The Need for Equitable Systems Design: Lessons Learned From A Co-design Study with Low-Income Communities

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ABSTRACT

In this work, we call for careful consideration of the need for equitable systems design. Our work so far has involved co-designing wearables with members of low-income communities. From this experience, we have identified significant themes and lessons learned. We discuss how the computing systems community can play a key role in addressing low-income communities' challenges, such as lack of access to equitable health, safety, and environmental infrastructures through intelligent, ultra-low power, and battery-free system architectures.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; *Ubiquitous and mobile computing systems and tools.*

KEYWORDS

Inclusive wearables, Equitable System Design, Inclusive System Design, Sustainable Computing,Ultra Low Power Computing, Batteryless computing, Safety

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1 PROBLEM STATEMENT

Innovations in wearable computing has enabled our abilities to gather rich data from on-body computations to monitor our health, track behaviors, and stay connected. Unfortunately, the high cost and disregard for the needs of low-income racially minoritized communities make wearable devices inaccessible, unusable, and even harmful for these individuals in marginalized groups. Marginalized groups face additional barriers and systemic structures of oppression, and excluding them from the design of technology further marginalizes these groups of their use [8, 12, 14].

To initiate the development of designing more inclusive and equitable wearables, we conducted a qualitative study with nineteen participants from minority low-income communities in two major urban cities - Chicago and Los Angeles. Our research questions were to 1) understand how members of low-income communities perceive wearable devices and 2) understand the barriers and facilitators toward adoption. To avoid conflating our findings from this large study, we have published two separate papers one that focuses on community safety and the other on health.

In our work, Equityware [10], our findings show that safety is a critical issue among participants. Unfortunately, current wearable technologies on the market centered on safety do not meet the needs of participants because they are too pricey, flashy, have poor battery-life, too intrusive or do not take into consideration the dangerous locations in which participants live in.

In our soon to be available publication [9], we show that as a result of the COVID-19 pandemic, members of low-income communities have an increasing interest in adopting wearable health tools as a means of monitoring vital health signals. This trend was attributed to lack of access to proper healthcare and a distrust in the healthcare system. Further, we bring attention to the harmful effects of current wearables on low-income racially minoritized communities (such as participants in our study). Specifically, we discuss the issue of hardware and software level bias in PPG sensors that has shown discriminatory effects against individuals with darker skin tones.[7].

For the rest of this workshop paper, we discuss our methods and summarize our findings relevant to computing systems and the computer architecture community. Then, we discuss our work in progress that sheds light on the negative environmental impacts participants continue to face and how we aim to engage in co-designing computing systems with members of marginalized communities to imagine sustainable futures for them and their communities. We discuss our Equityware research agenda and distill avenues on how the computer systems community can help enact this research agenda through inclusive, sustainable computing, emphasizing ultra-low power computing architectures, embedded AI, and battery-less computing. Finally, we end with the importance

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ID: Gender	Age Range	Education	Income Range	# of Persons in Household	Owns Wearables
P1: F	18-29	Bachelors	<26K	3+	No
P2: M	18-29	Two year / some college	<26K	1	No
P3: F	18-29	Two year / some college	26-50K	2	Apple Watch
P4: M	18-29	Bachelors	26-50K	2	Apple Watch
P5: F	30-44	High School	26-50K	2	Samsung Galaxy Watch
P6: F	30-44	Bachelors	<26K	1	No
P7: M	18-29	Bachelors	26-50K	1	No
P8: M	18-29	Bachelors	26-50K	1	No
P9: F	30-44	Two year / some college	26-50K	2	No
P10: F	18-29	High School	<26K	1	No
P11: F	18-29	Bachelors	26-50K	3+	Apple Watch
P12: F	18-29	Two year / some college	<26K	1	Apple Watch
P13: F	18-29	Two year / some college	<26K	2	No
P14: F	18-29	Bachelors	<26K	1	No
P15: M	30-44	Two year / some college	50-75K	2	No
P16: F	30-44	Two year / some college	50-75K	3+	No
P17: F	45-54	Two year / some college	50-75K	2	Fitbit (previously)
P18: F	30-44	Bachelors	26-50K	3+	Apple Watch
P19: F	18-29	High School	26-50K	1	Fitbit (previously)

Table 1: Participant demographics. All participants belong to Hispanic/Latinx groups.

and value of engaging and co-designing computing systems with members of marginalized groups.

2 METHODS

Between December 2021 and March 2022, we performed an exploratory study to understand the needs of low-income communities that influence the adoption and use of wearable devices. We conducted a series of semi-structured interviews with 19 participants who are members of low-income communities from two metropolitan cities (Los Angeles and Chicago). Table 1 shows particpants demographics.

A total of Nineteen semi-structured interviews were performed. Interviews took place in two parts; the first session focused on community members' general perspectives on wearables. Although safety, health, and the impacts of COVID-19 on the community were not a specific focus of the study procedure, it became a major focus of the discussion initiated and led by participants. This led to a second round of data collection with new participants focusing on their perspectives and recommendations on saafety and health wearables. This study was conducted from December 2021 to March 2022. Due to the COVID-19 Omicron variant, all interviews were conducted in English over a Zoom video call.

Audio recordings of the interviews were transcribed, resulting in 21 hours of interviews. The data was analyzed using a grounded theory approach, following the methods defined by Charmaz and Belgrave [18]. The lead author and two of the co-authors performed open coding on the transcripts and identified initial themes. The research team then reviewed the transcripts and collaboratively discussed associated codes to look for consistencies and differences in the data. Based on group discussions, themes were iteratively refined by the research team.

3 FINDINGS

In this section we highlight and summarize the high level themes from our published work centered on safety and health. We then discuss our findings on negative environmental impacts community members mentioned in conversation and how this led to our work in progress in co-designing computing systems and practices with marginalized communities to imagine sustainable futures that will empower and allow them and their communities to thrive as climate change continues to threaten their ways of living.

3.1 Safety

3.1.1 Major Themes Centered On Safety. In our work Equityware[10], addressing safety concerns was the most critical issue amongst our participants. Every participant discussed safety issues within their community, recalling many instances where crime and violence affected their lives. The main safety concerns were gang- and gender-based violence and lack of infrastructure and services (i.e. lack of lighting in underprivileged neighborhoods and distrust in local authorities). The following is a quote from a participant:

> *"I think more women would wear wearables for safety reasons since women are mostly targets of [violence], especially when we're out alone.*

Through our discussions, we found that there is a strong interest in using wearables to address these daily safety concerns, but the available technologies on the market are not cutting it. Currently, there are no existing tools that address the safety concerns of community members nor do the design and features of current wearables meet their needs. This leads to us to question, what are the limitations and harms of current wearable devices? Though we identified six critical barriers that lower the adoption of wearables, we will only focus on power unavailability. We encourage those interested in learning more about our findings to read our work.

3.1.2 Critical Barrier: Power Unavailability. Access to stable power and the ability to charge a wearable device was a critical barrier for participants. Participants mentioned they face multiple power outages in their neighborhoods throughout the year, leading to much lower adoption of wearable technology due to the inability to charge a wearable device consistently. Even when power is available, outlets and charging may not be available due to crowded housing. Hence a question to the computing systems field is, **how do we design around the environmental constraints that individuals from marginalized communities face?** Designing around these resource constraints, such as limited power availability, requires a fundamental rethinking of how the computer architectures of wearable systems are developed. We discuss possible solutions to address this issue in future work

3.2 Health

3.2.1 Major Themes Centered on Health. In our most recent work [9] we identified four main themes: How COVID-19 increased interest in personal health monitoring through wearables for health, Barriers to healthcare resources, Distrust in health care infrastructure and systems, and Community-based technical requirements. Every participant associated wearables with their immediate needs that affected them and their communities during the COVID-19 pandemic. In this workshop paper, however, we will only focus on the findings of "How COVID-19 changed community's members' interest in physiological measures and wearables for health".

All participants mentioned in conversations that they wanted to use wearables to measure and manage physiological signals, especially at the height of the pandemic which was around the time when this study took place. At the time of the study: 14/19

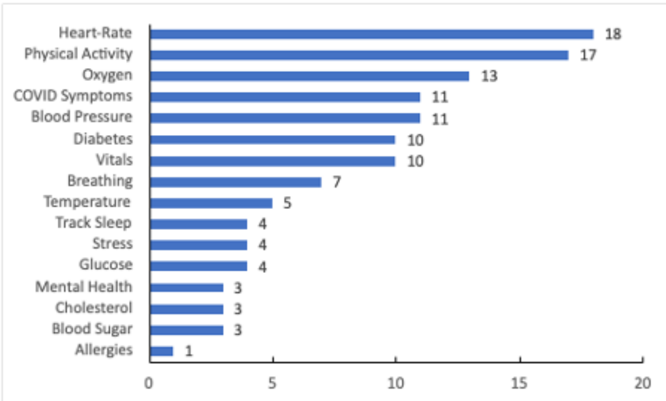

Figure 1: Signals participants (N=19) want to capture through wearable sensors

had been infected by COVID, 7/19 were experiencing long term COVID symptoms, and 13/19 lost direct family members to COVID. Participants shared that for the first time they are considering how valuable health data, such as monitoring their oxygen levels, could be helpful. One participant said the following:

> *"I guess the one thing that scares me that I never even thought of until I got COVID were my oxygen levels. Like am I at normal levels? Is that an issue that I need to kind of think about, you know?"*

Coping with lasting health effects of the COVID-19 pandemic resulted in a newfound interest in tools that provide participants with a greater ability to monitor their health in real-time on and their own terms. Figure 1 shows the most common health signals participants want to capture through wearables. The major takeaway from this finding is that members of low-income communities are seeking alternative healthcare solutions through wearables. Despite participants' desire to utilize wearable technology, current wearables are not designed to meet participant needs. Significant challenges in current wearables are that there exists bias in the hardware/software system stack , they are not durable and affordable, and are privacy-invasive. In this workshop paper, we will only focus on how bias in the hardware/software system stack is actively harmful to members of racially minoritized communities, such as our participants.

3.2.2 Critical Barrier: Bias In The Hardware and Software System Stack. From Figure 1, we see that participants' top three health metrics to monitor were heart rate, physical activity, and oxygen levels. However, a critical limitation of current commercial wearables is that the PPG sensors embedded in these devices and the signal processing methods used to measure physiological signals such as heart rate, blood oxygen levels, and physical activity do not work well on people with darker skin tones [7]. To address this issue there is a need for hardware systems research to develop new embedded electronic sensors in mHealth and clinical tools that do not perpetuate racial disparities. Additionally, the signal processing, machine learning, and high-level algorithmic approach to prediction from these sensors must be considered at the software level. It is imperative that software and firmware developers of wearable computing systems ensure that the algorithms they deploy to capture data from biomedical sensors do not perpetuate racial harms. We discuss possible solutions in Future Work

3.3 Work in Progress: Addressing Environmental Impacts on Marginalized Communities

Our study revealed significant health challenges community members face(e.g., cancer, asthma, and other respiratory issues) caused by environmental factors. One participant shared the following:

> *"The smog from the factories and congested freeways is the worst, especially when the smog is super heavy. It's not uncommon to find a lot of people in the area that have asthma. A lot of my neighbors that are still living here for 30+ years are now suddenly having cancer. Different forms of cancer. It's not uncommon to hear that's this neighbor got cancer here or that neighbor got cancer there'. So that's something we really struggle with."*

Participants (N=7) from both cities (Los Angeles and Chicago) echoed this participants quote. The negative environmental impacts on marginalized communities not only affect the air quality they breathe, but also have detrimental effects on their quality of life. The preliminary results of our study have inspired us to perform another round of data collection with a focus on co-designing computing systems with members of marginalized groups to imagine sustainable future technologies. Through focus groups and storytelling through storyboards, we aim to show how sustainable computing systems (i.e., interactive energy harvesting intermittent computing devices and sensor motes) are designed and how they can be deployed and maintained for long periods of time. We intend to elicit recommendations from participants on how they would feel most comfortable introducing these technologies in their communities, understand what is acceptable or unacceptable practices, and if they feel sustainable computing technologies can promote sustainable practices that can help mitigate the adverse effects of climate change and environmental injustices.

4 FUTURE WORK: SETTING THE EQUITYWARE RESEARCH AGENDA

Based on the findings laid out in our papers focused on health and safety, we believe these community-focused collaborations can greatly change the landscape of wearable devices for minoriized low-income communities. In [10] we set a research agenda we term 'Equityware', focused on the equitable democratization of computing technologies by co-designing inclusive technologies with and for marginalized communities. While we intend to focus their research on wearable technologies, the principles and concepts of Equityware must broadly expand to other branches of computing research to ensure an equitable future. We highlight opportunities for HCI, Ubicomp, and Computing Systems researchers to collaborate and contribute at three levels: hardware, software, and research

& education. In this workshop paper we will only focus and discuss how the computing systems community can contribute in this space at the hardware and software levels.

4.1 Possible Solutions in Hardware

Involving marginalized groups in the design process of future computing technologies helps to highlight diverse perspectives and address specific needs. For instance in regards to power availability, we found that even though participants live in a highly developed country, they and their communities face multiple power outages throughout the year. We asked the question: how do we design around the environmental constraints that individuals from low- SES communities face? Designing around these resource constraints, such as limited power availability, requires a fundamental rethinking of how wearable computing systems are developed. Possible solutions to address these resource constraints include developing computing hardware architectures that require little power or no power. This approach will help reduce power consumption in future wearable technologies and pave the way for energy harvesting applications. It may also enable battery-less environmental sensing capabilities, like designing and deploying sensor motes capable of measuring pollutants in the air in communities affected by heavy smog. We call for the computer systems community to push for sustainable computing practices through energy harvesting and intermittent computing methods.

Additionally, instead of building expensive, high-performance wearable computing devices with multi-core CPUs and graphics processors that have short battery lifetimes, we could opt for low-performance and low-cost MCUs. While these MCUs may not be capable of running power-hungry ML models, they can effectively process smaller models that provide valuable information about health metrics most useful to members of low-income communities, or they may be able to run small sound classification models in a safety wearable device. Current MCU architectures aimed to promote embedded AI capabilities face several resource constraints such as having small flash memory where ML model firmware needs to be flashed directly on the chip. This issue makes models less dynamic in practice. We call for the need to design edge cloud architectures that foster ML model adaptability, enabling real-time inference tailored to user-specific needs. These needs may encompass prioritizing privacy awareness, recognizing individuals' contextual and cultural perspectives, while also ensuring energy efficiency.

4.2 Possible Solutions in Software

Our findings centered on health has shown the glaring need to design wearable computing technologies from that center the needs of marginalized groups. Our paper and other works in the literature [1, 4, 5, 7, 13, 15] show the harmful effects PPG sensor can have on individuals with darker skin tones and how this has adverse affects on members of racially minoritized low-income communites, such as all of our participants, who are vastly over respresented in Black and Brown low-income communities [11]. While this example is compelling, fixing individual sensors or components to be less biased is not enough. The signal processing, machine learning, and high-level algorithmic approach to prediction from these sensors must be considered at the software level. Software mitigations for poor sensor resolution and precision are commonplace in critical systems– similar approaches are needed here. Wearable devices have the potential to perpetuate racial bias unless addressed. Many machine learning approaches to things like recidivism prediction for parolees [2], mortgage loans [3] and facial recognition [6], have already proven that without care and attention in their design and training, these software systems perpetuate racial discrimination amongst racially minoritized individuals. It is imperative that software and firmware developers of wearables ensure that the algorithms they deploy to capture data from biomedical sensors do perpetuate these racial harms.

5 CONCLUSION

Engaging in Co-design with marginalized communities helps bring diverse perspectives to light. It provides an understanding of how current computing systems can harm communities that are ignored in the technological design process and how the computing research community can do better. In this work, we summarize our findings and lessons learned from a Co-design study with members of low-income communities in two urban cities. We introduce our Equityware research agenda and provide possible solutions for how the computer systems and computer architecture community can contribute to helping to design socially responsible system design.

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