A PIEZOELECTRIC ENERGY-HARVESTING SHOE SYSTEM FOR PODIATRIC SENSING

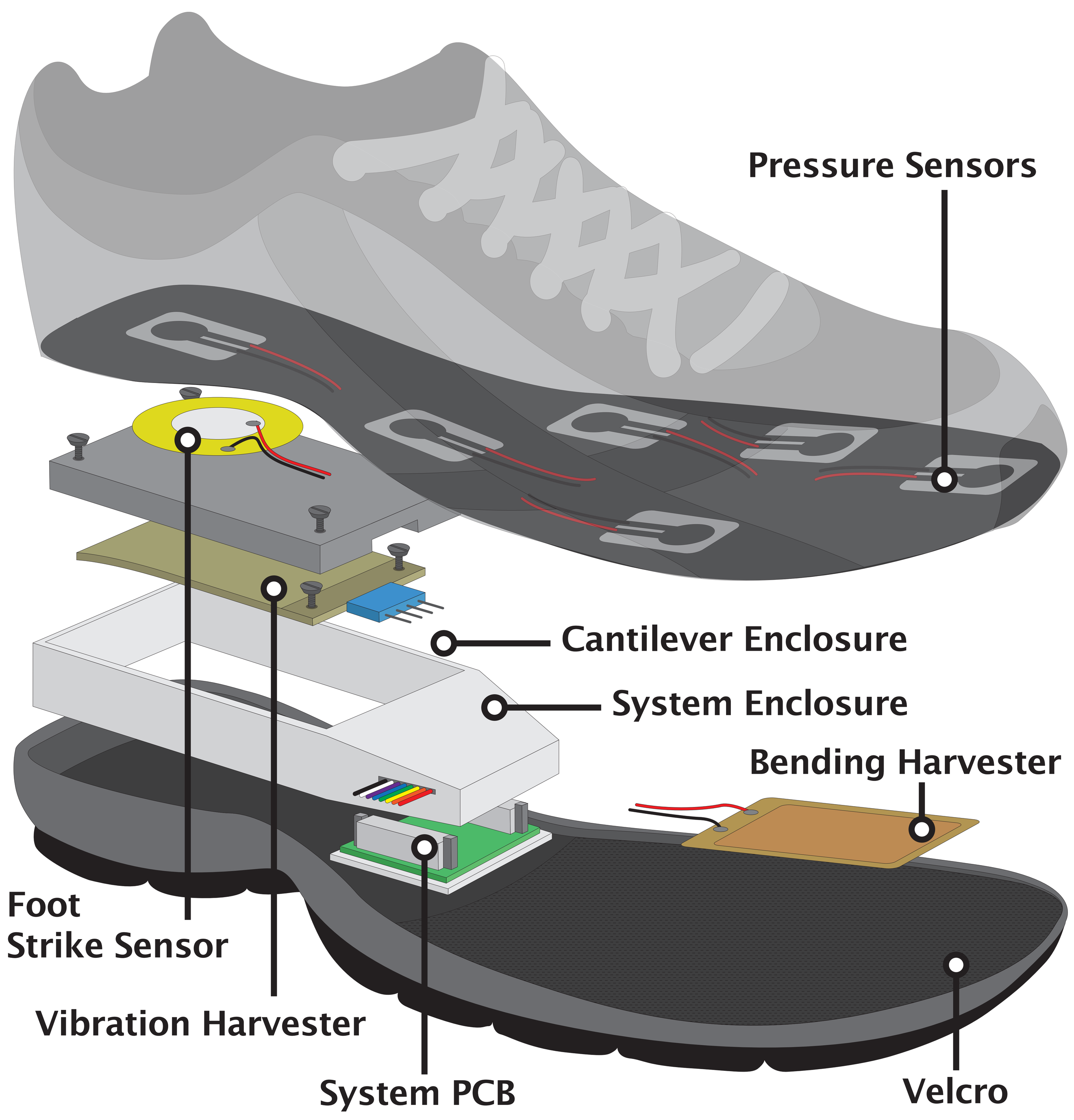
Rich Meier (Student, OSU), Nicholas Kelly (Student, OSU)*, Omri Almog (Student, OSU)*, and Patrick Chiang (Professor, OSU)*

Oregon State University
College of Engineering

Introduction

The STEPS system is meant to be an initial step towards the commercialization of wearable, energy-harvesting electronics. We see the STEPS system as proof that low-power energy harvesting applications can be integrated with today's (off-the-shelf) technology to provide useful data in a variety of medical applications. Our system utilizes piezoelectric transducers and pressure sensors to record the transition of shoe sole forces while the user is walking or running, allowing for later podiatric analysis.

Figure 1: Expanded System



Methods

The energy-harvesting capability of the system consists of a rigid energy-harvester and a flexible energy-harvester (Fig.1). The rigid transducer is placed in the heel and enclosed in a low-profile, custom 3D printed enclosure that allowed it to vibrate freely without breaking. The flexible-energy harvester is placed strategically at the ball of the foot to maximize foot strike excitations as well as bending excitations, via downward compression and foot flexion, respectively.

These transducers are paired with a power conditioning system which rectifies, converts (buck/boost), and stores generated energy. A small 50 μ Ah battery is utilized for RTC updates, which also serves as an indicator for acceptable measurement energy. Due to the low-power output of the piezo transducers, the system operates in two main power modes. Mode-2 is when the system is in a low-power state (4 μW) only updating the RTC. After sufficient energy has been stored (Fig. 2) and the user's the heel strikes the ground, the system briefly transitions to Mode-1 (~7.5 mW) where multiple samples of sole pressure are taken (in a low-power state between samples).

A piezo transducer on the heel is responsible for initiating a sample, while also consuming no energy. Samples are taken through six flexible, force resistive sensors which are at key points in the sole. All samples are stored on on-chip FRAM (16KB, nonvolatile), which allows for sufficient data to be recorded while consuming very little power. The data recorded on the device can be later downloaded via USB using custom, cross-platform software, which allows for visualization of the data as well as the customization of parameters on the device.

* Author notes:
- Rich Meier is currently a M.S. student in Energy Systems at OSU
- Nicholas Kelly is currently a M.S. student in Comp. Arch. at UT Austin
- Omri Almog is currently a M.S. student in Comp. Arch. at UCSB

Figure 2: Power System Operation

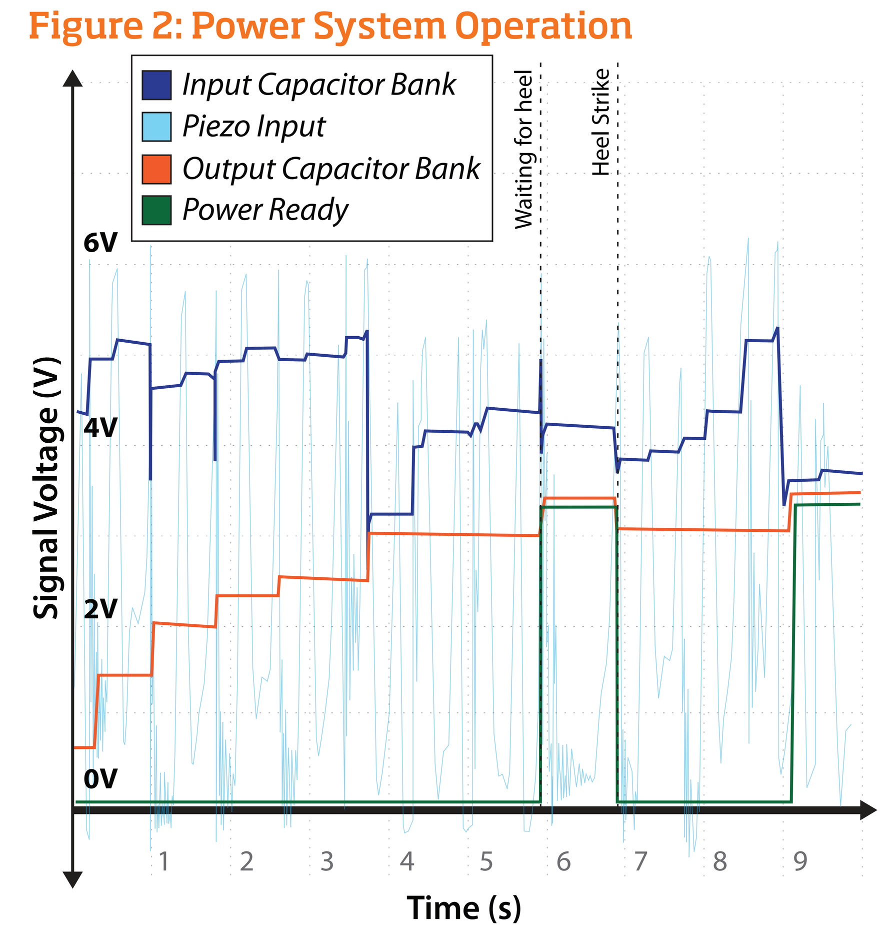
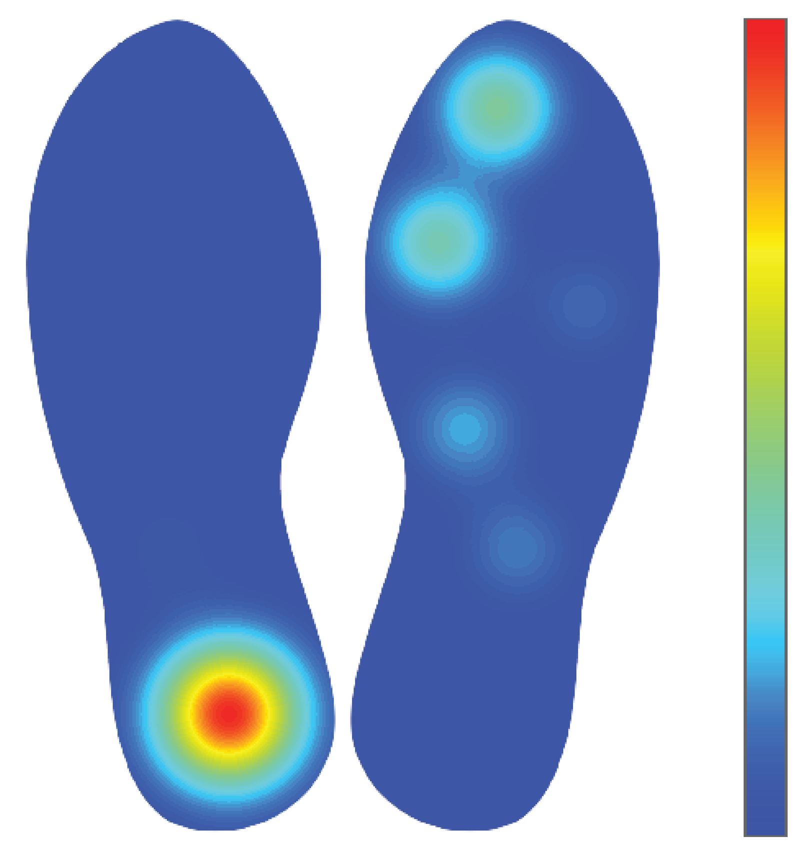


Figure 3: Pressure Map Visualization



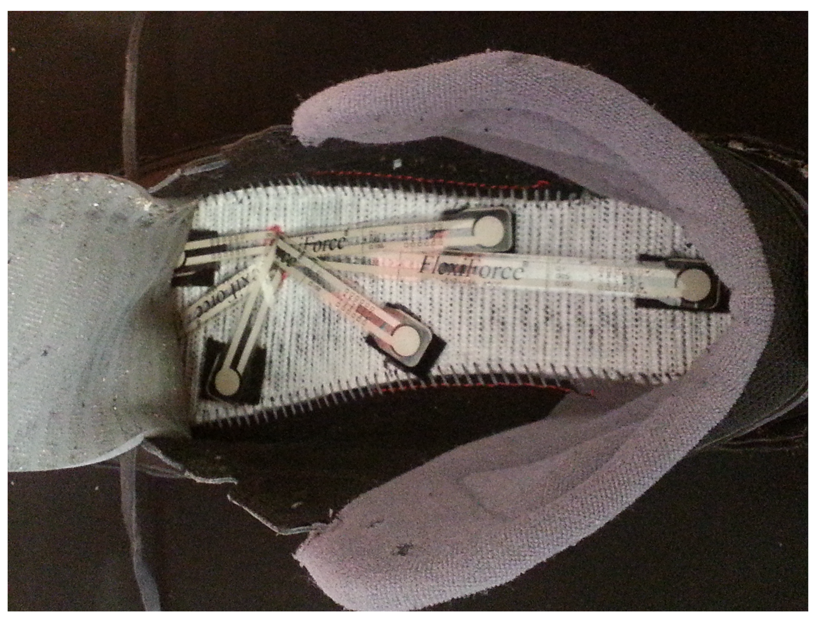
Results

The complete prototype, including the energy-harvesting and power circuitry, was able to sufficiently power the shoe system at different sensor capture rates, depending on the activity of the wearer. For typical walking situations, approximately 10-20 steps were needed during Mode-2, in order to have enough energy to enter into Mode-1 and capture sensor readings. During running, duty cycle relating to the number of steps required for each sensor reading was varied between 1 and 5 steps. Despite high variability in operating amplitude and frequency, we consistently observed an average of 10-20 μJ of energy capture per step.

In terms of sensor measurements, our results were as expected in terms of relative force. As the wearer walked around, the force transitioned from the heel to the toes, with most of the force occurring on the initial impact of the heel (Fig. 3). This is in contrast to running or walking down stairs, where the force is mostly centered around the ball of the foot, with less impact on the heel. While our system measures force in Newtons, actual force measurements inside the shoe were not verified by another device. Therefore, the sensor data recorded is currently qualitative. Though with further calibration and refinement of our sensor voltage versus force correlation (currently an exponential best-fit), it is possible to obtain accurate, quantitative force data (which would be included in future work).

Conclusion

The system is designed to be robust, mobile, and fully embedded in the patients normal routine, allowing for podiatric analysis in a variety of environments. Due to the low-volume and low maintenance features, the device can be targeted for athletes, physical therapy patients, amputees, and those with muscular or nervous system disorders.



Acknowledgments

We would like to thank Joe Crop and Jacob Postman in Prof. Chiang's research group, and Don Heer for their knowledge and guidance. Thanks to David McKinley for his advise and hardware support. Finally, we would like to thank TekScan Inc. for supplying sensors for this research.