RAWAN ALHARBI | RESEARCH STATEMENT

The main goal of my research is to enable a sustainable future for wearable systems. I work at the intersection of **human-computer interaction**, **systems**, and **machine learning**, exploring how to develop intelligent, efficient, and responsible wearable systems that can *sustain* their efficacy as they integrate into everyday life. Wearable systems present the opportunity to understand and improve countless aspects of people's lives, including healthcare, education, and accessibility. Advancements in microcontrollers, along with their supporting tools and communities, have enabled the rapid building of many potentially helpful wearable systems. However, the integration of these wearable systems in everyday life is challenging, limiting their efficacy. Some roadblocks occur at societal (e.g., abandonment due to privacy concerns) or technical levels (e.g., inaccurate models due to the shortage in labeled data). Because these social and technical spheres often collide and interact, it is important to consider these factors simultaneously. In my research, I investigate and tackle challenges using a multidisciplinary lens that considers the tradeoffs within the technical divides between systems and ML research across various societal values. I believe that to improve wearable systems, we need to foreground moments of error, fragility, and failure. Through these ongoing tensions, a sustainable future for wearable systems and related aspects of ubiquitous computing can be imagined and built.

My research approach is multidisciplinary and consists of several phases. I (1) use qualitative and quantitative methods to identify and understand emerging issues preventing wearables from realizing their full potential. Then, I (2) re-imagine, build, and deploy practical and efficient systems by investigating the privacy, energy, burden, and information tradeoffs. I (3) collaborate with scholars in fields beyond Computing that benefit from using wearable systems– this aid my understanding of the messiness of wearable systems outside of the lab and as they integrate into people's lives. Currently, I closely collaborated with researchers at Northwestern's Department of Preventive Medicine interested in using wearable systems to understand and promote positive behavior change. In my dissertation research, I have used this approach to **design visual wearable systems that preserve privacy and enable efficient visual data collection and processing without compromising utility and energy.** My work has been published in top-tier Computer Science conferences (UbiComp/IMWUT, ISWC, PerCom) and presented in Behavioral Science conferences (Obesity and Society of Behavioral Medicine). In recognition of the significance of my work, I have been selected for the Rising Stars in EECS 2020.

RE-IMAGINING WEARABLE VISUAL SYSTEMS

Wearable visual systems, such as ego-centric wearable cameras, have failed to integrate into everyday life. We have witnessed the abandonment of wearable visual systems as consumer devices (e.g., Google Glass) and as research tools (e.g., SenseCam). While it is natural for some technologies to die out, **visual wearable systems are indispensable tools that advance the entire field of context-aware wearables**. Particularly, visual wearable systems can push the domain forward by (1) enabling interactive application that needs access to visual data and by (2) acting as a sense-making tool that helps in contextualizing data collected with other wearables that use non-visual sensors (e.g., accelerometers), allowing for further granularity in data set creation and improving the accuracy of data annotations used in machine learning-based model training and validation.

Both **technical and societal challenges** lead to the abandonment of wearable cameras. First, there are substantive privacy concerns and stigma around wearing cameras. Even when privacy measures are in place, many people refuse to wear them because they are regarded as invasive tools that cause discomfort, especially to bystanders. Second, it is hard to process images captured by wearable cameras. Performing typical image capturing and processing tasks requires significant computational and energy resources, making it impractical to develop potential methods that can truly enhance the privacy of these devices.

My work addresses these challenges by (1) providing a framework that helps in understanding and manipulating design factors to reduce privacy and stigma concerns, (2) developing a practical obfuscation method to enhance privacy in visual data collection while maintaining utility, (3) building novel and efficient dual-imaging visual systems enables practical data collection and processing, (4) investigating and building alternatives to light-based visual systems that can provide rich enough information for many human-centered applications without sacrificing privacy, efficiency or energy. By centering visual systems and addressing the ongoing tensions, my work paves the way for a sustainable future for both visual and non-visual wearable systems.

Reducing Discomfort and Enhancing Privacy of Wearable Visual Systems

Ego-centric wearable cameras, with a front-facing lens, are the most used wearable visual system. They are designed to capture the gaze or the view of the wearer, which explains the positioning of the camera to maximize general data capture. My work shows how by moving away from ego-centric framing to an activity-oriented framing— designed to capture a set of defined activities of interest— we can reduce the discomfort in wearing a camera by reducing privacy and stigma concerns. Specifically, I show how an activity-oriented framework helps us manipulate factors in the design of the wearable camera and modify the data collection process to reduce discomfort, enhance privacy and increase wearability while maintaining their utility in capturing fine-grained information about the wearer's activity.

Investigating recording affordances in activity-oriented wearable cameras. The design and the location of the wearable on the body can affect its acceptability and comfort. This inspired me to further investigate and unpack the effect of simple affordances in wearable cameras, such as lens location and orientation, on the comfort of wearing them. By analyzing data obtained from semi-structured in-field experiments and interviews, my work [1] introduces a conceptual model that explains data and device factors influencing the discomfort of wearable cameras. The model emphasizes the importance of matching both the device recording affordances (i.e., lens location and orientation) and data factor with the intention of recording. It explains the failure and inability of ego-centric cameras to reduce discomfort even when data privacy measures (e.g., blurring faces) are implemented. Such measures cannot be directly perceived by bystanders looking at a device with a lens directed at them. Changing the design of the wearable camera from the ego-centric position to an activity-oriented design allows us to implicitly communicate the intention or scope of the recording (Fig.1). In addition to the conceptual model, this research provides design recommendations to minimize discomfort in wearable cameras designed to enable human-centered applications.

Enhancing privacy by activity-oriented obfuscation. Computer vision obfuscation methods are used to limit the information collected from wearable cameras, which can significantly impact the privacy concerns of wearers and bystanders. However, when dealing with complex video data collected under various everyday contexts, it is difficult to define what regions should be obfuscated. My work [2] introduces and defines Activity-Oriented Obfuscation, a privacy-by-default approach that obfuscates all pixels except those surrounding the wearer's activity of interest (Fig.2). I analyzed the privacy-utility tradeoff of activity-oriented obfuscation using different image transformations. The utility here is defined as the image utility in preserving information about the wearer's hand-related activities, while privacy is defined as the bystander perceived privacy concerns. I have conducted an experiment to evaluate the effect of activity-oriented obfuscation on bystander privacy and visual confirmation utility for machine learning applications. Results show that activity-oriented partial obfuscation has the potential to significantly reduce privacy concerns while maintaining utility, even when extreme obfuscation filters are applied.

***Fig.1** Lens location and orientation can reduce the discomfort of wearable cameras by implicitly communicating the intention or scope of the recording to the bystanders.*

***Fig.1** Activity-Oriented Obfuscation* is *a privacy-by-default approach that obfuscates all pixels except those surrounding the wearer's activity of interest.*

Efficient Extracting and Processing of Wearable Visual Data

Although advancement in deep learning has improved our ability to process visual data, extracting relevant information from the enormous and challenging datasets produced by visual wearable systems remains impractical. I have shown that using low-resolution thermal imagers as a complementary data source aids in the fast, efficient processing of massive amounts of wearable visual data. The motivation behind investigating thermal cameras is that humans constantly emit thermal energy, making thermal an ideal sensing modality for human-centered applications.

Utilizing low-resolution thermal in extracting foreground information from RGB cameras. Using thermal as a second modality provides information that augments and complements RGB cameras' data. For example, RGB images are greatly affected by scene illumination, occlusion, and object positioning. In contrast, scene illumination does not affect thermal images, meaning that a thermal image obtained in the dark will look the same as a thermal image captured in a well-lit environment. My work presents ActiSight [3] (Fig.3), a practical, all-day battery-lifetime wearable camera platform that uses thermal imaging as a complementary data stream to extract pixels related to the wearer in a frame, reducing the captured information and simplifying processing tasks. This hardware platform is coupled with an energy-efficient pipeline for speeding up wearer extraction tasks (i.e., pixels related to the wearer's head and hands), a fundamental task of modern and future wearable video capture. Through real-world deployment, I show that the wearer foreground extracted with ActiSight achieves a high dice similarity score compared to state-of-the-art while significantly lowering execution time and energy cost. Currently, I am investigating the utility of thermal in improving the speed and accuracy of hand and object predictions to enable practical hand-based applications.

Investigating low-resolution thermal for human activity recognition. Low-resolution thermal sensors capture a rich stream of thermal, temporal, and spatial information about the wearer and their surrounding objects that can be used to model and detect human activity. HeatSight [4] (Fig.4), is a chest-worn wearable that I have developed to enable low-power omni sensing that tracks multiple parts of the wearer's body. Unlike RGB imagers, thermal sensors' field of view (FoV) cannot be easily changed using optical fish-eye lenses. In HeatSight, I enable a greater FoV by extracting and stitching thermal images obtained from five low-power thermal sensors positioned to offer a 180∘ FoV. To address the FoV-energy tradeoff, I developed a triggering mechanism that dynamically turns on and off thermal sensors as the hand and objects move in front of the sensors. Additionally, in SmokeMon [5] (Fig.5), I use low-resolution thermal sensors to unobtrusively measure smoking topography (i.e., puffing behavior, including measures of the number of puffs, puff volume, puff duration, and inter-puff interval). Knowing such measures can help in assessing and designing personalized smoking cessation interventions. Through real-world deployment, my work demonstrates how low-resolution thermal images coupled with efficient machine learning models enable accurate, all-day tracking of smoking and puffing behavior that people are willing to wear.

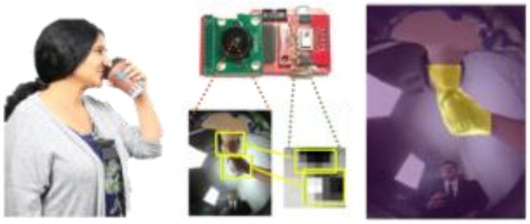

***Fig.3** ActiSight [3] is a practical wearable camera platform that uses thermal imaging as a complementary data stream to extract pixels related to the wearer.*

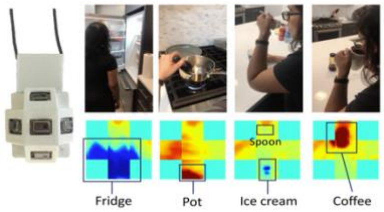

***Fig.4** HeatSight [4] is a chest-worn wearable enabling low-power omni sensing for human activity detection.*

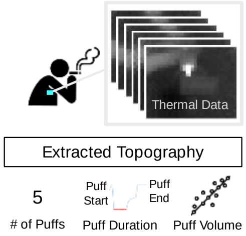

***Fig.5**. SmokeMon [5] measures fine-grained puffing behavior unobtrusively.*

FUTURE RESEARCH AGENDA

My long-term research goal is to continue developing strategies for a sustainable future for wearable systems, where wearables can integrate into our everyday life for the benefit of society. My Ph.D. work has focused on re-imagining visual systems as it is a generative start towards integrating more systems, including non-visual wearables, and serving various applications. I believe this is a step toward an extensive and exciting field that focuses on developing wearables that are long-lived, accurate, and account for human values. The following research questions are core to achieving a sustainable future for intelligent, efficient, and responsible wearable systems.

What new systems and methods enable the creation of *intelligent* wearables? Datasets are essential to the building and verification of machine learning models. Unfortunately, there is a lack of representative human activity datasets because it is challenging to collect and annotate sensor data obtained in natural settings. Systems like ActSight [3] enable the deployment of practical wearable cameras as a ground truth device, which helps create fine-grained labeled datasets for visual and non-visual wearable sensors. In fact, my work served as the basis of multiple NIH grants related to obtaining representative everyday datasets that help in building and validating wearables used to model eating behavior. To further advance the benefit of ActSight in creating labeled datasets, I plan to develop active learning methods that use thermal and RGB data to ease the data annotation task. I also aim to explore the power of generative deep learning models and simulation engines to synthesize activities of everyday living from data collected both inside and outside the lab. By focusing on the challenges of datasets creation and labeling, I aim to enable public human activity datasets for the community that will help in creating more intelligent wearable systems.

What new hardware and software can aid in creating *efficient* wearables? Computing on small, untethered, and resource-constrained devices is difficult. If wearables are not designed efficiently, we will end up with short-lived systems that require continuous charging. To make the wearable efficient, developers must pay attention to multiple levels, including the choice of hardware, implementation decisions for data acquisition and processing, and power sources. In my work [3,4,5], I have demonstrated how efficient wearables can be built by rethinking the types of sensing modality used, showing the potential of low-resolution thermal in wearables applications. Moving forward, I plan to experiment with creating novel low-power sensing opportunities and energy-harvesting methods for wearables through collaborating with researchers specializing in bioengineering and material science. Moreover, while there are general microcontrollers kits that have enabled prototyping of many sensor-based applications, they do not offer the required hardware and software to enable efficient long-term deployment needed in wearables. I see the benefit in developing hardware and software that can aid in the development of efficient wearables for the community.

What processes and frameworks can ensure the development of *responsible* wearables? Responsible systems should be transparent, accountable, and inclusive. Wearables are not technological advances that exist in a vacuum. They have a tremendous material effect on people, and therefore they should be developed, deployed, and maintained responsibly. The main reason why I wanted to re-imagine visual wearable systems is to increase the transparency of models, make them accountable to human values such as privacy, and foster inclusivity by developing methods that allow people with various infrastructures to process visual data. Moving forward, I intend to continue developing responsible systems by understanding the current and future use, non-use, and misuse of wearables. Moreover, I plan to increase my collaboration effort to include people beyond researchers to democratize the future of wearables by directly working with stakeholders to enable community-driven wearable solutions.

What new applications can intelligent, efficient, and responsible wearable enable? Developing useful real-world applications for wearables is essential for my research. It allows me to understand the challenges of sustaining wearables efficacy as they integrate into people's lives. I aim to continue working with researchers in medicine and public health to develop wearables that can improve people's healthcare and well-being. Wearable technologies also have applications in other domains that seek to understand human behavior in real-world contexts, such as child development and learning sciences. I am also interested in exploring the application of wearables as an interactive assistive technology to augment people's ability and aid in their everyday tasks. Overall, I am excited to explore new avenues and applications where wearables might be helpful in empowering people.

REFERENCES

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