We approach a future where sensing devices anticipate our needs and monitor our health to improve our quality of life. However, incidents of mishandled data have raised privacy concerns and hindered the adoption of information-rich sensors (e.g., microphones, cameras) in the areas where they are most needed. For example, falls in bedrooms and bathrooms are the leading cause of death among the elderly (38k/yr in the US [5]). Yet, cameras, while incredibly capable for fall detection, are not widely accepted by users as an intervention. Thus, despite technology's advancing capability for critical tasks, users' unmet privacy needs have limited the adoption of many innovative solutions.

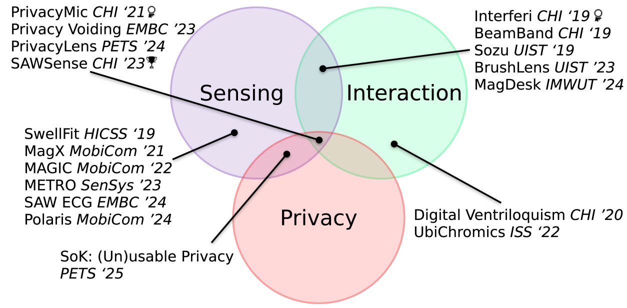

Figure 1: My research blends three areas to create devices that protect user privacy and support ubiquitous sensing applications.

A confounding factor, identified through my Systematization of Knowledge (SoK) work [8], is a research gap between sensing and usable privacy such that user-centric privacy mitigations are not often part of the design of sensing systems. In cases where usable privacy *is* considered, it is often after potentially private data has already been recorded, rather than at the device level to preempt its capture. To fill this gap, my work draws on three research areas (Figure 1): privacy, to understand user privacy needs and incorporate novel privacy-preserving measures; human-computer interaction, to identify user application needs and create interfaces that form trust; and sensing, to create sensing devices that meet both privacy and application needs.

Specifically, **I incorporate Privacy by Design (PbD) principles at the device level to create sensors that provide user privacy guarantees while supporting valuable interactive and ubiquitous sensing applications**. My research takes a unique approach by embedding PbD directly into the sensor hardware rather than relying solely on system-level privacy solutions or sanitization after the fact. This shift makes privacy a first-class consideration and allows for a preemptive privacy guarantee: sensitive data, such as speech or personal imagery, is *never recorded in the first place*. I have applied this approach to design novel sensors as a part of responsible AI-based systems in three distinct areas:

1) **privacy-aware microphones** that remove speech (or all audible content) and use ultrasound to outperform traditional microphones in event recognition and, as shown through its first in-home deployment study, can achieve equivalent on-device kidney health monitoring performance without any audible frequencies;
2) **privacy-aware cameras** that can remove persons from images entirely on-device, thus sanitizing images of personally identifiable information (PII), while supporting critical ML/CV applications, such as exercise tracking, activity recognition, and fall detection, without incurring a loss in application performance;
3) **novel privacy-aware sensing methods** that inherently reject sensitive information—rather than sanitize information—and only selectively capture alternative "safe" signals; for example, surface acoustic waves can track activities of daily living in the home or construct ECG signals from a single-point on the body.

These device-level privacy solutions are intended to work hand-in-hand with system-level security measures. This dual approach strengthens the privacy ecosystem from both ends and ensures a minimum guarantee of privacy, making users more willing to adopt these sensors and greatly increasing the real-world impact of ubiquitous sensing in the home and beyond. As data privacy laws are enacted (e.g., CPRA, GDPR), sensors' data collection behavior carries increasing liability risks and furthers an imperative to consider this approach.

Thus far, my research has led to 20 publications [1, 3, 4, 6–18, 20–23], a CSE Graduate Honors Competition Award, a Best Paper [13] (top 1%) and 2 Honorable Mention Awards [7, 12] (top 5%) at CHI, and is generously supported by the Meta PhD Research and Rackham Fellowships. In the short term, my work has shown early impact using privacy-aware approaches for health sensing [3, 17] and in-home activity recognition [7, 11, 13] for tracking Activities of Daily Living (ADLs), a valuable measure for monitoring chronic health conditions. **In the long term, privacy-aware sensing research will have a broad impact on policy (e.g., laws on how devices handle and secure sensitive user data), user trust and expectations, and the development and use of responsible AI sensing systems for privacy-sensitive contexts—ultimately leading to greater adoption by users seeking assurances of privacy in their internet-connected sensing devices.**

Area 1: Privacy-Aware Microphones for Acoustic Activity Recognition

Microphones are among the most ubiquitous sensors today, enabling a wide variety of tasks ranging from interactive applications to health monitoring. However, concerns about continuous audio recording—given incidents of mishandled data or leaked conversations—have made users hesitant to permit such recordings.

Since speech content is often unnecessary for many activity recognition tasks, we can design devices that filter out the frequency bands that contain speech—effectively removing conversations from recorded audio—to improve user privacy. However, eliminating these speech frequencies from traditional microphones, which are optimized for the human hearing range, significantly reduces recognition performance from 89.9% to 50.5% [7]. PrivacyMic addresses this issue by leveraging *inaudible* ultrasound signals, which exist beyond the human hearing range, to compensate for the removed speech frequencies.

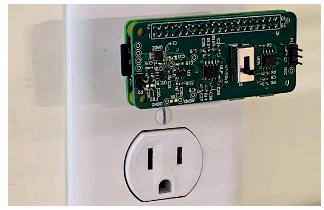

Figure 2: PrivacyMic's IoT form factor can support numerous privacy-aware acoustic tasks.

PrivacyMic: Outside of human hearing, the frequency bands with the highest feature importance (i.e., value for classification performance) are often in the ultrasonic range. The richness of ultrasound often comes from the electronic components in everyday devices that have been tuned to operate at inaudible frequencies. In our evaluation, all of the daily-use objects we studied emitted sounds outside of human hearing. Furthermore, certain items such as computer monitors or CFL bulbs *only* emitted ultrasonic frequencies, enabling recognition of "silent" events. PrivacyMic [7], the first of my privacy-aware sensor works, performs ultrasonic acoustic recognition of 127 objects related to daily activities (e.g., toilet flushing, brushing teeth) with an accuracy of 90.3% without using any privacy-invasive frequencies. PrivacyMic uses analog filters to completely remove speech/audible frequencies so that no conversations or sensitive content are ever digitized or recorded, ensuring a baseline standard of privacy for users. Lastly, PrivacyMic can process ultrasound with existing signal processing and ML approaches, thus reducing overhead when replacing traditional microphones. *This work received an Honorable Mention at CHI.*

Figure 3: In-home privacy-aware uroflowmetry can increase access to kidney health monitoring and support further clinical research.

Privacy Voiding: PrivacyMic can also be used to monitor chronic health conditions. Working with clinical collaborators, we identified a need for expanded access to cost-effective urinary voiding monitoring (i.e., uroflowmetry) at home. A problem with existing acoustic approaches is that they require users to open an app each time they void, leading to missed events and increased user burden, or leave the system continuously recording, which introduces privacy concerns and hampers adoption. Through an evaluation with in-home deployments, the PrivacyMic-based system was able to identify voiding events in ultrasound-alone and on-device with 97.6% accuracy [3]. Furthermore, ultrasound-only frequencies were able to match the human-audible voiding envelope, which is valuable for clinical and diagnostic purposes, such as identifying blockages. This approach has lowered the barrier to cost-effective, privacy-aware continuous monitoring, requiring no maintenance after setup, and supports clinical research with built-in privacy safeguards for patient privacy. Building on this work, we are now investigating methods to estimate liquid volume per voiding event, a key clinical metric. Ultimately, these privacy-aware microphones will empower clinicians to conduct long-term research with valuable acoustic data that was previously unattainable.

Area 2: Privacy-Aware Cameras to Support CV/ML Tasks

Figure 4: PrivacyLens removes PII and overlays images with relevant information on-device to support PII-free CV applications.

Like microphones, the ubiquity and utility of cameras have given rise to academic fields dedicated to harnessing their potential. However, cameras also have a history of privacy-related incidents—including a recent example where a Roomba took pictures of its owner using the toilet that human annotators subsequently shared on social media. Even more than audio recordings, images containing sensitive and intimate content evoke acute privacy concerns from users. Even though cameras are one of the best sensors for certain applications, such as detecting falls and performing important aging-in-place monitoring, their ability to capture intimate details of our lives makes it hard to convince users to place cameras in their bedrooms and bathrooms where they are often most needed. Thus, despite the amazing progress the CV/ML community has made in highlighting the versatility of camera-based systems, without privacy assurances users are unlikely to accept cameras in their homes for continuous monitoring outside of security contexts [11]. However, many CV/ML tasks do not actually require the pixels that correspond to humans and contain PII—in the aforementioned Roomba example, the images assist the robot to avoid objects and are sent to annotators to label furniture, but the PII in the images do not assist in either task. The challenge is how to remove PII in realtime and on-device without harming performance.

PrivacyLens: The human body's consistent temperature generates a thermal signature useful for detecting individuals beyond the visible spectrum. Autonomous vehicle systems leverage this thermal signature to overcome the limitations of RGB-only approaches, which struggle to reliably identify people in the environment. Similarly, for PII removal tasks, these RGB limitations can lead to PII leakage. PrivacyLens [11] uses an RGB and thermal camera pair to identify persons in the environment, create a segmentation mask, and efficiently remove PII from images using an embedded GPU. Through a deployment study collecting over 22 thousand images across three environments—an office atrium, family living room, and public park square—we found that PrivacyLens could effectively sanitize 99.1% of images of five forms of PII including face, skin, and hair color, gender, and body shape. In comparison, RGB-only approaches could only sanitize less than 57.6% of images. We utilize this robust ability to sanitize images to generate 6 image representations—such as replacing people with stick figures or replacing their faces with a generic face—that sanitize varying amounts of PII to balance the privacy needs of the user and the information needs of the application. Granting users control over how the camera operates establishes trust and allows them to select which representation they feel most comfortable with. PrivacyLens was used to support three illustrative CV/ML applications—exercise counting, hand-to-object detection, and fall detection—by utilizing PII-sanitized inputs with existing models without a loss in application performance. Ultimately, PrivacyLens presents an avenue to increase user comfort with in-home cameras, including for critical, life-saving tasks such as fall detection.

Area 3: Expanding Privacy-Aware Sensing Through Novel Sensing Approaches

While PrivacyMic and PrivacyLens sanitize private, sensitive content on-device to improve user privacy while maintaining device utility, microphones and cameras are indiscriminate general-purpose sensors that capture information regardless of its utility. As a complementary approach to improving user privacy, novel privacy-aware sensing approaches can be designed to capture specific signals and increase the variety of signals available for AI-based sensing systems. By selectively pairing a sensor to a signal, traditional benefits such as improved Signal-to-Noise Ratio (SNR) and robustness to environmental factors are coupled with user privacy benefits, where signals that contain sensitive information such as speech are actively avoided, rather than sanitized.

SAWSense: When a user turns on an appliance on a kitchen counter, surface acoustic waves (SAWs) travel along the surface of the counter in concert with sounds that travel in the air and 3D bulk vibrations that travel into the counter. SAWs have two unique properties that lend themselves to form a foundation for a privacy-aware sensing approach: 1) in-air sounds cannot induce SAWs, so speech cannot be captured by SAW sensors placed on objects or surfaces; and 2) SAWs are confined to a given surface which effectively defines the sensor's range (i.e., a sensor placed on a kitchen counter can only sense events on the counter and not from a different room). SAWSense repurposes VPU sensors to capture these SAW signals on virtually any surface and enables an approach where the users can easily understand the sensing extent of these devices and only instrument specific areas with the added benefit of increased SNR and robustness to signals that should be avoided. By instrumenting a kitchen counter, SAWSense was able to recognize 16 different kitchen activities with 99% accuracy. *This work received a Best Paper Award at CHI.*

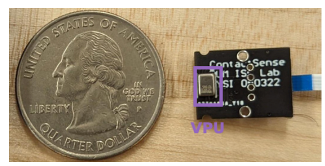

Figure 5: SAWSense's small footprint makes it easy to instrument a variety of objects and surfaces.

SAW ECG: Beyond activity recognition, SAWSense can capture expressive bioacoustic signals, akin to a higher-resolution phonocardiogram (PCG). In this work, I mentored a junior PhD student to create a low-cost method to "construct" ECG signals, enabling the accurate reconstruction of the PQRST complex that can indicate abnormalities, thus potentially expanding access to a vital diagnostic tool. This work was accepted to IEEE EMBC 2024, with one reviewer stating our approach is *"a method that could potentially revolutionize how cardiac rhythms are monitored outside of clinical settings."*

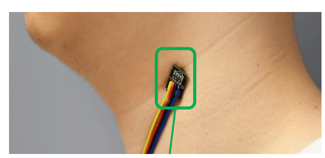
Figure 6: When placed on the neck, SAWSense can construct ECG signals from a single contact.

Other Privacy-Aware Sensing Approaches: SAWs are not the only signal source that can be used in novel privacy-aware sensing approaches. My work has also explored magnetic tracking [4, 6, 20–22], which offers an alternative to cameras or motion capture for high-resolution tracking of objects in 3D space. Additionally, I have utilized active ultrasonic signals via interferometery [12] (which received an Honorable Mention at CHI) and reflectrometry [9] for wearables to provide a camera-free method to estimate hand pose and gestures. Lastly, I have developed self-powered wireless sensor nodes [23] where the energy harvesting circuit both powers the tag and provides an expressive signal for activity recognition.

Future Research Directions

My research develops and deploys ubiquitous sensing systems that will improve the lives of users and patients while protecting their privacy. Building on my work thus far, I outline three areas for future research.

Designing Novel Privacy-Aware Sensors: My work has shown state-of-the-art capabilities but is not exhaustive of the types of sensors or data streams needed to support the information demands of a privacy-aware future. I will continue to research and develop novel sensors—such as those described in Area 3—to meet emerging needs in chronic health tracking and responsible multimodal AI-based sensing systems (further detailed below). As Mark Weiser suggested in the early days of ubiquitous computing, transformative technologies fade into the background, seamlessly integrating into daily life—a transition traditional sensing has already undergone. I believe the next generation of privacy-aware sensors will follow this same trajectory, evolving to become wireless, battery-free, or embedded within smart materials and wearables, providing a clear path for future research. These sensors will enable privacy-assured IoT sensing in healthcare, urban infrastructure, and future smart cities—all underpinned by robust and user-centric privacy guarantees.

Supporting Clinicians with Responsible AI-based Health Insights: With these novel sensors, privacy-aware health platforms have the potential to transform our understanding of chronic diseases by enabling continuous, privacy-protected monitoring that offers an unprecedented datastream to track disease progression and lifestyle impacts on outcomes. For instance, researchers studying conditions like multiple sclerosis (MS) aim to correlate symptoms like fatigue with specific activities, but current accelerometer-based wearable devices lack the resolution needed for detailed behavioral insights [2]. My research has shown that these systems significantly improve user comfort and trust [7, 11], which could unlock long-term adoption and provide richer datastreams without altering patient behavior. However, to transform individual health events into actionable insights, there is a need for responsible, AI-driven models that can leverage privacy-aware datastreams to connect daily activities with health metrics, such as the Functional Independence Measure (FIM) [19], a particularly important metric for chronic conditions [2]. Research in this area will support my clinical collaborators in their research on chronic conditions and can offer unprecedented insights into how specific activities impact symptoms and functional outcomes for those with chronic conditions.

Maximizing Privacy-Aware Sensing Through Responsible Multimodal AI Models: While no single privacy-aware sensing approach provides a full picture of activity recognition, together, they can be combined to complement each other. For example, recognizing all the elements of self-care behaviors may be challenging for acoustic (e.g., reading a book is "silent") or optical (e.g., events outside field of view) methods alone. Multimodal approaches have already shown that they can combine audio-visual information to outperform human perception in certain tasks, so what if these approaches were not bound to the way we sense the world (i.e., the limits of human sight and hearing)? My prior work has leveraged alternate information channels, which have individually outperformed traditional microphones and cameras. Future multimodal systems can utilize the mutual information in these expressive privacy-aware sensor streams to outperform systems limited to human senses—all while ensuring that sensitive information is never a part of the AI pipeline, making these systems more responsible. And, similar to applying PbD to sensors, future work can incorporate PbD into these models to limit them from gaining access to sensitive information and improperly disseminating it. It is imperative to identify cross-modal leakage to ensure their combination does not undermine user privacy, such as a system learning how to reconstruct speech from its other sensor streams despite its microphone having speech filters—privacy-aware models need safeguards for privacy-aware outputs. Additionally, work can explore on-device models to empower users with access and control.

Target Venues and Funding Agencies: Work in these research thrusts will primarily target venues in mobile systems (MobiCom, MobiSys, SenSys), HCI (CHI, IMWUT), and privacy (PETS, IEEE S&P, USENIX Security), as well as context-specific venues, such as in healthcare and policy. I will seek funding from governmental agencies such as the NSF (e.g., CISE, CCSS, CPS, IIS, HCC, and SCH), the ARO, and the NIH. I also intend to continue collaboration with industry partners, such as Meta, through sponsored research agreements.

To close, my background in sensing, interaction, and privacy gives me a unique perspective to develop solutions that are grounded in user-driven privacy and application needs. This perspective has allowed me to work with a variety of colleagues and granted me the privilege to tackle a wide range of sensing challenges ranging from AR/VR to accessibility to healthcare. Beyond my own research, I have found it incredibly rewarding to support my colleagues unlock opportunities in their own research domains, and I am excited to establish new partnerships to tackle novel challenges that *requiure* multi-disciplinary solutions.

References

[1] Amani Alkayyali, Yasha Iravantchi, Jaylin Herskovitz, and Alanson P. Sample. 2022. UbiChromics: Enabling Ubiquitously Deployable Interactive Displays with Photochromic Paint. *Proc. ACM Hum.-Comput. Interact.* 6, ISS, Article 561 (nov 2022), 25 pages. https://doi.org/10.1145/3567714

[2] Anindya Das Antar, Anna Kratz, and Nikola Banovic. 2023. Behavior Modeling Approach for Forecasting Physical Functioning of People with Multiple Sclerosis. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 7, 1, Article 7 (mar 2023), 29 pages. https://doi.org/10.1145/3580887

[3] Laura Arjona, Yasha Iravantchi, Alanson Sample, Marcos L. Alvarez, Alfonso Bahillo, and Elba Canalon. 2023. Privacy-Preserving Automatic Collection of Acoustic Voiding Events. In *2023 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. 1–4. https://doi.org/10.1109/EMBC40787.2023.10341012

[4] Dongyao Chen, Mingke Wang, Chenxi He, Qing Luo, Yasha Iravantchi, Alanson Sample, Kang G. Shin, and Xinbing Wang. 2021. MagX: wearable, untethered hands tracking with passive magnets. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking* (New Orleans, Louisiana) *(MobiCom '21)*. Association for Computing Machinery, New York, NY, USA, 269–282. https://doi.org/10.1145/3447993.3483260

[5] Centers for Disease Control and Prevention. 2024. About Falls. https://www.cdc.gov/falls/about/index.html. Accessed: 2024-09-19.

[6] Kunpeng Huang, Yasha Iravantchi, Dongyao Chen, and Alanson P. Sample. 2024. MagDesk: Interactive Tabletop Workspace Based on Passive Magnetic Tracking. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 8, 4, Article 170 (Nov. 2024), 31 pages. https://doi.org/10.1145/3699756

[7] Yasha Iravantchi, Karan Ahuja, Mayank Goel, Chris Harrison, and Alanson Sample. 2021. PrivacyMic: Utilizing Inaudible Frequencies for Privacy Preserving Daily Activity Recognition. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 198, 13 pages. https://doi.org/10.1145/3411764.3445169

[8] Yasha Iravantchi, Pardis Emami-Naeini, and Alanson Sample. 2025. SoK: (Un)usable Privacy: the Lack of Overlap between Privacy-Aware Sensing and Usable Privacy Research. In *Proceedings on Privacy Enhancing Technologies 2025(1)* (Washington, DC, USA) *(PoPETs '25, Vol. 2025)*. 472–490. Issue 1. https://doi.org/10.56553/popets-2025-0026

[9] Yasha Iravantchi, Mayank Goel, and Chris Harrison. 2019. BeamBand: Hand Gesture Sensing with Ultrasonic Beamforming. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3290605.3300245

[10] Yasha Iravantchi, Mayank Goel, and Chris Harrison. 2020. Digital Ventriloquism: Giving Voice to Everyday Objects. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3313831.3376503

[11] Yasha Iravantchi, Thomas Krolikowski, William Wang, Kang G. Shin, and Alanson Sample. 2024. PrivacyLens: On-Device PII Removal from RGB Images using Thermally-Enhanced Sensing. In *Proceedings on Privacy Enhancing Technologies 2024(4)* (Bristol, UK) *(PoPETs '24, Vol. 2024)*. 872–891. Issue 4. https://doi.org/10.56553/popets-2024-0146

[12] Yasha Iravantchi, Yang Zhang, Evi Bernitsas, Mayank Goel, and Chris Harrison. 2019. Interferi: Gesture Sensing using On-Body Acoustic Interferometry. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300506

[13] Yasha Iravantchi, Yi Zhao, Kenrick Kin, and Alanson P. Sample. 2023. SAWSense: Using Surface Acoustic Waves for Surface-bound Event Recognition. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 422, 18 pages. https://doi.org/10.1145/3544548.3580991

[14] Sunyoung Kim, Yasha Iravantchi, and Krzysztof Z. Gajos. 2019. SwellFit: Developing a Wearable Sensor for Monitoring Peripheral Edema. In *Proceedings of the 52nd Hawaii International Conference on System Sciences (HICSS-52)* (Vancouver, BC, Canada). Hawaii International Conference on System Sciences. http://hdl.handle.net/10125/59823

[15] Sunyoung Kim, Yasha Iravantchi, Krzysztof Z. Gajos, and Barbara Grosz. 2015. Exploring Opportunities for Social Infrastructure in Congestive Heart Failure Management. In *Proceedings of the CSCW 2015 Workshop on Moving Beyond e-Health and the Quantified Self* (Vancouver, BC, Canada). Association for Computing Machinery, New York, NY, USA. https://dash.harvard.edu/handle/1/22719470

[16] Sunyoung Kim, Yasha Iravantchi, Krzysztof Z. Gajos, and Barbara Grosz. 2016. SwellFit: a Wearable Sensor for Patients with Congestive Heart Failure. In *Proceedings of the CHI 2016 Workshop on Interactive Systems in Healthcare (WISH)* (San Jose, CA, USA). Association for Computing Machinery, New York, NY, USA. https://dash.harvard.edu/handle/1/29405813

[17] Yaxuan Li, Yasha Iravantchi, Hyunmin Park, Yiming Liu, and Alanson Sample. 2024. ECG Signal Construction From Heart Sounds via Single Node, Surface Acoustic Sensing. In *2024 46th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. 1–4. https://yasha.xyz/assets/pdf/Li24EMBC.pdf

[18] Chen Liang, Yasha Iravantchi, Thomas Krolikowski, Ruijie Geng, Alanson P. Sample, and Anhong Guo. 2023. BrushLens: Hardware Interaction Proxies for Accessible Touchscreen Interface Actuation. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (San Francisco, CA, USA) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 36, 17 pages. https://doi.org/10.1145/3586183.3606730

[19] Kenneth J. Ottenbacher, Yungwen Hsu, Carl V. Granger, and Roger C. Fiedler. 1996. The reliability of the functional independence measure: A quantitative review. *Archives of Physical Medicine and Rehabilitation* 77, 12 (1996), 1226–1232. https://doi.org/10.1016/S0003-9993(96)90184-7

[20] Jike Wang, Yasha Iravantchi, Alanson Sample, Kang G. Shin, Xinbing Wang, and Dongyao Chen. 2024. Polaris: Accurate, Vision-free Fiducials for Mobile Robots with Magnetic Constellation. In *Proceedings of the 30th Annual International Conference on Mobile Computing And Networking* (Washington, DC, USA) *(MobiCom '24)*. Association for Computing Machinery, New York, NY, USA. https://yasha.xyz/assets/pdf/Wang24Polaris.pdf

[21] Jike Wang, Shanmu Wang, Yasha Iravantchi, Mingke Wang, Alanson Sample, Kang G. Shin, Xinbing Wang, Chenghu Zhou, and

Dongyao Chen. 2024. METRO: Magnetic Road Markings for All-weather, Smart Roads. In *Proceedings of the 21st ACM Conference on Embedded Networked Sensor Systems* (Istanbul, Turkiye) *(SenSys '23)*. Association for Computing Machinery, New York, NY, USA, 280–293. https://doi.org/10.1145/3625687.3625809

[22] Mingke Wang, Qing Luo, Yasha Iravantchi, Xiaomeng Chen, Alanson Sample, Kang G. Shin, Xiaohua Tian, Xinbing Wang, and Dongyao Chen. 2022. Automatic calibration of magnetic tracking. In *Proceedings of the 28th Annual International Conference on Mobile Computing And Networking* (Sydney, NSW, Australia) *(MobiCom '22)*. Association for Computing Machinery, New York, NY, USA, 391–404. https://doi.org/10.1145/3495243.3558760

[23] Yang Zhang, Yasha Iravantchi, Haojian Jin, Swarun Kumar, and Chris Harrison. 2019. Sozu: Self-Powered Radio Tags for Building-Scale Activity Sensing. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 973–985. https://doi.org/10.1145/3332165.3347952