Sensory Input Through Haptic Feedback Using a Pressure Mapping Sensor

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Motivation and Description of the Problem/Need:

According to the National Health Interview Survey (NHIS), as of 2005, there were over 1.6 million people who had undergone limb amputation in the United States with an additional 185,000 people each year [1]. While this statistic accounts for both upper and lower limb amputees, our project focuses on people with loss of lower limbs. Lower limb amputees often experience loss of balance due to a lack of sensory input from their prosthesis. Their balance is strongly linked to their ability to ambulate confidently and comfortably [2]. This loss of balance is further impaired on uneven or sloped surfaces. To provide feedback, human mechanoreceptors can be imitated using a pressure sensor insole that is placed at the base of the prosthetic foot [3]. These sensors then collect pressure data which can be converted into signals to be sent to the user, through a haptic response, to provide them with sensory input [2].

Design goals:

Our goal is to generate a feedback system to provide people with prosthetics a sense of comfort while walking on the surfaces that they encounter in everyday life and to reduce their risk of injury. We are designing a pressure insole that will collect pressure data from the weight distribution of the foot and relay it up to the user through a vibrotactile band. This band will be worn on the thigh and will vibrate upon stimulation to provide the user with a form of sensory input, therefore giving them a sense of environmental awareness (proprioception). We have designed our system with emphasis on human factors, in hopes of making our system comfortable and easy to use. The material for the band was chosen based on comfort level, the boot was chosen to be easy to wear, and additional testing equipment will be held in a waistband pouch for functionality. We also designed our testing equipment to replicate obstacles and surfaces that are encountered in everyday life. We decided to use both a shallow incline and a steeper incline to meet a wider range of angled ground that people encounter on a regular basis. Therefore, we will test our device on a ramp that meets the standards of the Americans with Disabilities Act (ADA) with a rise of 1 inch per 1 foot run and one that exceeds the angle requirement [4].

Competition and differentiation:

Current solutions that exist use similar haptic feedback systems that have a variety of different motors for sensory input. Motor options include vibrotactile actuators, pneumatically driven actuators, and shape memory alloys, among others [3]. Other systems utilize individual pressure points to relay the pressure data up to the vibrotactile band. Our design uses a mapping system which is divided into regions to collect data from the weight distribution (Fig 1). Our solution will detect sensory information from a wider range of pressure points within the foot and convey it to the user, providing a greater extent of sensory awareness. We are primarily focusing on pressure points at the ball, heel, blade, and instep of the foot, each of which align with the quadrants of our pressure mapping system.

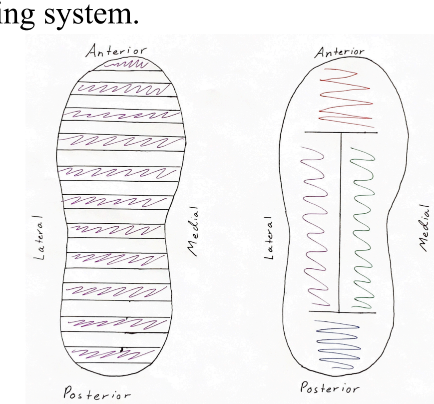

Figure 1. Insoles with pressure sensing mapping. Shows the horizontal strips of conductive fabric tape we will use to create the prototype pressure map. The design uses four quadrants (foot, heel, blade, and instep of the foot) to

detect threshold values and send signals to the vibrotactile motors.

Design process:

Our project, a small subset of a larger research project, has been designed with prosthetic users in mind. This project was initiated in the Wearable Biosensing Lab at the University of Rhode Island under the supervision of Joshua Gyllinsky and Kunal Mankodiya [5]. Our system is a continuation of a previous project, developed by Jose M Canton Leal [6].

We wanted to find a boot or shoe that able-bodied participants could wear that would mimic the sensation that prosthetic-users experience with their prosthesis. Therefore, we started with the idea of using a large ski boot with a hard rubber bottom which would help to limit the amount of sensory feedback that our research participants could feel. However, after discussion we decided to use a smaller medical surgical boot which has a hard bottom. This shoe is much easier for participants to take on and off, is more comfortable to walk in, and can accommodate many different foot sizes. Our system has been designed to be inserted underneath the insole of a shoe, to prevent major wear and tear as the user moves their foot in and out of the boot. Additionally, the band has been created out of a comfortable, elastic material so that it can easily form to the shape of the participants leg. The band also has a velcro strip so that it can be adjusted to fit a range of leg sizes.

Prototype of the design:

Our system will utilize an insole with a pressure mapping system, constructed of conductive fabric tape and velostat, and a set of vibrotactile motors that will be integrated into a thigh band. The pressure mapping components will be inserted in a wearable medical boot and worn by participants during testing. We will be creating a "velostat sandwich" containing two sides; one with six vertical strips of conductive tape and the other with fifteen horizontal strips of conductive tape. Using ribbon cable, we soldered connection wires to each of the vertical and horizontal strips, with the other end to be inserted into our corresponding breadboard circuit (Fig 2).

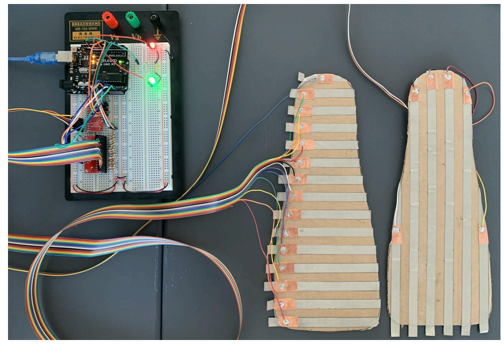

Figure 2: First prototype design of our feedback system. On the left is our breadboard circuit connected to an Arduino. Ribbon cables connect the circuit with soldered connections to vertical and horizontal conductive fabric strips to create a grid pattern pressure map. Velostat material not pictured.

To complete the "velostat sandwich" a layer of velostat will be inserted in between the two cardboard pieces and then placed on top of each other with the tape side facing inward. In our prototype, each of the 15 rows is supplied 5V power using the analog multiplexers (outputting 5mA using 1k Ohm resistors). The six columns act as inputs into the breadboard circuit. We utilized a circuit diagram from the O-Mat project by OniriaMX [7] to assist us in the development of our feedback system (Fig 3).

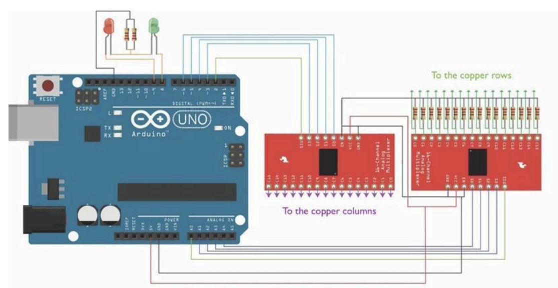

Figure 3. Pressure mapping circuit used in our project, modified from the O-Mat project [7].

As we apply pressure to the map, the distance between the layers decreases, causing resistance in the velostat to also decrease. We are able to record this data in real-time and see instantaneous pressure points on our pressure map. The pressure mapping system will then be divided into four regions (Fig 1) and each will correspond to one of the four vibrotactile motors located on the thigh band. Varying pressure readings, depending on region and magnitude, will send a signal up to the correlating vibrotactile motor, providing the sensory feedback to the user. Greater pressure will correspond to a more intense vibrational pulse.

Testing and results:

The system will be tested by research participants upon completion, and is pending approval from the Institutional Review Board. The participants will be asked to walk on a series of surfaces to test the effectiveness of the system at providing sensory information and gauge how well the vibrotactile signals can assist in preventing loss of balance. Three different surfaces have been constructed for testing: (1) an uneven surface made with rubber mounds; (2) a local wheelchair accessible ramp will serve as the gradually inclined surface; and (3) a steeper sloped surface will be constructed using wood and a portable wheelchair ramp. The ramp is meant to mimic a steeper slope that people may encounter on a regular basis, such as a medium grade hill, while still providing additional safety through the accessibility of a railing. Throughout the experiment, a survey will be filled out by each participant to record their observations and experiences with the system. We have created a graphical user interface (GUI) which allows us to see the instantaneous pressure points measured by the pressure mapping system (Fig 4).

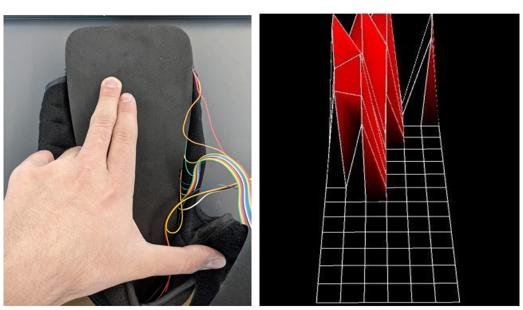

Figure 4. Pressure mapping GUI generated by the pressure mapping system showing dispersion and peaks of pressure.

By testing the pressure mapping system, we can identify if the participants are given a sense of awareness of the surfaces that they are walking on. In the future, the system can be evaluated with prosthetic users to test if they are able to walk more comfortably and confidently on different surfaces. The initial participants for the experiments will be fully able-bodied persons. They will be able to provide similar feedback as prosthetic users, while having a minimized potential for risk.

Value proposition and potential impact:

Our solution will provide prosthetic users with valuable sensory input which will aid them with environmental and spatial awareness. This awareness allows for prosthetic users to comfortably walk over adverse terrain and conditions that could otherwise promote injury. The design created within this project is non-invasive, easy to use, and provides the user with a product that mitigates risk in performing every day activities. As a whole, our device will provide users with a relatively inexpensive and durable product that would greatly improve their quality of life and allow them to perform tasks that would be otherwise high risk.

References:

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