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Design and Fabricate Personal Health Sensing Devices

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ABSTRACT

With the development of low-cost electronics, rapid prototyping techniques, as well as widely available mobile devices (e.g. mobile phones, smart watches), users are able to develop their own basic interactive functional applications, either on top of existing device platforms, or as stand-alone devices. However, the boundary for creating personal health sensing devices, both function prototyping and fabrication -wise, are still high. In this paper, I present my works on designing and fabricating personal health sensing devices with rapid function prototyping techniques and novel sensing technologies. Through these projects and ongoing future research, I am working towards my vision that everyone can design and fabricate highly-customized health sensing devices based on their body form and desired functions.

CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**; **Ubiquitous and mobile devices**; **Accessibility systems and tools**.

KEYWORDS

health sensing, personal fabrication, rapid function prototyping, sensing technologies

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1 INTRODUCTION

With the development of low-cost electronics, rapid prototyping techniques, as well as widely available mobile devices (e.g. mobile phones, smart watches), projects related to health sensing applications have emerged in the last decade. These projects are usually either built on top of existing device platforms, such as mobile phones, and smart watches, or as stand-alone devices. More recently, with the assistance of interactive device prototyping tools, as well as widely available personal fabrication machines (e.g., 3D printers, laser cutters), users with limited electronics knowledge can also design and fabricate customized interactive functional devices, which opens up opportunities for the development of personal health sensing devices.

However, the boundary for designing and fabricating personal health sensing devices are still high. Depending on the purpose of the health sensing device, the challenges for users can be more or less difficult to solve. Based on the usage environment and design emphasis, I categorize the personal health sensing devices into the following two types: (1) scenario oriented and (2) function oriented personal health sensing devices. The scenario oriented personal health sensing devices include most daily use wearable devices with conventional health sensing functions (e.g. heart rate, blood oxygen level, behavior monitoring). These devices can usually be designed with existing sensor modules and tend to be less sensitive over the sensing environment (e.g. you can monitor heart rate on wrist, fingertip, or chest area), therefore the personalization of scenario oriented health sensing devices focus on the design and prototyping of the device form factor, accessibility, and novel device interfaces. The function oriented personal health sensing devices, on the other hand, represent health sensing devices designed for more specific usage environment (e.g. home health monitoring, unsupervised physical rehabilitation) and medical conditions (e.g. anemia, blood pressure monitoring). The design and personalization of these devices usually require highly-customized sensing boards and/or novel sensing technologies.

In this paper, I present my works on designing and fabricating personal health sensing devices with rapid function prototyping techniques and novel sensing technologies. Based on the aspects each project contributes to the personal health sensing devices, I will introduce them in the following three sections: (1) health sensing via existing platforms, (2) customized health sensing devices, and (3) prototyping health sensing devices. I will also include some ongoing and future projects along with each category.

2 HEALTH SENSING VIA EXISTING PLATFORMS

My research in personal health sensing domain started with developing personal health applications via existing sensing platforms. My first projects used the sensors available in standard smart phones, such as IMUs, camera, microphone etc., to help users monitor different types of health issues. These applications utilize and combine sensors on personal portable devices (e.g. mobile phone, smart watch) that are not traditionally designed for bio-signal detection, and convert them into function oriented personal health sensing devices.

One of my earlier research projects HemaApp IR ([2, 4]), for instance, measures hemoglobin levels and screens for anemia non-invasively by illuminating the patient's finger with a smartphone's

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build-in camera flash and an IR ToF sensor (Figure 1.a). By filtering and analyzing the image data, we are able to extract the color absorption and reflection rates on patients' fingertips across different light wavelengths, which corresponds to concentrations of hemoglobin and other blood components, such as plasma.

In another project called Seismo [3] (Figure 1.b), we developed a smart-phone based blood pressure monitoring application, which measures the time between the opening of the aortic valve and the pulse later reaching a periphery arterial site (i.e. PTT, or pulse transit time). It uses the smartphone's accelerometer to measure the vibration caused by the heart valve movements (Seismocardiography (SCG)) and the smartphone's camera to measure the pulse at the fingertip (photoplethysmography (PPG)). Seismo relies on Seismocardiography (SCG), which uses the vibration caused by the movement of the blood and valve activities as the heart beats, allowing for accurate measurement of aortic valve opening time. The SCG is captured using the phone's accelerometer pressed against the chest (Figure 1.b). In this position, the user holds the phone with their finger covering the camera, which then captures the photoplethysmogram (PPG) at the finger, thus measuring the pulse as it arrives. This technique conveniently captures both the proximal (close to the heart) and distal (away from the heart) timing all from one device, without the need for any supplemental hardware. Additionally, PTT-based techniques can measure beat-to-beat blood pressure, thus it can more reliably measure short-term blood pressure changes (such as post-exercise), which are difficult to measure using cuff-based devices.

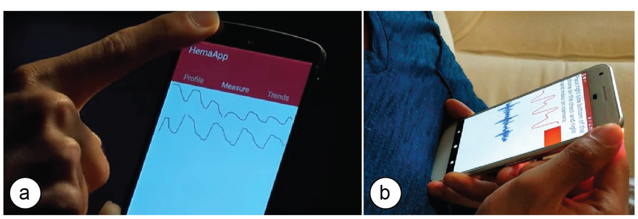

Figure 1: (a) HemaApp measures hemoglobin level in blood for anemia detection, and (b) Seismo measures blood pressure over long period of time.

3 CUSTOMIZED HEALTH SENSING DEVICES

An important insight I had when I worked on those health sensing projects is that we as human beings, are all unique and "highly-customized". Thus, developing health sensing devices that are highly customized to each user is one of the most important factors for better acquiring health information. In this section, I will mainly introduce design and fabrication of personal health sensing devices that uses sensing functions that was previously not accessible outside of clinical environment (i.e. function oriented).

In collaboration with researchers from Harvard Medical School, Massachusetts General Hospital and Northeastern University, I developed a prototyping toolkit, EIT-kit [7], that allows for the fast generation of highly customized health sensing devices that work based on Electrical Impedance Tomography (EIT). Electrical Impedance Tomography (EIT) is an imaging technique that measures conductivity, permittivity, and impedance of a subject. It works by attaching electrodes to the surface of the subject, and then using the electrodes to either inject current or measure the resulting voltages. Interpolating the raw signals then results in an image of the subject's internal conductivity.

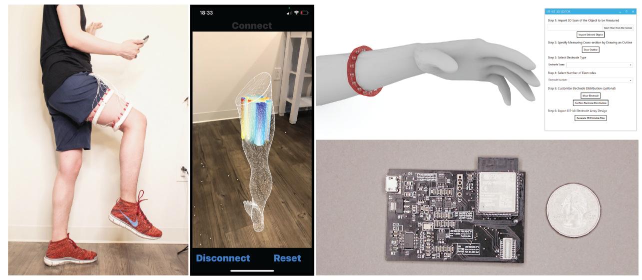

Figure 2: EIT-kit supports users in creating a variety of EIT sensing devices and visualizing the resulting data. EIT-kit provides a 3D editor plugin, a sensing motherboard and microcontroller library, as well as an image reconstruction API

Devices generated with my prototyping toolkit EIT-kit [7] can monitor which muscles a user is engaging and how much they are contracted, as well as motion sensing, which are useful in many different applications, from physical rehabilitation to monitoring athletes to prevent overstraining muscles. As shown in Figure 2, EIT-kit contains (1) a 3D editor for personalizing measuring setups based on each patient's unique body physique, (2) a customized EIT sensing motherboard that supports different measurement setups (2- and 4-terminal, up to 64 electrodes, and single or multiple (up to four) electrode arrays), and that provides adjustable AC injecting current to improve the quality of the signals, (3) a microcontroller library that automates the calibration of the signals and facilitates data collection, and (4) an image reconstruction API for mobile devices that can be used to interpolate and then visualize the data. As a result, EIT-kit contributes to the design and fabrication of function oriented (i.e. electrical impedance tomography) personal health sensing devices with custom form factor, and supports users across the different stages of EIT device development.

One of the personal health sensing devices that I built for unsupervised physical rehabilitation is called MuscleRehab [6], a rehabilitation training environment that uses EIT data to visualize to patients if they are engaging the correct muscle for a rehabilitation exercise and provides guidance to correct the muscle engagement if needed. For our research, we focused on exercises for Total Knee Arthroplasty (TKA) and thus specifically monitored the thigh muscle groups, as shown in Figure 3. To accurately map the conductivity changes from the EIT data onto the muscles, I created a custom 3D forward model based on users' body form factors and visualize them onto a muscle skeleton avatar in VR environment, as shown in Figure 4. The results from our user studies showed that monitoring and visualizing muscle engagement can improve both the therapeutic exercise accuracy for users during rehabilitation, as well as the accuracy of post-rehabilitation evaluation for physical therapists.

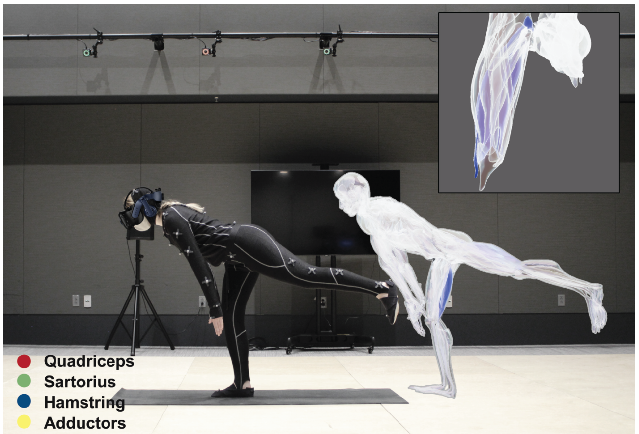

Figure 3: MuscleRehab is an electrical impedance tomography and optical motion tracking enhanced rehabilitation system for visualizing muscle engagement and motion data during unsupervised physical rehabilitation.

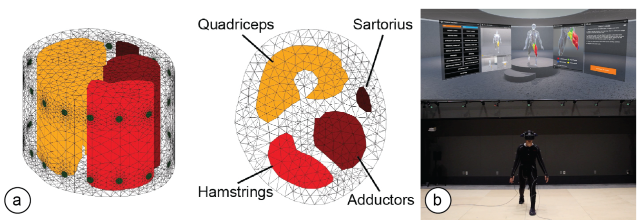

Figure 4: (a) Side (left) and Top (right) View of the Customized Thigh Forward Model, (b) MuscleVR system setup & UI.

I am currently building additional custom FEM models for different human body parts, including the wrist, upper arm, waist and breast. For the ladder, I'm working with Brigham and Women's Hospital to extend my technology for breast cancer treatment evaluation. We will open source the models, along with the image reconstruction and visualization algorithms to the community as software support for personal health sensing devices using EIT.

4 PROTOTYPING HEALTH SENSING DEVICES

To speed up the development of personalized health sensing devices, I also developed several prototyping and design tools that integrate the device form and electronic function in the same design space, to assist personal health sensing devices development. These design and fabrication tools are mainly for the scenario oriented personal health sensing devices, as they are optimized for rapid function prototyping with off-the-shelf sensor modules.

CurveBoards [5], for instance, are 3D breadboards that serve as a circuit prototyping platform for prototyping health sensing functions in the context of an object's form. As shown in the Figure 5, some of the personal health sensing CurveBoard prototypes we built include a general wearable device that's being used for prototyping a daily dietary recorder, as well as a decorative bracelet which is also a heart rate monitor.

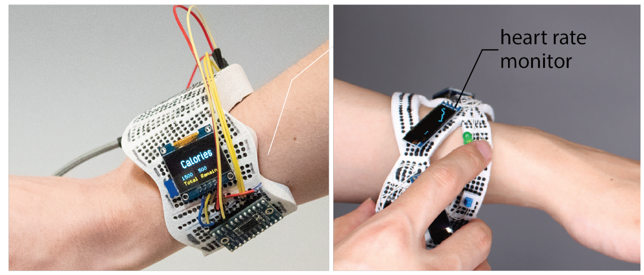

Figure 5: CurveBoards are 3D breadboards for prototyping health sensing functions in the context of an object's form.

MorphSensor [8] is a 3D electronic design tool that morphs existing sensor modules of pre-defined two-dimensional shape into free-form electronic component arrangements that better integrate with the customized health sensing devices form. As demonstrated in Figure 6, some of the personal health sensing devices we built with MorphSensor system includes (1) a pair of glasses that detect excessive blue light exposure and alarm the user, (2) a soldering iron that detects and records the level of smoke in the air to prevent lung diseases, (3)an N95 mask that detects if the mask substrate is contaminated, and needs to be replaced, and (4) a pair of earpods that can non-intrusively measure users sleep quality via their sleeping behavior.

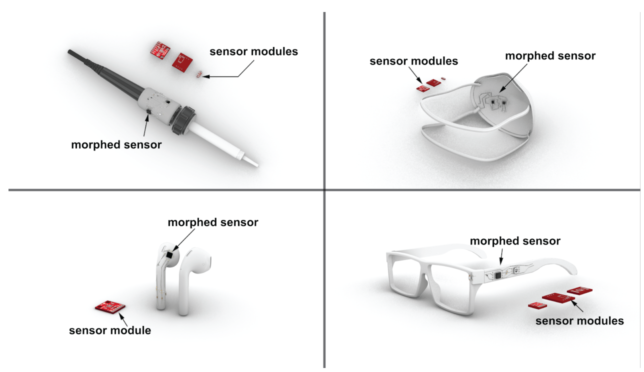

Figure 6: MorphSensor is a 3D electronic design tool that morphs existing sensor modules into free-form electronic component arrangements that better integrate with the customized health sensing devices form.

SensorViz [1] is a prototyping and visualization tool that visualizes sensors' invisible Field of View (FoV) in the context of a prototype to support users in finding the best configuration of sensors, which can better assist the sensor selection, sensing location, and device integration for prototyping personal health sensing devices.

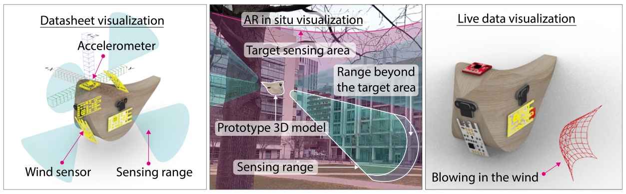

Figure 7: SensorViz a prototyping and visualization tool that supports novice makers by visualizing sensor information at each stage of the prototyping process.

5 CONCLUSION AND FUTURE WORK

In this paper, I present my works on designing and fabricating personal health sensing devices with rapid function prototyping techniques and novel sensing technologies. I will keep pushing on developing novel sensing technologies in health monitoring and create improved design tools for prototyping personal health sensing devices. I believe in a future where everyone can design and fabricate highly-customized health sensing devices based on their body form and desired functions, and I am dedicated to working towards this vision.

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REFERENCES

[1] Yoonji Kim, Junyi Zhu, Mihir Trivedi, Dishita Turakhia, Ngai Hang Wu, Donghyeon Ko, Michael Wessely, and Stefanie Mueller. 2022. SensorViz: Visualizing Sensor Data Across Different Stages of Prototyping Interactive Objects. In *Designing Interactive Systems Conference* (Virtual Event, Australia) *(DIS '22)*. Association for Computing Machinery, New York, NY, USA, 987–1001. https://doi.org/10.1145/3532106.3533481

[2] Edward Wang, William Li, Junyi Zhu, Rajneil Rana, and Shwetak Patel. 2017. Noninvasive hemoglobin measurement using unmodified smartphone camera and white flash. *Conference proceedings: ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference* 2017, 2333–2336. https://doi.org/10.1109/EMBC.2017.8037323

[3] Edward Jay Wang, Junyi Zhu, Mohit Jain, Tien-Jui Lee, Elliot Saba, Lama Nachman, and Shwetak N. Patel. 2018. Seismo: Blood Pressure Monitoring Using Built-in Smartphone Accelerometer and Camera. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3173574.3173999

[4] Edward Jay Wang, Junyi Zhu, William Li, Rajneil Rana, and Shwetak Patel. 2017. HemaApp IR: Noninvasive Hemoglobin Measurement Using Unmodified Smartphone Cameras and Built-in LEDs. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (Maui, Hawaii) *(UbiComp '17)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3123024.3123180

[5] Junyi Zhu, Lotta-Gili Blumberg, Yunyi Zhu, Martin Nisser, Ethan Levi Carlson, Xin Wen, Kevin Shum, Jessica Ayeley Quaye, and Stefanie Mueller. 2020. CurveBoards: Integrating Breadboards into Physical Objects to Prototype Function in the Context of Form. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[6] Junyi Zhu, Yuxuan Lei, Aashini Shah, Gila Schein, Hamid Ghaednia, Joseph H Schwab, Casper Harteveld, and Stefanie Mueller. 2022. MuscleRehab: Improving Unsupervised Physical Rehabilitation by Monitoring and Visualizing Muscle Engagement. In *The 35th Annual ACM Symposium on User Interface Software and Technology* (Bend, Oregon, USA) *(UIST '22)*. Association for Computing Machinery, New York, NY, USA.

[7] Junyi Zhu, Jackson Snowden, Joshua Verdejo, Emily Chen, Paul Zhang, Hamid Ghaednia, Joseph H. Schwab, and Stefanie Mueller. 2021. EIT-kit: An Electrical Impedance Tomography Toolkit for Health and Motion Sensing. In *Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology*. https://doi.org/10.1145/3472749.3474758

[8] Junyi Zhu, Yunyi Zhu, Jiaming Cui, Leon Cheng, Jackson Snowden, Mark Chounlakone, Michael Wessely, and Stefanie Mueller. 2020. MorphSensor: A 3D Electronic Design Tool for Reforming Sensor Modules. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*.