EDWARD JAY WANG | RESEARCH STATEMENT

My research is largely in the space of mobile health (mHealth), which I broadly define as using mobile technology to expand the reach of healthcare in traditionally non-clinical settings. mHealth is inherently a cross-disciplinary endeavor that brings together technology, data science, medicine, and governance to establish a new form of healthcare that covers a more diverse population, with higher frequency, and at lower cost. Within this space, my research focuses on developing technological solutions to invent a new class of “medical monitors” that can support mHealth scenarios by gathering novel health data. Grounded in this premise, my research looks to enable medical sensing beyond the current clinical paradigm by (1) re-appropriating existing mobile sensor infrastructure to enable low-cost and widespread medical sensing and (2) exploring novel sensor solutions that perform continuous health tracking for passive, long-term insights to a person’s health. My work explores practical solutions to address real-world medical needs drawn from conversations and requests from clinicians and world health organizations, but solved in new, creative ways that leverage state-of-the-art applied machine learning, embedded systems, and analog circuitry. In this pursuit, I have developed novel wearable devices for continuous activity and physiological measurements, investigated signal processing and machine learning techniques for new types mobile sensor data, and spent countless hours as a clinical researcher in cancer patient rooms and even the Peruvian jungle working with patients to validate the technology I’ve built.

I have published 10 papers at top-tier computer science and IEEE conferences (UbiComp/IMWUT, ISWC, CHI, UIST, IEEE EMBC), for which I received 3 paper awards (1 Honorable Mention, 2 Best Paper Awards). I have participated in the 2018 Heidelberg Laureate Forum and recently placed as a finalist for the Gaetano Borriello Outstanding Student Award. My PhD has been supported by the NSF GRFP and the ARCS Fellowship. I have had lasting collaborations with industry (e.g. Microsoft Research w/Desney Tan, Huawei Research w/Vincent Li, and Intel Labs w/Lama Nachman) and foundations (e.g. Fred Hutchinson Cancer Research Institute, Bill and Melinda Gates Foundation).

As a faculty member, I intend to dive deeper in cutting across the boundaries of medicine and computation by exploring how applications of ubiquitous computing can transcend the mere replication of existing medical sensing capabilities. My research will focus on incorporating more semi-supervised and unsupervised learning techniques to allow mHealth monitoring systems to take advantage of scale. Furthermore, I want to dive more deeply into the use of mHealth in directing individualized treatments, with attention to the accompanying ethical issues, including the development of sensing techniques that are inherently privacy preserving. Most importantly, I want to tackle comingling novel health information with traditional medical data in order to truly bridge mHealth from simple personal tracking to a legitimate medical discipline. I look forward to collaborating with domain experts in various computational methods and clinical specialties that these key challenges will draw upon and bring my application-driven thought and design process to delivering ubiquitous and predictive healthcare to all.

Bootstrapping the Next Billion Medical Devices

Today’s medical devices are typically centralized in high-resource places like hospitals and cities, underservicing large populations in low-income regions, rural areas, and chronic at home care scenarios. The proliferation of smartphones presents an opportunity to address this issue of global access to medical screening and management. By tapping into the versatile arsenal of built-in smartphone sensors through software augmentations, I have built solutions with the potential to transform the billions of smartphones into medical devices with simple app downloads. A main thread of my PhD has been exploring this concept extensively by developing screening and monitoring solutions for anemia [10], blood pressure [7], eye pressure [5], and osteoporosis [undergoing validation] using only the built-in smartphone sensors. My work combines novel use of sensors augmented with signal processing, ML, and domain knowledge of both physics and physiology to transform smartphones into medical devices that satisfy the WHO’s guideline for ASSURED: Affordable, Sensitive, Specific, User-friendly, Rapid, Equipment-free [no large electricity dependent machinery], and Delivered to the target population [4].

In this domain, my deepest investigation has been the use of smartphones to perform anemia screening. Anemia, characterized by a low hemoglobin level, assumes a disproportionate burden in resource-limited areas and is deemed a “severe” health problem by the World Health Organization in much of the developing world [1]. Despite the morbidity, mortality, and economic consequences resulting from anemia, this condition is often under-diagnosed or diagnosed late due to limited access to the required testing infrastructure [6]. Peripheral blood testing to assess the hemoglobin level is the gold standard; however, such invasive testing is costly and associated with infection and bleeding risks, as well as anxiety and fear.

Figure 1: Me performing an in-field measurement using the smartphone hemoglobin measuring app in a deployment in a jungle community in the Peruvian jungle

Figure 2: Smartphones are equipped with a large variety of sensors that can be utilized for measuring physiological metrics. In my PhD, I have transformed smartphones to measure hemoglobin, blood pressure, eye pressure, and bone density.
To this end, I have been developing a solution that uses the smartphone camera to perform noninvasive, skin-tone agnostic, measurements of hemoglobin, called HemaApp \[10\].

The inner workings of HemaApp rely on a biophysics-based measurement of hemoglobin concentration using absorption spectrometry. The system works by having the patient place their finger over the camera and measure the absorptive properties of the blood inside the finger. In our initial exploration, we extensively tested a variety of lighting sources from visible to near infrared spectrum to fully explore the design space of this method (Best Paper at UbiComp ‘16) \[10\]. I then extended this initial feasibility development to use only the camera and white LED housed on a typical smartphone \[8\]. The conversion from video recordings of the finger to hemoglobin is achieved by a combination of signal pre-processing using standard filtering techniques and machine learning (SVM) using domain knowledge driven features. The data-driven approach allows for the system to learn non-linear relationships between the raw camera measurements and the theoretical absorption properties affected by blood component concentrations. I partnered with doctors at the UW Medical Center and Seattle Children’s Hospital to perform a series of validation studies, refining the design and ultimately collecting the data needed for training and testing the model. In this process I spearheaded the passing of a HIPAA compliant, cross institutional IRB, and also learned how to work with patients in both outpatient and inpatient situations. I even obtained certifications for a clinical researcher access to the University of Washington Medical Center, an experience that has helped many of my colleagues learn how to obtain similar clearances.

Through the development of this work, I’ve gained extremely valuable experience working as a clinical researcher and established personal connections with medical practitioners and global health organizations around the world. I have since performed multiple rounds of in-clinic studies with UW Medical Center and Seattle Children’s Hospital; I recently started new large scale (N > 1000) and longitudinal (N = 10, 6 month tracking) studies with Harborview Medical Center and the Fred Hutchinson Cancer Institute. In addition to evaluating HemaApp in clinical settings, I’ve worked with NGOs in Peru to test the concept at ground zero. In a weeklong deployment I visited the Amazon Jungle in Peru with Red Innova to perform an in-field anemia screening study with HemaApp. This experience has been vital to the formation of usability considerations for end-users. HemaApp will continue to be developed and distributed through a non-profit organization (under my guidance) with an aim to commercialize HemaApp, allowing NGOs and patients around the world to perform low cost anemia screening.

Passive and Continuous Health Sensing with Wearable Devices
The smartphone presents an excellent platform to enable widespread medical monitoring through re-appropriation of the sensors already deployed ubiquitously. However, I believe that there is a vast opportunity to explore new forms of mobile devices, particularly wearable devices that can provide passive and continuous measurements. A new generation of medical devices will take the form of “everyday” things like clothing, glasses, watches, tattoos and maybe even tooth fillings. These devices will behave more like hospital room medical devices, acting continuously in the background. They will provide continuous insights used in testing hypotheses about a person’s conditions, even before the onset of an ailment. During my PhD, I have begun my exploration into this space, particularly focusing on a broad exploration of new sensing approaches to capture previously unexplored metrics.

Glabella is a pair of glasses that measures blood pressure changes at every heartbeat (IMWUT Volume 1 Issue 3, Distinguished Paper Award) \[3\]. It achieves this by measuring the time difference of when the heartbeat pulse waves arrive at different peripheral arterial sites on the body. An increase in the blood pressure causes a smaller measured time difference (pulse transit time). By placing reflective optical pulse sensors on the nose bridge and ear piece of a pair of glasses, the pulse arrival times are captured at two spatially different arterial sites on the face. Together with Microsoft Researcher, Christian Holz, we designed the sensor housing and custom circuit board all integrated into a low-profile, unassuming pair of glasses. Drawing from my experience with complex study design, I developed a weeklong validation protocol for participants to wear the Glabella glasses for a week in their natural daily environment and measure their blood pressure multiple times an hour using a blood pressure monitor. We demonstrated that the pulse transit time difference measurements are well correlated to the changing blood pressure for each individual. Through Glabella, our goal is to not only enable the next generation of blood pressure measurement, but also explore the design space of new wearables beyond the wrist-worn devices available today. Our form factor hides in plain sight; Glabella can be embedded into helmets or goggles for monitoring during sports, ordinary glasses for everyday use, and head mounted displays for enriching VR/AR experiences by constantly tracking physiological and emotional state of the user.
CASPER is a wearable device charging solution that uses the body as a conductive element for a 13.56MHz AC capacitive charger to charge devices worn on the user’s body [9]. Many current approaches to next generation wearables fixate on a single point sensing device attempting to sense every metric on the body from a single source (e.g. the wrist, face, or waist). Instead, a more effective solution could be to have devices distributed on the body where they are needed. For example, the healing process of a wound should be monitored by a device at the site of the wound, rather than from a wristwatch, for example. A fundamental obstacle towards realizing this future is devising a solution for charging many on-body devices without requiring frequent removal or human intervention. I developed a capacitive charging solution, CASPER, that can be embedded in beds, seats, and other common furniture so that serendipitous daily contacts can facilitate opportunistic AC power circuits through the body to trickle charge body-worn devices. Using our charging system, we designed a wrist monitoring gauze pad that charges each night in bed and monitors the patient’s wound with optical pH sensing and capacitive wetness sensing to indicate whether it is time to replace the gauze pad. This e-bandage design can recharge each night whenever the patient is in bed without ever needing to be removed.

MagnifiSense is a wrist-worn magnetic sensing technique to capture what a person is doing by detecting the electronic environment in their presence. Just as important as physiological monitoring, so is the need to understand a person’s context and daily activity in order to work towards meaningful inferences about someone’s health. We want to be able to ask questions like “how does daily driving affect someone’s blood pressure?” Techniques today rely mainly on motion sensing, but motion alone is a very information limited signal and very individual-dependent. MagnifiSense tracks a person’s activity by taking advantage of the unique electromagnetic radiation caused by electronic components such as motors, power switches, processors, heating elements, etc. For example, by detecting a stove burner turning on, it is possible to infer a cooking activity. Similarly, the EMI footprint is distinct for driving, bus riding, and biking, providing information about commute patterns. EMI-based classification of activity patterns provides a rich set of information while maintaining better power and privacy requirements compared to vision-based systems. This method also only requires a single wrist-worn device, eliminating the need to instrument the entire environment. Using designed features to capture electrical component noise combined with a random forest ML model, our system is capable of segmenting and classifying electronic devices common in daily interaction.

Future Research: Beyond Replicating Medical Devices

As a faculty member, my research agenda will continue to center on the goal of bringing medical sensing out of the clinic and into our daily lives for preventative healthcare. While my PhD has focused on developing new sensors through software and hardware solutions that replicate medical devices in cheaper and more deployable ways, looking forward, I want to harness my experience to advance new research agendas. My research will focus on generating new health data streams by studying (1) largescale open-world deployment of mHealth monitoring technologies, (2) individualized adaptive treatment, (3) privacy preserving monitoring systems, and (4) how this new class of information will be used in conjunction with traditional medical data. There is a wide variety of funding opportunities for my work, from sources such as the NSF, NIH, Gates Foundation, and industry collaborations such as Intel Labs, Huawei, Microsoft, Samsung, and Google. Many of the industry collaborations have already expressed their support of my work and already engaging with me about potential future collaborations and funding.

Largescale Open-world Health Monitoring

All of the systems I have developed, and many others in this line of work, have heavily relied on supervised learning with clinical gold standards for labeled training data. Although this is a direct approach to verify feasibility, (e.g., whether the phone camera can indeed be used to estimate hemoglobin, blood pressure, etc.), it is a very slow process and is almost no different than the way medical devices are developed today. Having spent the last 5 years of my PhD pioneering the development of mobile phone based medical monitors, I have gathered core competencies in developing new technologies in addition to a strong working knowledge of the nuances to deployments and validations. One of the most interesting progressions of my current work with mobile phone health sensing is exploring ways to truly leverage the downloadability of applications by using this deployment mechanism to perform large scale studies. Instead of relying on large sets of labeled data, there is a promising opportunity to explore semi-supervised or even unsupervised solutions. For example, instead of crafting validations to obtain blood tests, we could instead provide HemaApp for a general population to download, using the resulting feature space distribution, demographic information, and populational statistics to learn or augment a hemoglobin estimation model. I have begun planning future collaborations with the non-profit mHealth organization, Sage Bionetworks,
and Intel Labs, who have previously funded my blood pressure work, for ways to extend my current developments in hemoglobin, blood pressure, and bone density sensing as a starting point to this new endeavor.

A major hurdle to deploying applications for large-scale public data collection is the concern of low-quality data. For example, correct usage of HemaApp requires that the camera is fully covered, there is no interference from ambient light, and and the user is not pressing too firmly (resulting in cutting off circulation). Other projects like Goel et al.’s phone-based spirometry work [2] suffer from ambient noise that can potentially overshadow the intended measurement. Although the complexity of factors that are difficult to control are often domain specific, I believe the number of use cases that the research community has uncovered for the use of phone sensors to perform physiological/behavioral measurements has hit a critical mass to begin formalizing data quality assessment algorithms that can be generalized across different sensor streams and classes of problems. Instead of individualized solutions, I intend to explore crowdsourced error labeling for training semi-supervised automated quality detection systems. Another challenging facet related to data quality is ensuring that the intended biomarker is actually being recorded. With open-world health monitoring, contextual and physiological state is difficult to control and thus highly variable. How can we guarantee that measurements are comparable between individuals or between repetitions? For example, in cardiovascular risk assessment, instead of purely measuring heart rate and blood pressure, which vary significantly with context, one interesting solution could be to pair measurements with micro-experiments. For example, asking someone to perform a breath holding challenge or rhythmic breathing, and using the induced sympathetic regulation of the cardiovascular system as the biomarker. Given my background working on a large variety of mHealth solutions, I have a solid grasp on how to tackle this promising direction which is now ripe for exploration.

**Individualized Adaptive Treatment**

Many of the most pressing health challenges are very individualistic. For example, the period between transfusions for Sickle Cell Disease patients averages one month, but depending on the weather and daily activity could range from 2 weeks to 6 weeks. Through a collaboration at the Fred Hutchinson Cancer Research Institute, I am working on adjusting HemaApp to work for Sickle Cell Disease patients to perform daily monitoring of their hemoglobin levels. Through this monitoring, we believe it will be possible to investigate new treatment scheduling based on individual trends. Similarly, there are numerous migraine triggers and just as many symptomatic progressions. Through careful clinical diaries, it is possible for some patients to slowly decipher their triggers. However, patients are still limited in their ability to prevent head splitting pain because migraine medication is most effective when used before the actual pain onset. In a collaboration with UW Bioinformatics, I am co-leading an exploratory wearable device development for trigger tracking for migraine patients. I see an opportunity to continue these explorations to deep dive into how mHealth medical monitors can start to generate more clinically actionable metrics to adapt treatments to individuals rather than requiring individuals to adapt to treatments.

Obtaining clinically actionable individualized metrics is complicated by policies and ethics. Beyond FDA approval of system efficacy (a domain I have had extensive exposure to through the work of my graduate advisor), there are many intricate barriers to mHealth monitors such as social acceptance, interpretability, and clinical workflow integration. The importance of this topic should not be understated and will be a large cross-institutional, cross academic-industry-governance effort that I fully intend to engage closely with to work towards effective and responsible solutions.

**Widely Deployable Health Sensors with Inherent Privacy Preservation**

The proliferation of mHealth is in a constant struggle between data and privacy. With both widespread collection and individualized tracking, more comprehensively collected data leads to emerging security vulnerabilities and heightened privacy risks. I am particularly interested in targeting this issue with inherently privacy-preserving sensors at the hardware and processing layer. A typical sensing system’s workflow entails digitizing physical phenomenon (e.g., optical, chemical, magnetic), processing the digitized information, and communicating the processed information to be used in command execution or model training. Once a physical phenomenon is accessible by the processor, a potential for data-breach is introduced. I am interested in targeting this issue at the earliest part of the pipeline, at the transduction layer. In a new collaboration with the computational fabrication community at CMU and UW through Jennifer Mankoff, we are exploring the use of new sensor fabrication techniques that combine computational fabrication with mHealth to tune transduction properties of wearable sensors. Currently we are exploring the use of conductive fabric to perform early detection of apnea episodes to prevent Sudden Infant Death Syndrome (SIDS). To avoid using intrusive solutions like camera, we designed our system so
that our sensing system such that the mechanical properties of the fabric sensor respond with bandwidth limitation and captures only breathing motion. In the same space, I’m also brainstorming ideas for designing microphones with a frequency response that only captures cough sounds and does not respond to speech. The interweaving of computational fabrication methods and mHealth is in its early stages and I believe there are interesting opportunities to be a pioneer in this space. Along with bandwidth-limited transduction designs, I am also interested in collaborating with machine learning experts on the use of federated learning to preserve privacy of sensitive data collected by new mHealth monitors.

Comingle Continuous Sensor and Sporadic Behavioral Data to Current Medical Data

Ultimately, I believe that to realize the full utility of ubiquitous health sensing, we must study how to comingle this information with high entropy data sources like sparse hospital visits, imaging, and genomic data. Today, the research community has started work in performing large-scale populational understanding through analyzing mobile and wearable mobility data. I think this becomes far more complicated when we introduce information gain from micro-experimentations for individual findings, daily monitoring of a large number of physiological measurements, and populational trends that are uncovered through anonymous community health data. I believe that this is a truly wicked problem that, at the center, will require an application-minded researcher to identify the most important medical and health data to enable meaningful health predictions and augmentation for global health.

References