Using Off-the-shelf Sensors for Ad-hoc Smart Sole Prototyping

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Abstract
In this paper, we propose a platform for simple and fast prototyping of real-time assistive systems using a smart insole. We describe the setup of the sole which uses a micro-controller and up to 6 pressure sensitive resistors. By discussing several application scenarios, we show how such a platform can be used for fast and easy implementation of proof-of-concept assistive systems for running, rock-climbing, and hiking.

Author Keywords
Werables; Insoles; Sensor; Real-Time Feedback; Assistive Systems; Platform

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
A large number of people perform outdoor activities like running, hiking and climbing. These activities can be done for recreational purposes or to achieve sports-orientated goals and challenges. Although walking on two feet has a long tradition since stone age, performing such activities requires decent technical skills to prevent (long term) injuries (e.g. knees, back, etc.). So far, commercially available wearables like running watches or shoe sensors have

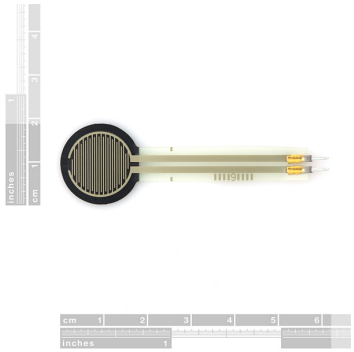

Figure 1: Sparkfun - Force Sensitive Resistors used for prototyping force sensitive insoles.

only been used for tracking the performance (i.e. speed, distance) of a runner, but not that much for real time technique assistance. The aim of this work is not to reinvent the wheel, since the idea of putting sensors in insoles of shoes is not new, but to provide an open source platform that relies on affordable hardware. With this platform we invite researchers to rapidly deploy ad-hoc prototypes of smart shoes or insoles. We are providing a set of templates and instructions that enables the developer to quickly implement a bluetooth enabled, smart insole which streams sensor readings in real-time, that could be used in walking, running, or even climbing.

Related Work

Using sensors in insoles has a long tradition in gait analysis for physical therapy and orthopedics. A selection of these works is described in this section. In [3] Xu et al. proposed a smart insole for a wearable gait analysis system. They used a textile sensor array consisting of a three layer setup, combining two zebra textiles, separated by a conductive, but highly resistive second fabric. Using a grid pattern of the zebra-fabrics it is possible to measure the resistance and with that, the pressure on the individual intersections.

Morris et al. [1] implemented a compact wearable sensor package for clinical gait monitoring. They utilized a set of different sensors, including an IMU, a sonar, capacitive sensors, bend resistive sensors, and also force sensitive resistors. Their initial results showed that the system was capable to detect changes in the foot motion during different types of gait like walking at low and high speed, as also shuffling of the feet. Although the sensor system provides a large amount of sensor data the weight of 200g may severely affect the natural gait of the user.

Tirosh et al. [2] present the development of a wearable textile sensor sock. The sensors are constructed from conductive thread and are connected to a data logger which stores the data on a SD card for post processing. Despite the title of the paper, the sensor are just incorporated in the bottom of the sock, thus registering only pressure immediately below the foot. Measuring of pressure on the sides, top, or tip of the foot are not possible. Furthermore, their system is not designed to stream the sensor data in real-time.

Although all presented works are suitable for the applications proposed, we found that most of them are either too sophisticated, too expensive, or not flexible enough for ad-hoc prototyping of proof-of-concept real-time assistive systems.

Platform

We are proposing a platform for ad-hoc prototyping of sensor augmented insoles. While there are existing several commercially available sensor insoles, our platform consists of “off the shelf” hardware which is easily available on the internet and has a very low overhead when deploying it. When compiling the platform we wanted it (1) to be fast and easily deployable, (2) to be reusable, and (3) to be simple enough to be adapted to the individual purpose.

The system consists of a maximum of 6 force resistors[1], which are able to sense forces between 100g to 10 kg (see Figure 1). Additionally an RFDuino (an Arduino compatible micro-controller with onboard BLE support) and a battery (see github[2] for a complete BOM) is used to process the sensor values. A simple firmware for the micro-controller was implemented which continuously streams the available sensor data to any BLE compatible device as a byte array.

[1] https://www.sparkfun.com/products/9375
[2] https://github.com/felixkosmalla/sensor-insole-prototyping

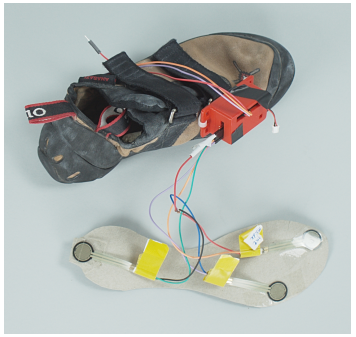

Figure 2: Sensors deployed on a cardboard insole for a climbing shoe

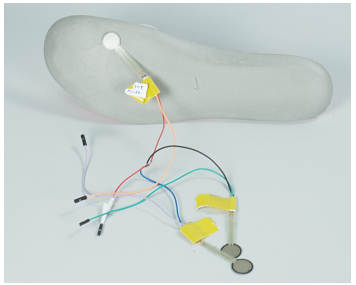

Figure 3: Sensors attached to the insole of running shoe

For fast prototyping we implemented a small Python client which makes it easy to start analysing the data collected in real time.

Assembly

Using a perfboard, or, if available a custom etched PCB, the micro-controller, the $1k\Omega$ resistors, and the sensors are connected as depicted in Figure 4. For already existing insoles, like in running or hiking shoes, the insole can be easily equipped with the sensors by using the peel-and-stick rubber backing of the sensors (see Figure 3). For shoes which do not come with an insole, using a custom fitted cardboard proved to be a good practice (see Figure 2).

Applications for Smart Shoe Soles in Mountain Sports

While we successfully applied the sensors to running shoes, we think that there is also a large potential in rock climbing and hiking.

Running

A correct running technique is important for both amateurs and professional athletes. Improving the running technique helps to prevent injuries and to run faster. While there is not one correct running technique, there are some running mistakes, that can be solved by real-time tracking and notification of the runner. Both heel striking and overpronation are problems which may arise when the foot lands on the ground. Overpronation occurs when the foot is bent inwards while touching the ground. When heel striking, the heel touches the ground first, followed by the forefoot instead of vice versa. Both are common mistakes which increase strain, can lead to injuries and make the running less efficient.

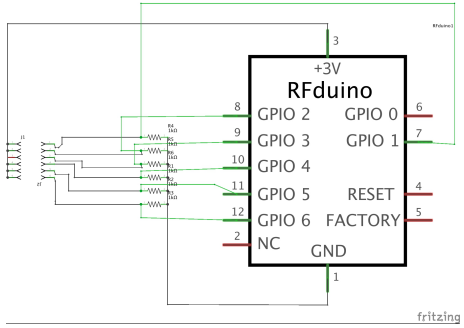

Figure 4: Circuit of the sensor platform

In our current approach we mainly focused on real-time assistance for track and street running. We extended the platform above by using a set of vibration motors which were attached via an elastic strip (see Figure5). The sensor were placed on the insole on the inside and outside of the forefoot and one additional sensor was attached where the heel is. With some simple thresholding we were able to give instantaneous feedback on the running technique: if the user does one of the detected running mistakes, feedback starts before the foot leaves the ground again and is already over by the time the foot touches the ground for the next step.

As a next step we aim to explore trail running. Due to the uneven and sometimes steep terrain, trail running is more complex and requires much more engagement in running technique and concentration during the workout.

Rock Climbing

In climbing a smart sole can be used to train foot technique. Although when addressing climbing technique, the emphasis is almost always put on upper body strength, learning to optimally place and weight the feet reduces strain on the forearms and helps to get into a position to efficiently reach

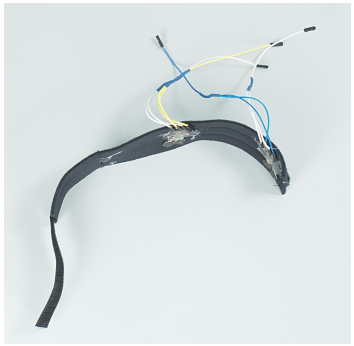

Figure 5: Vibration motors attached to an elastic strip to give real-time feedback while running.

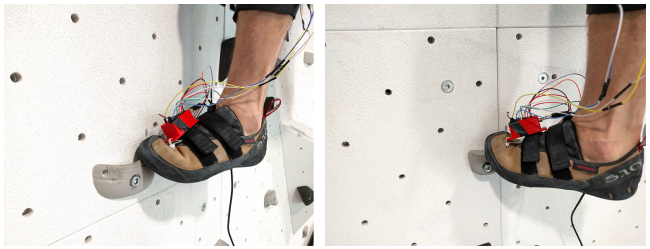

Figure 6: Vibration motors attached to an elastic strip to give real-time feedback while running.

the next holds. A precise matching of foot holds (i.e. stepping correctly on the foot hold without the need for repositioning) saves energy and thus increases the chance of successfully sending a route. A smart sole can be used to detect weaknesses regarding foot technique (e.g. slipping, replacing the feet to often on the same hold, etc). Using a simple tracking mechanism, could give the climber a better feeling about her foot techniques: We deployed the sensors on a cardboard insole in a climbing shoe (see Figure 2) and in a first test, could recognize if the climber used the tip or the side of her shoe.

Hiking

Hiking in mountainous areas often require confidence and sure-footedness in steep terrain. Smart shoe soles have the potential to monitor the confidence of a hiker and in case of critical situations warn him/her or provide support. Furthermore, smart insoles could be used in diabetes treatment. Many people suffering from diabetes also suffer from polyneuropathy, resulting in numbness of the feet. A smart insole could detect pressure points and warn the patient at an early stage to prevent severe, slow-healing wounds.

Summary and Future Work

In this paper, we proposed a simple platform for ad-hoc prototyping of smart insoles. We showed that even simple mechanism like force sensitive resistors and a microcontroller can be used to detect a large variety of feet related events. In the future we want to extend the platform by a skeleton of an Android application which should enable the developer to make the prototypes more portable. Furthermore we want to investigate the design and possibilities of the platform during a workshop.

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