressure cells to the seat pad of an office chair to test if both the cells and their placement were suitable for pressure map reconstruction. When tested for 10 different postures, the results showed distinguishable pressure maps for each posture, making the pressure cells suitable for pressure map reconstruction and posture evaluation. This paper also presents a briefly description of our vision and goals for the intelligent chair project.

1 INTRODUCTION

The evolution of the society significantly reduced the demands for physical activity. Changes in transportation, communications, workplace and entertainment introduced into our population sedentary behaviours. While some of these behaviours can be avoided, some activities force us to spend long periods of time in a sitting position. The consequences of slouching and poor posture are well documented and can lead to a number of detrimental health issues like anatomical characteristics changes of the spine, problems with intervertebral discs and joints, back and neck pain, headaches, fatigue and others (John Schubbe, 2004).

The long term goal of this project is to build an intelligent chair that effectively corrects and prevents bad posture adoption in order to minimize the health issues previously described.

Our main hypothesis is that by increasing discomfort when a poor posture is adopted, the user will be encouraged to change his position. The conformation changes in the chair will be made through the use of pressure cells that we developed, which are also responsible for evaluating the posture through their integrated pressure sensor.

The second hypothesis is that slight changes in the chair conformation over long periods of time, may help to evenly distribute the applied pressure on contact zones, reducing fatigue and discomfort. This could help preventing the adoption of incorrect postures over long periods of time due to the need of pressure relief on compressed tissues.

In this paper, we introduce the pressure cell concept and its results in differentiating 10 different postures using only a seat pad with 4 pressure cells. We also present a global vision of our approach to an intelligent chair for postural guidance and correction.

2 RELATED WORK

Over the years, several research groups have studied postural sensing and classification systems and applied them in several different areas, such as irregular behavior detection, emotional evaluation and biometric authentication. Others have used haptic feedback responses to control human-computer interactions. However, few have applied them to posture guidance and correction and no studies were found in pressure relief patterns in seated position. In this section we describe the most relevant papers on posture detection and correction in seated position.

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Tan et al (2001) described the use of a chair as a haptic interface for human-computer interactions. This work used two Tekscan® sensor sheets, with 42-by-48 sensing units to monitor the pressure distribution in both the seat pad and the backrest. The use of pattern recognition technics to develop a static posture classification algorithm, such as Principal Component Analyses (PCA), achieved an overall classification accuracy of 96% and 79% for familiar and unfamiliar users, respectively.

Other researchers used the same sensing system configuration to test other classification algorithms. Mota and Picard (2003) used Neural Networks to classify 9 static postures in real time, achieving an overall accuracy of 87.6%. In addition, Hidden Markov Models were used to associate seated postures with affective states. The algorithm achieved an overall performance of 82.3% with postures sequences coming from known subjects and 76.5% from unknown subjects. Zhu et al. (2003) tested several classification algorithms to find which one suits best static posture classification. Between k-Nearest Neighbor, PCA, Linear Discriminant Analysis and Sliced Inverse Regression (SIR), the authors found PCA and SIR comparable in performance and both outperformed the other methods tested.

As suggested by Tan et al (1997, pp.57) “a low-cost and low-resolution pressure sensing system will then be developed to facilitate the widespread use of smart chairs”. Mutlu et al (2007) adopted a near optimal sensor placement approach to drastically reduce the number of pressure sensors used. The algorithm down-sampled the sensor data from the high resolution sensor sheets used in previous researches (Tan et al 2001; Mota and Picard 2003; Zhu et al 2003) and determined the near optimal placement of 19 one-and-a-half-inch-square FSR (Force Sensitive Resistors) sensors. The system achieved 78% accuracy with 19 sensors, and 87% using data from 31 sensors.

More recently, Zheng and Morrell (2010) developed a system with only 7 FSR and 6 vibrotactile actuators, specifically designed to posture guidance through haptic feedback. With a classification algorithm based on the mean squared error between the pressure measurements and the reference pressure for each static posture, an overall accuracy of 86.4% was achieved when distinguishing among 10 postures. This study has also successfully shown the effectiveness of haptic feedback for coaching motor behavior in the form of seated posture.

3 CHAIR DEVELOPMENT

3.1 Pressure Cells

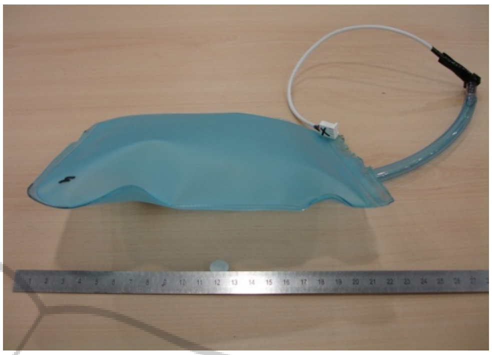

Figure 1: An inflated pressure cell with a gauge pressure sensor attached.

The objectives of this project required an interface that could measure the applied pressure and also change the chair´s conformation. Taking in consideration a low cost and commercial available solution, we developed the pressure cells. This pressure cells can sense pressure and serve as actuators, by inflation and deflation, for posture guidance and correction.

As seen in figure 1, a pressure cell is composed of a large sealed thermoplastic polyurethane pocket with 20x19cm of dimensions with a rubber pipe attached. On the other end of the rubber pipe there is a piezoelectric gauge pressure sensor to measure the internal pressure of the cell. All cells have an equal residual air volume for a baseline pressure measurement. The gauge pressure sensors used were the Honeywell 24PC series rated to 15PSI. In order to compensate the inherent linear differences and offsets between the sensors, calibration curves were taken and corrected in software data processing, so the sensors better match themselves.

3.2 Cells Placement

The use of a low resolution sensor matrix requires a strategically sensor placement in order to achieve good performance results. Two main strategies were identified on previous literature. A pure mathematical and statistical approach (Mutlu et al., 2007) and an anatomical approach (Zheng and Morrell, 2010) which considered the ischial tuberosities, the thigh region behind the knee, the lumbar region of the spine and the shoulder blades as the most important and distinguishable areas of the body for detecting postures.

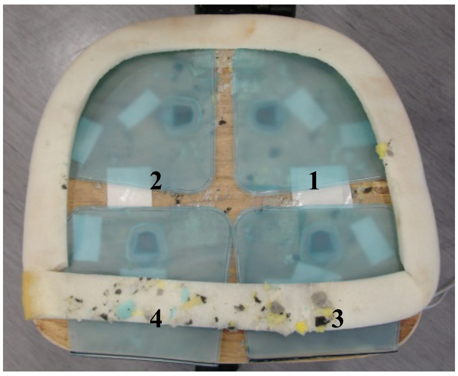

Figure 2: Seat pad stripped of padding foam, showing the individual pressure cells placement. 1. Back Left (BL), 2. Back right (BR), 3. Front left (FL), 4. Front right (FR).

We concur with the anatomical approach since those are the areas where most pressure is applied in the seated position. It is also the approach that uses the least number of sensors, which is helpful in reducing the overall cost of the chair. Therefore, the seat pad was divided into 2-by-2 similar areas, one area to each ischial tuberosities, and one area to each thigh region behind the knee. The cells were placed beneath the chair's padding foam to maintain the anatomical cut of the seat pad. The seat pad division is illustrated in figure 2.

To ensure that the interesting areas are always on top of the respective pressure cell, we developed large cells that cover almost the entire seat pad. This also brings an extra advantage of minimizing the gaps between cells, which could prove uncomfortable for the users.

The backrest is planned to follow the same criteria as the seat pad.

4 EVALUATION AND RESULTS

To evaluate our pressure cells performance and their placement [Back Left (BL); Back right (BR), Front left (FL), Front right (FR)] on the seat pad we resort to a posture list used in previous related papers (Tan et al. 2001; Mutlu et al. 2007; Ying and Morrell. 2010). Those positions are:

1. Upright;
2. Slouching;
3. Leaning forward;
4. Leaning back;
5. Leaning left;
6. Leaning right;
7. Left leg crossed over right;
8. Right leg crossed over left;
9. Left leg crossed over right and leaning right;
10. Right leg crossed over left and leaning left.

The user started in position 1. and successively changed to the next position with an interval of approximately 5 seconds. The data was acquired in real time with a sampling rate of 20Hz and the results are displayed in Figure 3.

The best scenario to characterize a posture is to have a unique pressure distribution to each posture. Our system was able to produce a different pressure distribution for each of the 10 postures evaluated, using only 4 sensible areas in the seat pad, thus allowing an easy characterization of each posture.

Also, we noticed that every time the user changed is position the output of the pressure cells was divided into two zones: a "transient zone" and a "stable zone", showed in figure 4.

On changing posture from leaning right to left leg crossed over right, the pressure on the back left cell (BL) rapidly increased as expected. Also, the user spent 2 to 3 seconds in the "transient zone" before reaching the "stable zone". This could be relevant to a real time monitoring system so that classification algorithms won't get confused in the "transient zone", or even to develop algorithms that based on the "transient zone" are able to predict what will the user's posture be.

5 CONCLUSIONS AND FUTURE WORK

As a first step for our intelligente chair approach our pressure cells were able to produce distinguishable pressure maps for each of the 10 posture tested. We therefore conclude that the pressure cells conjugated with the cell placement of this study are suitable for our intelligent chair project as a pressure mapping system.

The next step is to control the air pressure and volume inside the pressure cells, allowing for changes in the chair conformation and stiffness.

In other applications, hydrogel pads have been widely used to reduce discomfort in compressed areas. In a later stage of this project, we plan to use hydrogel, instead of air, to fill the pressure cells in an attempt to further increase the chair´s overall comfort.

Upon conclusion of the chair fabrication, algorithms will be developed for posture evaluation and correction. A temporal analysis of a person sitting behaviour will be needed, in order to study an

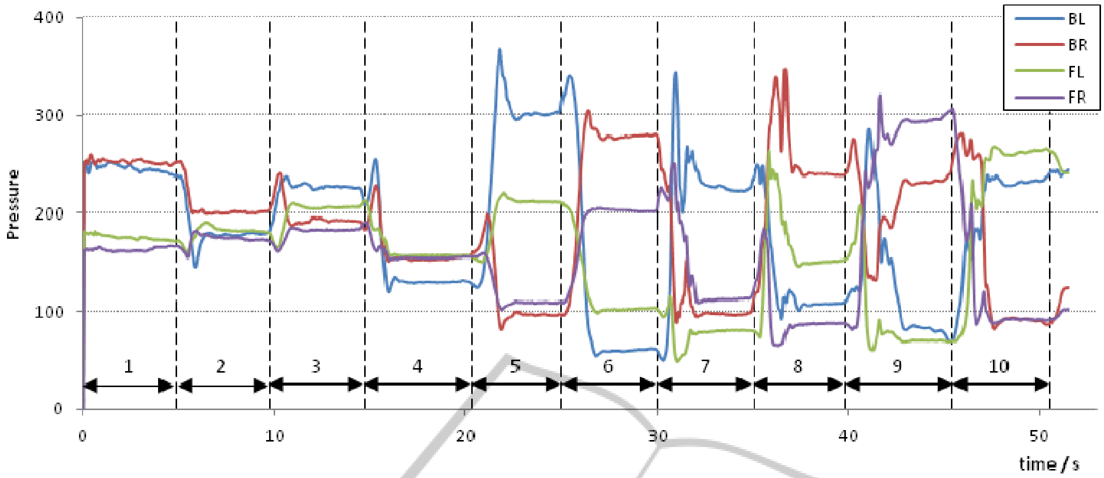

Figure 3: Real time pressure measurements from each cell for the 10 reference postures previously described.

effective pressure relief pattern. At this point, clinical studies should be made in order to evaluate the correction models applied and the benefits to the target population.

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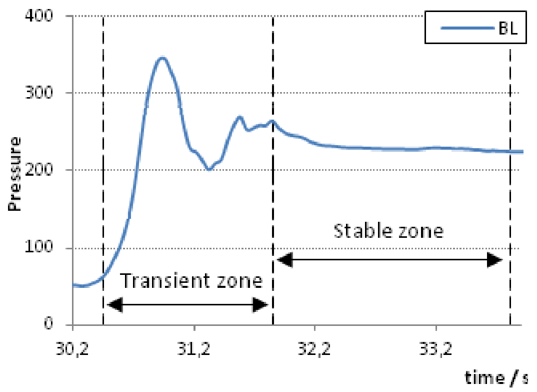

Figure 4: Pressure cell measurement from the back left cell during posture change from position 6. to position 7.

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