Yang Zhang | Research Statement

My research interest lies in the technical aspects of human-computer interaction (HCI) with a focus on sensing technologies that bring computing and interactivity closer to users. Sensing technologies are critical in many applications especially those around users, where interactive systems leverage sensors to perceive users, infer their intentions, and enhance their abilities. However, the perceptual capabilities of today's devices have become a major bottleneck to unlocking a wider range of convenient and immediate computing applications. For instance, everyday objects we routinely use often have zero sensing power. Mobile devices rely on small touchscreens for input, and supposedly "smart" home appliances often have no knowledge about what the user is doing right next to them. Despite their physical proximity, the lack of effective perceptual capabilities undercuts the usefulness and smartness of interactive systems, which keeps computing and interactivity at a distance with users. My research on sensing technologies boosts the perceptual capabilities of computing devices, which improves their interactions and context awareness for better convenience and immediacy. By inventing new and powerful sensing techniques, I have unlocked new practical applications based on my research to be used as building blocks in two domains – **interactivity** and **activity recognition** (Figure 1). This effort has led to 17 publications at top venues, for which I received 2 Best Paper and 4 Honorable Mention awards. There are three key approaches I have pursued:

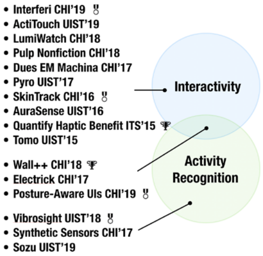

Figure 1. My research on sensing technologies unlocks new practical applications in two domains.

1) Bringing interactive functionality to everyday **objects** through novel fabrication and sensing.
2) Enhancing input on computing **devices** with interactive sensing beyond conventional touchscreens.
3) Practical wide-area detection of human activities in **environments** to enhance smart devices.

1. Computationally Enhanced Objects through Novel Sensing and Fabrication Techniques

As computers continue to become less expensive and smaller with advancements in technology, they offer affordability to many passive objects, providing enhanced functionalities such as sensing and interaction. Ideally, computer integration would not affect the form factor of their host objects and offer a modest price tag. Only then is it possible for objects with complex geometries (e.g., steering wheel) and those that are low-cost (e.g., paper) or large (e.g., furniture, walls), which remain challenging to achieve. In my research, I have been inventing practical sensing techniques which can easily be integrated into a wide array of fabrication processes to empower computers to sense through computationally enhanced objects.

In **Electrick** [11], I developed a low-cost and versatile touch sensing technique based on Electric Field Tomography (EFT) – a reconstruction technique which leverages capacitive sensing to recover an object interior. Specifically, Electrick projects an electric field into a mildly conductive surface, such as carbon-loaded paints, which can be easily coated onto objects. Finger contacts shunt a small amount of current to the ground, resulting in a low electric field density area. Electrick then tracks this to detect touch locations (Figure 2). Electrick enables touch sensing on complex geometries at under $1 per square foot, while being compatible with a variety of fabrication and finishing processes (see Figure 3 & 4 for two examples). This research opens new sensing opportunities to a wide range of everyday objects such as tools, toys, and even paper products which I investigated in follow-up work [10]. To date, Electrick has resulted in 6 commercial licenses and ongoing collaborations with industrial partners.

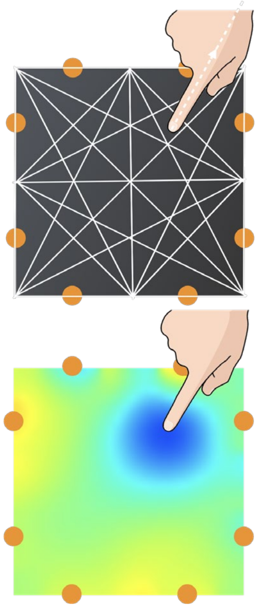

Figure 2. Electric field tomography leverages cross-sectional capacitive measurements to recover electric field distribution. Low-density area (blue) is recognized as finger touch.

Figure 3. Electrick enables multi-touch sensing on complex objects. For instance, a touch-sensitive steering wheel can monitor drivers for safety behaviors.

Beyond small and movable objects, infrastructures can also be computationally enhanced, which can uniquely enable room-scale interactions and computation. One such example is walls, which often make up more than half of indoor surface area, yet walls are inactive, offering no interactive or computational abilities. In **Wall++** [9], I instrumented walls with patterned conductive paints and leveraged mutual capacitive sensing to make them responsive to users' touch and postures for interactions. These enhanced walls can also capture electromagnetic signals from active appliances for activity monitoring or from wearables for user localization. Collectively, these novel sensing capabilities allow computers to better perceive users at a room scale for Internet-of-Things (IoT) and smart home applications.

2. Devices with Convenient Interactions beyond Touchscreens

My research also targets mobile devices, which are computing platforms that are already around us. Though mobile devices such as smartwatches and phones have become ubiquitous, their mobility comes at the cost of physical space, which constrains user input. Additionally, almost all mobile devices rely on touch input, overlooking a user's background which has rich contextual information that can improve input expressivity. In response, I have developed new sensing techniques to track user finger locations, gestures, and postures, which lead to natural and efficient interactions on mobile devices in various contexts (i.e., smartwatch [1, 12, 13, 15], phone [4], tablet [7], and AR/VR headset [2, 6]).

Tomo [13, 15] and **SkinTrack** [12] tackle the "fat finger" problem of smartwatches which are notorious for small screens. In both projects, I leveraged the conductivity of the human body. Specifically, Tomo measures cross-sectional impedances of a user's wrist for interior reconstruction, functioning like a miniaturized "x-ray" machine. Muscle movements caused by hand gestures can therefore be detected, allowing users to manipulate their smartwatches through hand gestures. SkinTrack turns a user's finger into a Radio Frequency (RF) emitter which inserts an RF wave into the opposing arm at finger touch, the location of which can be triangulated by electrodes underneath a smartwatch strap. This allows users to use the skin surrounding their smartwatches as a trackpad (Figure 5).

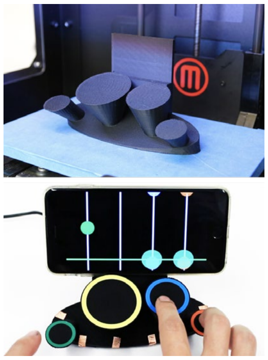

Figure 4. As a design tool, Electrick enables rapid iterations of both form and function, such as this 3D printed bongo game.

I have also been researching next-generation mobile devices in collaborations with industry for potential impact on millions of users. With Microsoft Research, I built a series of **posture-aware interfaces** based on capacitive sensing on tablet bezels [7]. Through sensing user background such as shifting hand grips, planting the palm while sketching, and what direction the hands approach from, our posture-aware interfaces can morph to user-centric frames of reference for more convenient use. With Facebook Reality Labs, I developed **ActiTouch** [6], a hybrid approach that turns a user's hands and arms into readily available touch input surfaces in AR/VR, opening new interaction opportunities beyond controllers and in-air gestures. Our approach combines computer vision for hand tracking and active RF sensing for touch segmentation, which uniquely enables fine-grained touch interactions such as scrolling and swiping.

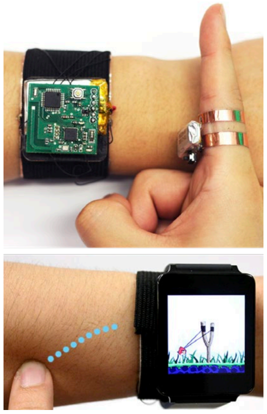

Figure 5. SkinTrack turns skin around a smartwatch into a trackpad.

3. Event and Activity Detection through Wide-Area Environment Sensing (Dissertation Work)

Mobile devices are discrete and sparse, but our physical world is large and continuous, which leaves gaps where computers are incapable of enhancing users (e.g., logging activities and environmental facets for healthier and more productive life and work decisions; assistive and autonomous technologies). Additionally, most interactive systems today demand a user's attention and explicit input due to the lack of contextual information, eliminating immediate response to user needs. My research aims to fill in these spatial and informational gaps through deployed sensors in environments. This environment-centric approach complements the above object- and device-centric approaches. In this line of research, I propose **wide-area** sensing where each sensor can capture user and environmental information throughout a room, a building, and beyond. Compared with existing sensing techniques which often require dense sensor deployments, wide-area sensors can be powered in a battery-free manner, and can retrofit to existing environments with sparse installations, both of which significantly lower a user's maintenance cost.

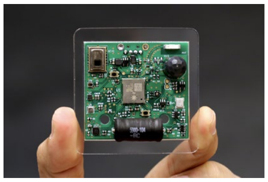

Figure 6. My general-purpose sensor board can turn into a wide variety of software-defined "synthetic sensors" such as door sensor and cooking detector.

However, sparse sensor installation is inherently challenging to achieve due to two factors: 1) longer sensing distances lower signal-to-noise ratio due to the attenuation of signals over space, which demands highly sensitive hardware with advanced algorithms; and 2) human activities are extremely diverse, ranging from pruning leaves to making coffee, which demands high sensing versatility. I tackled these challenges with different approaches. One approach to detect a wide range of activities is to have a variety of sensors working together. In **Synthetic Sensors** [3], I created a new and compact sensor board (Figure 6) incorporating 33 sensor channels, which through machine learning, can recognize a wide variety of environmental facets (e.g., HVAC, water, gas) and user activities (e.g., cooking, exercising, operating tools) from only a single sensing point in a room.

Wide-area sensing requires long-range sensors whereas off-the-shelf sensors (e.g., optical vibrometer) are often impractical for average homeowners due to their high price tag (i.e., cost tens of thousands of dollars) and obtrusive set up. In response, I created low-cost sensing techniques that users can easily install or that are ultra-low-cost for potential manufacture integrations. In these projects, I leveraged signals that can travel long distances such as laser and RF broadcasts. **Vibrosight** [8] detects vibrations as byproducts of human activities. Regardless of whether we are running on a treadmill, chopping vegetables, or operating machines, vibrations are everywhere, and have distinctive patterns which can be used to infer activity types and states (Figure 7). With laser vibrometry, a technique that can reconstruct vibrations from afar, Vibrosight can recognize activities inside its host room at high accuracies – 92.1% for activity type recognition and 98.4%

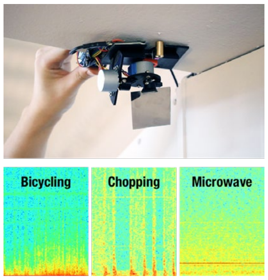

Figure 7. Users can easily install Vibrosight on a ceiling. It then collects vibrations remotely from surroundings to infer activity types and states.

for activity state detection, while costing only $80 for our research prototype. To facilitate others' hands-on experience with Vibrosight, I have open sourced this research: https://github.com/figlab/vibrosight.

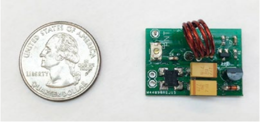

Figure 8. Sozu tags are battery-free and cost less than $1, opening new opportunities for practical whole-building sensing.

Sozu [5] extends activity sensing from room-scale to building-scale with self-powered RF tags. Specifically, Sozu tags act like miniature radio stations, which convert energy residues from user activities into RF broadcasts. Such RF broadcasts carry the activity information of their host objects, travel through walls and floors, and are captured by a remote receiver that can be potentially integrated into future smart devices such as virtual home assistants. Through a careful analog circuit design, Sozu tags have no digital components such as microcontrollers or Bluetooth, reducing the tag cost to lower than $1 (Figure 8). A three-week evaluation at three test locations with 30 activities indicated a detection accuracy exceeding 99%. To cultivate collaboration, Sozu is open sourced and available as a toolkit: https://github.com/figlab/sozu. To date, this toolkit has been distributed to colleagues at 15 universities and 6 industrial labs.

Future Research

My PhD research boosts the perceptual capabilities of computers through novel sensing technologies. However, much work remains to be done, which I look forward to investigating as faculty. I strongly believe that computer scientists need interdisciplinary approaches to tackle real world problems with real world user populations. I am eager to start new collaborations with future colleagues where I can extend my existing skillset in HCI, computer science, electronics, and fabrication. Some areas of future research that I plan to initiate at my new institution include:

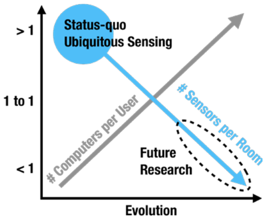

Figure 9. The average number of computers per user has been increasing. Following this trend, status-quo ubiquitous sensing relies on an increasing number of sensors in a room – a dense deployment. I want to achieve a sparse sensor deployment where each sensor can detect user activities and environmental facets throughout a room, a building, or even a city.

Explore and advance novel sensing, fabrication, and machine learning techniques: I believe that applications of sensing will continue to expand and grow as we deepen our understanding of technologies and their use domains. One example is my research on EFT. I have been improving this technique as well as extending its use cases to a variety of applications [10, 11, 13, 15]. I am excited about exploring and advancing more fundamental enabling techniques to solve important challenges in HCI. Since fabrication decides the characteristics of materials that conduct signals, it has a profound role in sensing. I am eager to look for opportunities to integrate novel sensing into fabrication techniques – from fast prototyping methods to mass production processes. Additionally, I plan to investigate machine learning techniques tailored to novel activity sensing as existing techniques are often best suited for and confined to conventional sensor data (e.g., camera, microphone, and accelerometer) – a missed opportunity. Finally, I will continue to open source my lab's projects to facilitate collaborations and real-world impact.

Ultra-sparse sensor deployments: I want to deepen my research on wide-area sensing to achieve truly ubiquitous coverage through ultra-sparse sensor deployments (Figure 9). My previous work has demonstrated that ubiquitous sensing can be achieved without the ubiquity of sensors – a single powerful sensor can cover a wide area for practical sensing. Can we push the limits of wide-area sensing and build sensing technologies where one single sensor can cover an entire neighborhood or even an entire city? Fulfilling this future will significantly lower the cost of ubiquitous sensing while making it much easier to maintain. It is unclear what sensing principles we should leverage and what sensing granularity we can achieve. I want to answer these types of research questions with my future work where I will develop long-range and versatile sensing techniques for city-scale applications, such as parking management, smart lighting, traffic and environmental monitoring, and beyond. I believe my future work in this area will radically change the way people implement IoT and smart environments, and make their applications more practical to be widely adopted across society.

New application domains: I am also eager to expand my research to broader application domains, extending from homes to hospitals, farms, factories, and beyond, where sensing technologies are crucial in applications such as sleep monitoring, digital agriculture, and equipment maintenance. I am equally excited about research fields including digital healthcare, accessibility, K-12 education, and end-user programming (e.g., IFTTT), where I believe my expertise in sensing will fuel new collaborations. Additionally, I am interested in utilizing my research as an evaluation vessel to study privacy, security, behavioral science, and experience design. Broadening application and research domains means shifting from humans to plants, animals, vehicles, or to a wide range of environmental facets, from individuals, to families, crowds and cities, all of which demand highly interdisciplinary skillsets which I have demonstrated with my research, and will continue to develop with my team and through collaborations with future colleagues.

Reference

1. Jun Gong, **Yang Zhang**, Xia Zhou, and Xing-dong Yang. 2017. Pyro: Thumb-Tip Gesture Recognition Using Pyroelectric Infrared Sensing. In *Proceedings of the 30th Annual Symposium on User Interface Software and Technology* (UIST '17). ACM, New York, NY, USA, 553-563. Video

2. 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* (CHI '19). ACM, New York, NY, USA, 13 pages. Video **(Honorable Mention Award)**

3. Gierad Laput, **Yang Zhang**, and Chris Harrison. 2017. Synthetic Sensors: Towards General-Purpose Sensing. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17). ACM, New York, NY, USA, 3986-3999. Video

4. Robert Xiao, Gierad Laput, **Yang Zhang**, and Chris Harrison. 2017. Deus EM Machina: On-Touch Contextual Functionality for Smart IoT Appliances. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17). ACM, New York, NY, USA, 4000-4008. Video

5. **Yang Zhang**, Yasha Iravantchi, Haojian Jin, Swarun Kumar, Chris Harrison. 2019. Sozu: Self-Powered Radio Tags for Building-Scale Activity Sensing. In *Proceedings of the 32th Annual Symposium on User Interface Software and Technology* (UIST '19). ACM, New York, NY, USA. Video

6. **Yang Zhang**, Wolf Kienzle, Yanjun Ma, Shiu S. Ng, Hrvoje Benko, Chris Harrison. 2019. ActiTouch: Robust Touch Detection for On-Skin AR/VR Interfaces. In *Proceedings of the 32th Annual Symposium on User Interface Software and Technology* (UIST '19). ACM, New York, NY, USA. Video

7. **Yang Zhang**, Michel Pahud, Christian Holz, Haijun Xia, Gierad Laput, Michael McGuffin, Xiao Tu, Andrew Mittereder, Fei Su, William Buxton, and Ken Hinckley. 2019. Sensing Posture-Aware Pen+Touch Interaction on Tablets. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (CHI '19). ACM, New York, NY, USA, 14 pages. Video **(Honorable Mention Award)**

8. **Yang Zhang**, Gierad Laput and Chris Harrison. 2018. Vibrosight: Long-Range Vibrometry for Smart Environment Sensing. In *Proceedings of the 31st Annual Symposium on User Interface Software and Technology* (UIST '18). ACM, New York, NY, USA, 225-236. Video **(Honorable Mention Award)**

9. **Yang Zhang**, Chouchang (Jack) Yang, Scott E. Hudson, Chris Harrison, and Alanson Sample. 2018. Wall++: Room-Scale Interactive and Context-Aware Sensing. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18). ACM, New York, NY, USA, Paper 273. Video **(Best Paper Award)**

10. **Yang Zhang** and Chris Harrison. 2018. Pulp Nonfiction: Low-Cost Touch Tracking for Paper. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18). ACM, New York, NY, USA, Paper 117. Video

11. **Yang Zhang**, Gierad Laput, and Chris Harrison. 2017. Electrick: Low-Cost Touch Sensing Using Electric Field Tomography. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17). ACM, New York, NY, USA, 1-14. Video

12. **Yang Zhang**, Junhan Zhou, Gierad Laput, and Chris Harrison. 2016. SkinTrack: Using the Body as an Electrical Waveguide for Continuous Finger Tracking on the Skin. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 1491-1503. Video **(Honorable Mention Award)**

13. **Yang Zhang**, Robert Xiao, and Chris Harrison. 2016. Advancing Hand Gesture Recognition with High Resolution Electrical Impedance Tomography. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (UIST '16). ACM, New York, NY, USA, 843-850. Video

14. **Yang Zhang** and Chris Harrison. 2015. Quantifying the Targeting Performance Benefit of Electrostatic Haptic Feedback on Touchscreens. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces* (ITS '15). ACM, New York, NY, USA, 43-46. **(Best Short Paper Award)**

15. **Yang Zhang** and Chris Harrison. 2015. Tomo: Wearable, Low-Cost Electrical Impedance Tomography for Hand Gesture Recognition. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software and Technology* (UIST '15). ACM, New York, NY, USA, 167-173. Video