**Topic: Energy Harvesting AI Enabled Wearables for Supporting the Well-Being of Marginalized Populations**

*Keywords: Energy Harvesting, Ubiquitous computing, Embedded and Cyber-physical systems, AI, HCI, Mobile Health, Accessibility.*

**Introduction/Motivation**

Access to power, connectivity, and proper healthcare are the fundamental resources people need to thrive in modern-day society. Smart devices are utilized to make one’s life simpler and enable independence, quick access to information, better decision making, and even safeguard life. Smart devices, such as wearables, are currently seen to be affordable only to those who live comfortably. Worse, lack of access to computing widens the existing chasm between the haves and have-nots. If we as a community want computing and the associated benefits to be available for all, we need to design useful computing devices that are affordable, durable, long-lasting, and reliable.

Building devices that fill this gap requires a fundamental rethinking of how we design smart devices.  Energy harvesting smart devices is a solution to fill the gap between using computing for social good to help marginalized populations because these devices are more affordable, low-powered, durable, and scalable due to their ability to harvest energy; eliminating the need for batteries. Batteries are one of the most expensive components in smart devices, take up the most space, and need to be replaced after a year or two, contributing to more pollutants that cripple our planet's climate change. These devices lose charge, requiring access to infrastructure like power that is not always guaranteed for those who live on the margins. Finally, device obsolescence requires replacing entire devices due to short battery lifetimes, an untenable requirement for many. Smart, energy harvesting devices could fill this gap. By harvesting energy from the sun, human motion, thermal gradients, RFID, or other energy sources, a device could last without a battery for decades. Enabling the use of smart, energy harvesting devices opens the opportunities to implement multiple sensors on a wearable that can help monitor vital signs, heart variability, and breathing volume that help improve one's health without the dependency of a battery. However, smart energy harvesting devices are hard to build because they are highly dynamic, resources are constrained, and the data they need to process is high speed and complex. Having relied on batteries since the inception of computing for a stable power supply, we would need to determine new ways to design these devices with energy harvesting in mind. We would need to research machine learning models, smart inference, and energy harvesting modalities to discover new ways to harvest energy. Marginalized populations would benefit from these energy-harvesting smart devices in many ways if they had access to them. For instance, a person who has diabetes that has limited access to healthcare providers may use an energy harvesting enabled Fitbit-like device that could be used not only for activity tracking but also for monitoring their vitals and insulin levels, reducing the need to seek care in person. Alternatively, a wearable camera, no larger than the size of a button, can be used with a Fitbit via BLE that turns on and records whenever a person's vitals go up and can potentially indicate if they are being harassed or racially profiled. Such a device would harvest energy from a user's motions and eliminate the need for a replacement since a battery is no longer needed. Furthermore, these devices can help address long term types of preventable health issues such as obesity, smoking, mental health, and respiratory problems, which has affected many as a result of COVID-19. I intend to push the field of energy harvesting to develop these devices that are intelligent and accessible for marginalized populations.

**Why Now?** Investing in energy harvesting AI enabled wearables for supporting the well-being of marginalized populations is important to address now  for three reasons: 1) energy harvesting technology has advanced to the point where it is able to be embedded in small devices, 2) developing battery-less technologies is inexpensive and more sustainable for the planet, and 3) making cheap and efficient devices allow resources to be made more accessible for marginalized populations, 4) due to the COVID-19 pandemic, poverty has risen; many people have lost their jobs and access to health insurance making it difficult to seek medical attention. People affected would need to have an alternative to monitor their symptoms before spending money on a hospital visit.

**Why Me?** Having grown up in a low-income household in East Los Angeles, where access to power, connectivity, and healthcare were limited, I know what problems need to be solved to address these issues and confidently believe that pushing for the development of these smart energy harvesting wearables would have a positive impact in my community. Particularly for immigrants who lack access to affordable healthcare, wearables can help them monitor their temperature making them aware of potential fevers, their heart variability which can notify them if any abnormal activity is happening, or a smart PPE mask that monitors their respiration if they work in hazardous conditions such as the field crops in California. For these reasons, I want to build, design, program, and deploy smart energy harvesting wearables. Given that I am in a Ph.D. program in a metropolitan city like Chicago where marginalized populations are high, have advisors that conduct research in energy harvesting and mobile health computing, and have previous experience in these areas of research, I believe I am the perfect candidate to carry out this research.

**Approach:** I intend to use high-performance, low power microcontrollers such as ARM MCU’s to build the hardware system design. I will use intermittent computing and checkpointing techniques to implement the energy harvesting assembly. For the A.I. portion of my proposal, I will experiment with sensor-assisted attention models for early-exit inference to reduce energy costs of communication and storage, accepting accuracy that is “good enough” rather than having nothing at all. Lastly, I would deploy my system on people to assess and ensure that they work. I anticipate that these technological advancements we develop for marginalized populations also help advance the future of computing by paving the way for low powered, battery-less, high performance interactive, human-centric applications and empower inclusivity from all backgrounds in the future of computing.

**Background**

The evolution of energy harvesting technologies, along with recent advancements in intermittent computing hardware and software interfaces [botoks, amulet,gobieski,2, zygard], have paved the way for the possibility of low power machine learning running on an energy harvesting system. Energy harvesting devices have emerged to be a feasible alternative to battery-powered devices, which are traditionally bulky, hazardous, and need replacement due their short life span. The most recent energy harvesting applications have consisted of a phone[cite], implantables[cite], machine learning[cite], have been deployed underwater[cite], and most recent in a battery-free Nintendo. Wearables, particularly for mobile health purposes, seem to be the next step in using energy harvesting. Though not necessarily battery-free, my PI’s work Amulet[cite] was the first smartwatch with a 9-month battery lifetime. I anticipate to continue the improvements of amulet and have it work in an energy harvesting platform with the capabilities of using AI [cite] to enable inference on intermittent sensor data.

However, having a dependency on volatile harvested energy causes battery-less energy harvesting sensors to fail intermittently, where frequent power failures occur. The main research challenge here is being able to “preserve the state of execution across power failures”[cite papers]. My PI’s work has revolved around addressing this problem by developing hardware platforms to support reliable intermittent computing[flicker,ink], language, and runtime support for preserving forward progress, and toolchains for program inspection and testing. It’s successor, BFree, mentioned below and with which I have had the honor to contribute, is the newest platform that I intend to use for prototyping these intermittent challenges.

**Preliminary Research**

Over the past year as a first-year Ph.D. student, I have been working on the intersection of mobile computing, human-computer interaction, and A.I. My research has focused, in one way or another, on marginalized populations. The goal of the BFree project is to democratize coding for everyone. The Smoking Topography project is intended to assist with the difficulties of smoking addiction. Lastly, Viz-IoT aims to inform the general public of who is screening them over in their homes. As I have been looking at different angles to utilize my position as a researcher to use computing for social good, the intersection of the projects I describe below has led me towards enabling energy harvesting smart devices to help underserved, marginalized communities.

A close up of text on a white background

Description automatically generated

***Battery-less computing:***

In the space of battery-less computing, I have worked in collaboration with colleagues at Northwestern University and researchers from Delft University of Technology to build BFree. BFree is the first general-purpose hardware platform for battery-free, energy harvesting devices that allows makers, hobbyists, and novice embedded programmers to develop battery-free applications using Python and hobbyist maker platforms such as Arduino and Circuit Python. This work was submitted and accepted with major revisions to Ubicomp/IMWUT 2021 conference.

***Smoking Topography wearable:***

A screenshot of a cell phone

Description automatically generatedCurrently, I am working with collaborators from Northwestern’s Habits Lab in the Feinberg School of Medicine Department of Preventative and Behavioral Medicine. I have developed a prototype for a wearable device that measures smoking topography, SmokeMon. SmokeMon is intended to be used as an alternative for current obtrusive non-wearable bulky devices that need people to smoke through to measure smoking topography. The novelty of this work is that it is a low cost, low powered device that uses a thermal heat sensor array to measure smoking topography passively and unobtrusively without interfering with the smoking behavior. We use machine learning to extract, examine, and interpret the sensor’s data. This work will soon be submitted to Ubicomp’s 2021 conference in November.

***Privacy and Security in Smart Homes:***

As more homes are becoming increasingly more instrumented with smart internet connected devices; be they voice assisted devices, smart tv’s, smart light bulbs, and other in-home appliances; the data these devices gather are not transparent to the user nor does the user know how their data is being used. To address these concerns and explore the feasibility of using Augmented Reality to inspect and monitor network traffic in the home I, along with collaborators from my lab, New York University, and the University of California, Riverside developed Viz-IoT. Viz-IoT is a network trafficking tool, usable on an iOS phone or tablet, that allows the user to inspect and explore the network traffic in a user’s home emanating from smart devices in real-time to help identify privacy leaks. This work will also soon be submitted to Ubicomp’s 2021 conference in November.

**Proposed research and evaluation**

Theme 1: reduce accuracy of inference to get any result versus no results at all, 80% versus none at all.

Theme 2: Use a dynamic set of sensor signals that let me skip machine learning algorithms to reduce and speed up machine learning algorithms.

Theme 3: make these accessible and feasible for them to be used as tools that help people with limited resources.

These are the foundational concepts that we can use to advance low power machine learning.

***How will you do it?***

*Will make hardware and software interfaces*

*Research innovations:*

*Train networks: big challenges in training, we would have to look at every sequence of the layer*

*Make an architecture that uses low power neural nets*

*Speed this up by using sensor assisted attention models*

*We can tune the sensor that we use to the application*

*Assume we build hardware platform from bfree and smokemon*

Sensor values to skip the expensive computational parts of an algorithm

*Explore real time sensor trigger/sensor assisting  machine learning where i define rules that find values that allow me to skip guess image sensing*

I am going to cheat with sensors signals and accept low accuracy

**Graduate Study Plan**

**Professional Development**

**Collaborations**

As mentioned before, I have had the opportunity to collaborate with researchers from Delft University and Northwestern’s Habits Lab in Feinberg’s department of Preventative medicine

**References:**

[1] Vamsi Talla, Bryce Kellogg, Shyamnath Gollakota, and Joshua R. Smith. 2017. Battery-Free Cellphone. Proc. ACM Interact. Mob.Wearable Ubiquitous Technol. 1, 2 (June 2017), 25:1–25:20.

[2] Alexei Colin, Emily Ruppel, and Brandon Lucia. 2018. A Reconfigurable Energy Storage Architecture for Energy-harvesting Devices. InProc. ASPLOS (March 24–28). ACM, Williamsburg, VA, USA, 767–781.

[3] Yunfei Ma, Zhihong Luo, Christoph Steiger, Giovanni Traverso, and Fadel Adib. 2018. Enabling Deep-Tissue Networking for Miniature Medical Devices. In Proc. SIGCOMM (Aug. 20–25). ACM, Budapest, Hungary, 417–431.

[4]Seulki Lee, Bashima Islam, Yubo Luo, and Shahriar Nirjon. 2019. Intermittent Learning: On-Device Machine Learning on Intermittently Powered System. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 3, 4 (Dec. 2019), 141:1–141:30.

[5] Josiah Hester and Jacob Sorber. 2017. The Future of Sensing is Batteryless, Intermittent, and Awesome. In Proc. SenSys (Nov. 6–8). ACM, [33] Josiah Hester and Jacob Sorber. 2019. Batteries not Included. XRDS: Crossroads, The ACM Magazine for Students 26, 1 (2019), 23–27.Delft, The Netherlands, 21:1–21:6.

[6] Brandon Lucia, Vignesh Balaji, Alexei Colin, Kiwan Maeng, and Emily Ruppel. 2017. Intermittent Computing: Challenges and Opportunities. In Proc. SNAPL (May 7–10). ACM, Alisomar, CA, USA, 8:1–8:14.

[7] Brandon Lucia and Benjamin Ransford. 2015. A simpler, Safer Programming and Execution Model for Intermittent Systems. In Proc. PLDI (Aug. 13–17). ACM, Portland, OR, USA, 575–585.

[8] Alexei Colin and Brandon Lucia. 2016. Chain: Tasks and Channels for Reliable Intermittent Programs. In Proc. OOPSLA (Oct. 30 – Nov.4). ACM, Amsterdam, The Netherlands, 514–530.

[9] Brandon Lucia and Benjamin Ransford. 2015. A simpler, Safer Programming and Execution Model for Intermittent Systems. In Proc. PLDI (Aug. 13–17). ACM, Portland, OR, USA, 575–585.

[10] Kiwan Maeng, Alexei Colin, and Brandon Lucia. 2017. Alpaca: Intermittent Execution without Checkpoints. In Proc. OOPSLA (Oct. 22–27). ACM, Vancouver, BC, Canada, 96:1–96:30.

[11] Kasım Sinan Yıldırım, Amjad Yousef Majid, Dimitris Patoukas, Koen Schaper, Przemysław Pawełczak, and Josiah Hester. 2018. InK: Reactive kernel for tiny batteryless sensors. In Proc. SenSys (Nov. 4–7). ACM, Shenzhen, China, 41–53.

[12] Jasper de Winkel, Carlo Delle Donne, Kasım Sinan Yıldırım, Przemysław Pawełczak, and Josiah Hester. 2020. Reliable Timekeeping for IntermittentComputing.InProc.ASPLOS(March16–20).ACM,Lausanne,Switzerland,53âAS ̧–67.

[13] Graham Gobieski, Nathan Beckmann, and Brandon Lucia. 2018. Intermittent Deep Neural Network Inference. SysML (2018).

[14] Graham Gobieski, Brandon Lucia, and Nathan Beckmann. 2019. Intelligence Beyond the Edge: Inference on Intermittent Embedded Systems. In Proceedings of the Twenty-Fourth International Conference on Architectural Support for Programming Languages and Operating Systems. ACM, 199–213.

[15] Benjamin Ransford, Jacob Sorber, and Kevin Fu. 2011. Mementos: System Support for Long-running Computation on RFID-scale Devices. In Proc. ASPLOS (March 5–11). ACM, Newport Beach, CA, USA, 159–170.

[16] Jethro Tan, Przemysław Pawełczak, Aaron Parks, and Joshua R. Smith. 2016. Wisent: Robust Downstream Communication and Storage for Computational RFIDs. In Proc. INFOCOM (April 10–15). IEEE, San Francisco, CA, USA, 1–9.

[17 ]Surat Teerapittayanon, Bradley McDanel, and Hsiang-Tsung Kung. 2016. Branchynet: Fast inference via early exiting from deep neural networks. In 2016 23rd International Conference on Pattern Recognition (ICPR). IEEE, 2464–2469.