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The Advancement of Smart Cushion Product and System Design Enhancing Public Health and Well-Being at Workplace

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Abstract**—**This research project brings together experts in multiple disciplines to bring product design, sensor design, algorithms, and health intervention studies to develop a product and system that helps reduce the amount of time sitting at the workplace. This paper illustrates ongoing improvements to prototypes the research team developed in initial research; including working prototypes with a software application, which were developed and demonstrated for users. Additional modifications were made to improve functionality, aesthetics, and ease of use, which will be discussed in this paper. Extending on the foundations created in the initial phase, our approach sought to further improve the product by conducting additional human factor research, studying deficiencies in competitive products, testing various materials/forms, developing working prototypes, and obtaining feedback from additional potential users. The solution consisted of an aesthetically pleasing seat cover cushion that easily attaches to common office chairs found in most workplaces, ensuring that a wide variety of people can use the product. The product discreetly contains sensors that track when the user sits on their chair, sending information to a phone app that triggers reminders for users to stand up and move around after sitting for a set amount of time. This paper also presents the analyzed typical office aesthetics and selected materials, colors, and forms that complimented the working environment. Comfort and ease of use remained a high priority as the design team sought to provide a product and system that integrated into the workplace. As the research team continues to test, improve, and implement this solution for the sedentary workplace, the team seeks to create a viable product that acts as an impetus for a more active workday and lifestyle, further decreasing the proliferation of chronic disease and health issues for sedentary working people. This paper illustrates in detail the processes of engineering, product design, methodology, and testing results.

Keywords**—**Anti-sedentary work behavior, new product development, sensor design, health intervention studies.

I. Introduction

WORKING adults accumulate large volumes of sitting at work and interventions have been developed to reduce sitting in the workplace. Physical inactivity accounts for roughly 8.7% of U.S. health care expenditures, or approximately $117 billion per year [1]. Sedentary behavior, or sitting, has emerged as a potential risk factor for numerous chronic diseases and all-cause mortality during the last decade. According to the Bureau of Labor Statistics, professions such as software developers, dispatchers, accountants and auditors spend more than 90% of their workday sitting [2]. A recent review [3] suggests the workplace as a prime target for behavioral interventions. Motivated by these findings, our long-term goal is to develop new designs for instrumented sit-stand work-stations, that can help move the needle in reducing sedentary behavior at the workplace, create solutions that are functional, ergonomic, and also enlivened via simple media cues for long-term use. We also hope that through the integration of design principles and electronics development, we can create useful experimental measurement devices as well, that can form the basis for further research in complex human activity modeling, and media feedback systems. In this paper, we report on ongoing developments and improvements made on our initial prototype, which was described in an earlier paper [4].

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II. Sensor and Controller Design and Upgrades

Herein we describe improvements made to the sensor and controller of the add-on cushion that is designed to fit comfortably on most popular office chairs. The cushion is fitted with sensors and a controller that collects worker presence and posture data and transmits it to the worker's mobile phone and the cloud. A companion Android application installed on the worker's phone notifies the worker with appropriate messages to encourage them to leave their seat and move around based on clinically determined sitting and standing/walking periods. Data collected and derived from the sensors are also stored and graphically presented at MATLAB's Thingspeak servers. While the general system functional design remained the same as in the previous phase of this project, significant improvements discussed in subsequent sections will be the subject of this paper.

A. Summary of Improvements Implemented

- Controller built into the cushion, not externally mounted.
- Relocated back sensor installation area.
- Redesigned controller with replaceable, higher capacity rechargeable battery.
- Android App upgraded with
  a. Auto-connect function
  b. Expanded notifications with dual operating modes.
  c. Improved and easier to use interface

B. Improvement Details

Larger FSR Sensor: We used the larger Interlink 406 FSR sensor (Fig. 1) which has 800% more sensing area for this iteration. This FSR is 9x larger than model 402 sensor used in the previous version.

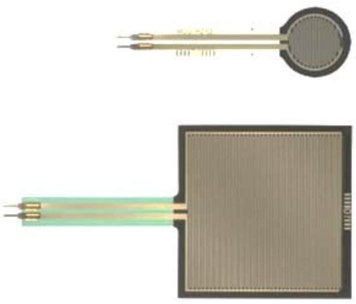

Fig. 1 Comparison of FSR models 402 & 406

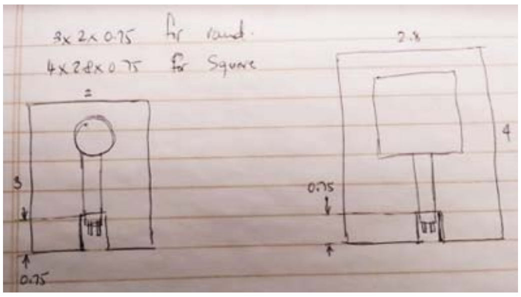

Fig. 2 Sizing sketch of FSRs and frames

The overall sensitivity of the system is significantly improved with this change. The acrylic sensor backing frame is consequently enlarged (Fig. 2) to match the sensor.

Fig. 3 Controller location

Fig. 4 Board and enclosure

Controller Built into Cushion: The main controller of the system is now built into the cushion. The controller of the previous version was mounted outside on a convenient part of the office chair using strap belts or magnetically mounted to a metal section. The current version is built into the cushion and placed at the lower left corner (Fig. 3) of the back section. Access is provided for the main switch and the micro-USB charging connector.

The controller can be removed easily for maintenance or battery replacement by opening the zipper. The size and shape of the controller was minimized and the installation location was selected to maximize the comfort of the worker.

Relocated back sensors: Extensive and prolonged tests of our previous cushion revealed that the back sensors were rarely activated. While in most cases that was due to the person not actually using the back, in many cases, even when the worker is using the back, only one of the sensors is activated and it was registering very low-level values lacking sensitivity. The tests were performed with subjects of both small and large frames and the results were similar suggesting that the 6-inch distance between the sensors is too large.

Fig. 5 Typical office chairs

A broad review of the ergonomics of several commercial office chairs (Fig. 5) also revealed that the center line of the back rest needs to be avoided due to the valley topology widely used. Hence, the ideal locations for the sensors (Fig. 6) on the back were determined [5] to be one inch off both sides of the center line at 6” and 12” heights from the seat and back joint. A more scientific and large data set study may be needed to come up with a more precise estimate but we feel the selected values should provide satisfactory results for small frame, large frame, tall, and short people and most currently available commercial office chairs.

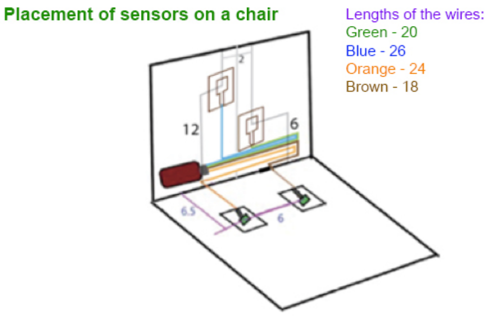

Fig. 6 Sensor locations layout

Fig. 7 New battery

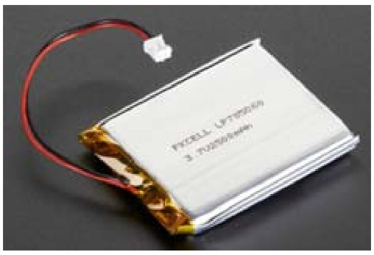

Fig. 8 Old battery

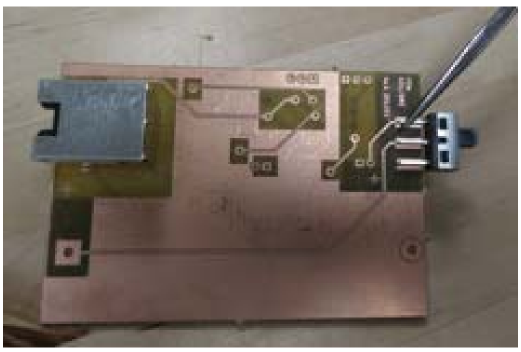

Fig. 9 Partly assembled controller board

Redesigned Controller: The electronic circuit design of the controller remained pretty much the same, but many parts and the physical layout as well as the firmware were revised. Chief among the changes is the replacement of the flat rectangular lithium battery (Fig. 8) with a user replaceable 18650 type (Fig. 7) slightly higher capacity battery. When the time comes to replace the battery, the user will be able to replace the battery without a need for a service facility.

Other changes include a PCB integrated Ethernet connector (Fig. 9) and a higher cur-rent capacity main switch. The main PCB was also redesigned to accommodate these changes. A redesigned enclosure (Fig. 4) to easily pop out the main controller to replace the battery completes the improvements to the controller.

Android Phone Application Upgrades: The latest version of the phone application has a Bluetooth Auto connect (Fig. 10) feature. This feature introduces advantages over the previous manual connection procedure:

1. Easier and fewer steps to connect to the SmartMat cushion. The manual connection required searching for the device and manually connecting to it in 3 steps. Using the auto connection, the user stands close to the SmartMat he wants to connect to and start the application and the phone will make the connection automatically. Connection is confirmed by displaying the name of the device connected.
2. In settings where multiple SmartMats are being used in the same room, the user does not need to remember the name of the SmartMat device. The phone automatically connects to the closer device.

The second improvement is the introduction of sound notification modes (Fig. 11). The user now has the option of selecting a specific sound for notification out of an expanded selection of notification sounds. Or the user can select ‘random mode’ where the system randomly selects a notification sound out of the available list.

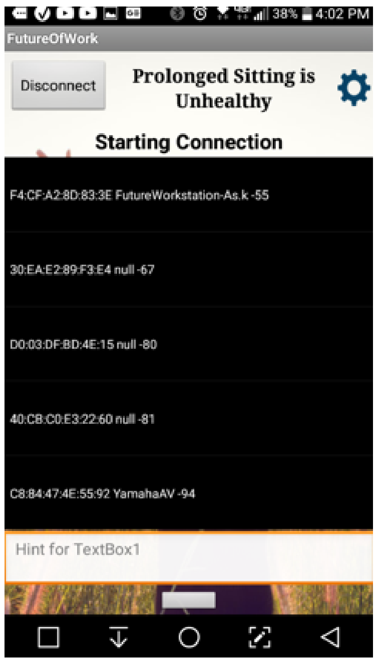

Fig. 10 Auto connect

Fig. 11 Notification mode selection page

Fig. 12 Companion app with heartbeat animation

The final improvement with the phone application includes changes to the layout of but-tons for ease of operation and uninterrupted use. We have also added a heartbeat graphic animation (Fig. 12) that gives the user feedback of normal operation.

III. Aesthetic, Ergonomic, and Usability Upgrades

This article describes the various improvements made to previous iterations of the "Future of Work" office cushions. The new cushion design features improved aesthetics, deeper consideration of ergonomics, and added usability functions. To better compliment the modern workspace, calming neutral colors were applied to surfaces and smooth shapes and curves were used for the forms, replacing the previous prototype's polarizing vivid colors and rigid shapes. The new version exudes an organic aesthetic, overcoming the utilitarian look of the previous version.

A variety of office chairs and materials were examined, providing enough data to ensure the new office cushion aligned with proper ergonomics, ensuring that users have a positive sitting experience, improving their health and work conditions. Each moment of user interaction was analyzed and multiple solutions were devised, ultimately leading to the use of a collection of ergonomic and effective zippers, clips, straps, and more to ensure an enjoyable user experience. The sensor locations were made adjustable, the battery controller more accessible, and the cushions slip resistant. The overall result of these efforts led to a product with more universal appeal than the previous iteration. The goal is for these improvements to provide users with the product they need to better control their health and productivity in the modern workplace.

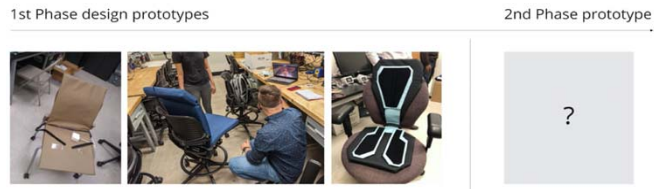

Fig. 13 Prototype improvement

A. Summary of Implemented Improvements

- Updated aesthetics for the modern workspace.
- Enhanced cushion comfort and ergonomics.
- Improved user experience.

B. Improvement Details

1. Updated Aesthetics for the Modern Workspace

The utilitarian look and feel of the previous iteration were reduced by removing the rigid shapes and structures and adding smooth, soft, and flowing shapes. These curved shapes better compliment the curves of most office chairs, providing a more approachable feel, along with helping the cushions blend in more than stand out. The colors and patterns were changed to align with more office environments, allowing users to select from a variety of color options that better suits their tastes. Materials like soft fabrics and faux leather lining convey a sense of luxury, giving users pride in owning and using this product.

2. Enhanced Cushion Comfort and Ergonomics

The cushion thickness was greatly reduced from 1 inch to 0.5 inches, allowing the cushion to form more easily and comfortably to the chair it rests on. With reduced cushion thickness the chair's natural ergonomic shape was not diminished. The material for the cushions struck a balance between soft and firm, providing users comfort [6], [7] while still protecting the sensors. The sensors were positioned in the cushion to sit discreetly within the cushion's top foam layer, while still exposed enough to effectively collect data. The battery controller was repositioned to a location that would not interfere with comfort and allowed the controller to fit discreetly within the product.

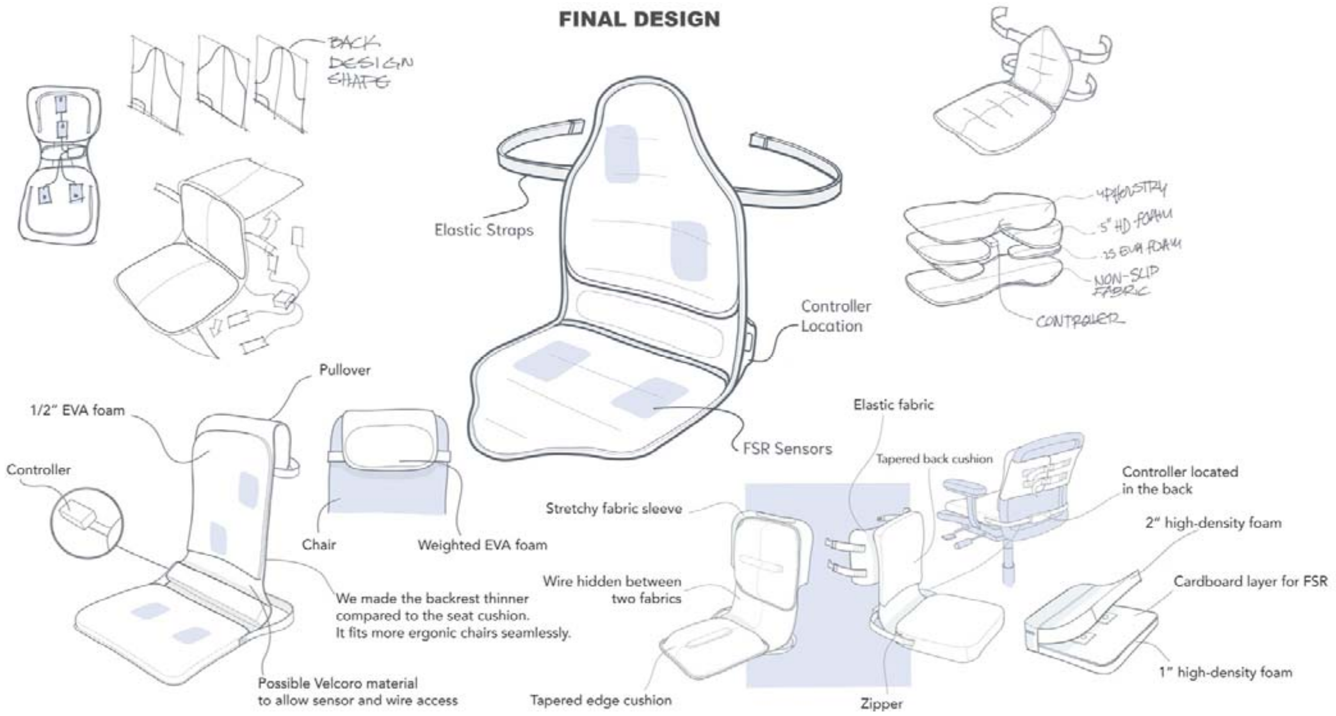

Fig. 14 Concept refinement

Fig. 15 New cushion fabrication

Fig. 16 Cushion design exploration

Fig. 17 Comfort and ergonomics study

3. Improved User Experience

Several prototypes were created to test and ultimately incorporate the most user-friendly touch points. An elastic band was selected to form tightly around the office chair, connected via a simple clip.

Fig. 18 Elastic band shape explorations

A non-slip rubber was selected for the backing to help keep the cushions in place. The elastic band and the non-slip rubber provided enough stability to eliminate the need for a second strap around the back of the chair. A zipper was added to provide access to the battery controller, along with Velcro straps to easily access the sensors.

Fig. 19 Internal compartments

IV. Conclusion

As future work, we seek to deploy and test our prototypes, conduct user studies of experiences, and embedded our devices into workplaces with a large sedentary work-force. Toward this end, we will seek to partnering with researchers in the area of work-place health interventions. We also seek to develop immersive-media based room-scale wellness pods, that can be deployed on sites, which in conjunction with the work-stations can lead to a more comprehensive approach for promotion of physical activity and mindfulness.

Acknowledgment

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