Research Statement

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My research interests fall within the general area of mobile computing. More than 90% of the world population is covered by cellular networks and over half of rural households in many developing countries have a mobile phone, making them humanity's most pervasive platform. Mobile computing can not only provide IT access to users of all socioeconomic statuses, but revolutionize lifestyles, healthcare, and communication. It is a young field teeming with challenges and opportunities. My research is focused on system solutions for highly efficient and usable mobile devices. In the past five years, my research has covered system energy efficiency, human factors, and biomedical applications. My research has been collaborative and interdisciplinary, and I have become an expert in building complete systems and evaluating them through lab and field user studies. My research can be summarized into two categories:

1. Context Aware System Design

A unifying theme of my research experience is the use of context information and statistical learning to improve the performance and usability of mobile systems. Modern mobile systems can increasingly assess their context; they are aware of time, location, movement, and network conditions. They can hear and see surroundings, and have access to users' current and historical network and usage details, including viewed content. Context awareness can be further enhanced through external sensors and by prompting the user directly. Such capabilities have inspired novel applications such as health monitoring, life logging, participatory sensing, and sensor-based interaction. Yet, my research has brought context awareness into the foundations of computing and communication in novel ways, improving their efficiency, usability, and performance. My research has also developed new principles for applying human factors and sensing in system design. I would like to continue this track in my career.

Context-Driven Network Management: My research has evaluated and highlighted the complementary power characteristics of the multiple wireless networks in modern mobile devices, e.g. Wi-Fi and cellular, and identified novel solutions for combining these networks [1, 2]. In order to improve the energy consumption, coverage and speed of mobile Internet, *Context-for-Wireless* estimates and predicts network conditions using context information without actively probing the network. *Context-for-Wireless* can improve the average battery lifetime of a commercial smartphone by 30 to 40% for an ECG health reporting application, based on real-life network and context traces we collected in a two month user study. Our experimentation using a proof-of-concept device confirmed these findings. Using the same traces, my research demonstrated that it is possible to predict Wi-Fi availability for 1 and 10 hours into the future with 95% and 90% accuracy, respectively, earning the *Spotlight Paper* status for the January 2011 issue of IEEE Trans. on Mobile Computing [2]. Since its publication, *Context-for-Wireless* has inspired many uses of context information in system energy optimization, with over 80 citations [1].

In order to realize *Context-for-Wireless* for preexisting applications, it is often necessary to switch between networks. My research and IP traffic characterization on 27 iPhone 3GS users [3] demonstrates that this is possible by establishing new flows on the new network while allowing pre-existing flows to terminate naturally, and by taking advantage of the resumption functionality of modern protocols [4].

Sensor-Assisted Efficient Computing: My research integrates context sensing into the foundations of computing and human-computer interaction. First, it showed that the computational complexity of video encoding, thus its energy consumption, can be effectively reduced by sensing. Reducing the complexity and energy consumption of video compression has been the subject of many software and hardware research. My research provides a solution complementary to existing research; *Sensor-assisted Video Encoding* (SaVE) [5, 6] estimates device rotation from kinetic sensors and infers the global motion in the camera image sensor. In collaboration with researchers from the National University of Singapore, we showed that our solution simplifies state-of-the-art motion estimation algorithms by up to 27%. Second, my work has employed sensors to assist user interfaces. NoShake [7] addresses the display usability challenge when mobile devices are subject to shaking. NoShake uses readings from a built-in accelerometer, and dynamically compensates for the device shaking by shifting the screen content opposite the direction of the shake. NoShake is based on the physiology of the human eye and a physics inspired model based on a critically dampened mass-spring-damper system. We implemented a prototype of NoShake on the iPhone and evaluated it through user studies in a number of shaking scenarios.

Behavior-Driven Energy Management: While it has been commonly accepted that a longer battery lifetime is always desired, there has been a lack of understanding of how mobile users actually discharge and charge their devices. My research [8, 9] presented the first study regarding how smartphone users interact with their limited battery capacity, earning the *Best Paper Award* at the ACM MobileHCI'07. It pointed out the flaws in existing battery interfaces and motivated better designs that are now being adopted by the industry. Furthermore, the study showed different types of user attitudes regarding recharging; many recharges happen with significant remaining battery, suggesting that battery lifetime does not always matter as commonly assumed. These finding motivated our collaboration with Professor Mark Corner, from the University of Massachusetts Amherst, on context-adaptive energy management, which adapts energy management policies based on each user's charging behaviors and remaining battery levels. It takes advantage of the often unused battery capacity to increase performance and usability [10].

2. Understanding Users and Context through Field Studies

My research highlights the importance of long term and holistic user studies in the design and evaluation of mobile systems and services. An emerging vision within the academia and industry is that smartphones can provide pervasive access to IT, especially for underserved communities. Toward realizing this vision, my research has led the way for longitudinal field studies of smartphone usage. I will use my expertise in field studies to continue conducting grounded research with real-life impact.

Usage Evolution of Mobile Devices: My research is among the first to quantitatively reveal the long-term evolution of smartphone usage and the impact of socioeconomic status of users. To this end, I carried out a longitudinal field study over four months with 14 teenagers from Pecan Park, an underserved community in Houston, TX, where an open-access Wi-Fi network is available [11]. We used our prior pilot study with 10 Rice University students as a control group to highlight the impact of socioeconomic status [12-14]. From an unprecedented amount of qualitative and quantitative data, including focus groups, interviews, and in-device logging, my research showed that smartphone usage is highly context-dependent and may take many weeks to converge. My research highlighted the importance of long-term, holistic studies of mobile devices and services under real-life settings, and identified key factors that contribute to usage evolution. Another important finding was that the smartphones were actively shared by the owners, but privacy concerns over time reduced sharing. My research has subsequently provided a novel software solution to allow phone owners to easily specify the content and applications they wish to share with minimal social and performance implications. Collaborating with Microsoft Research Asia, we designed and implemented a proof-of-concept and evaluated it through long term user studies [15, 16], earning the *Spotlight Paper* status of the December 2010 issue of IEEE Trans. on Mobile Computing.

Ongoing Field Study of iPhone Users: Building upon our experience from the Pecan Park field study, we are carrying out a first-of-its-kind year-long field study of iPhone users. This field study is not only unique in its duration, but also the comprehensive in-device logging, the in-field updatability of the logger, and the large number of users (>25) with different socioeconomic statuses. This study not only reveals the long-term usage evolution of one of the most successful mobile systems, but also provides deeper answers to the research questions raised from the Pecan Park field study. Some of our early results have already been reported [3, 17], and we are actively working on several areas, including defining and measuring the context-dependency of mobile usage, user based driven clustering of mobile computing requirements, and user based coverage mapping. Furthermore, we are gradually releasing the data we have collected after anonymization, assisting research communities worldwide.

In parallel with context-awareness, healthcare has been a consistent highlight of my work. Pervasive health and biomedical sensors are an emerging field that will revolutionize healthcare. Biomedical sensors are not only an important source of context information, but provide cutting edge applications for mobile computing, pushing systems beyond their current limits and serving as benchmarks for system performance. Energy efficiency is often the bottleneck of such systems, affecting security, usability, and costs. My research addresses these challenges in a system wide and multidisciplinary manner. My research will increasingly focus on pervasive health because of its impact on computing systems and the society as a whole. In what follows, I present several health related highlights of my work.

I have led the design and implementation of the Rice Orbit Platform [18], an open source research platform for mobile and embedded computing. It includes ultra low power Bluetooth sensors based on the MSP430 microcontroller, and one or multiple sensors and analog inputs, e.g. an accelerometer, compass, gyroscope, and/or a thermometer. The Orbit platform has been extensively used for health applications and research. One example is our Orbit-ECG, an Electrocardiogram reporting application [19]. Energy consumption is a major bottleneck, and we showed that Context-for-Wireless can increase the battery lifetime of a smartphone by up to 40% for this application. Another example is our Dandelion software framework for wireless body sensor applications [20]. Dandelion is based upon the Orbit platform and provides platform-agnostic programming abstraction for in-sensor data processing.

My research has had real-world impact on multidisciplinary applications. For instance, my collaborators at the Abramson Center of The Methodist Hospital and I designed the Blue Box, an affordable biomedical measurement device for detecting and reporting chronic heart failures [21]. It uses the Orbit Platform design and our Context-for-Wireless energy saving techniques. The SenseBrush is another example developing in collaboration with UT Dental Branch. We have added sensors based on the Orbit Platform to a commercial electric toothbrush in order to create a smart toothbrush that senses how users brush their teeth. It can detect the location, time, and pressure of brushing. The data is automatically transferred to the user's phone and subsequently uploaded to a server for analysis. SenseBrush can provide feedback to users and dental experts alike, solving the current challenge of patients misrepresenting their brushing patterns. We hypothesize that SenseBrush can significantly improve that oral health.

In conclusion, my research interests leverage a multidisciplinary approach to enable novel breakthroughs. I have consistently been involved in high-impact, collaborative, and interdisciplinary research, working with experts in the medical, dental, computer video, and operating system areas. I have evaluated my research not only in theory, but by building complete systems and evaluating them through measurements and user studies in the lab and in the field. I am confident that my research career will not only have an impact in academic circles, but improve communities and human life as a whole.

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