

Research Statement

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Background

Sensing has been the bedrock for connecting humans and machines. From cameras that capture visible light to microphones that detect sound, these traditional sensors have driven technological innovation. However, as our computing world evolves fast with novel platforms, e.g., smartphones, self-driving vehicles, and humanoid robots, the sensing capability is **emerging as a key bottleneck** for achieving seamless and reliable interaction between us and machines. The root causes are: (1) **limited sensing modalities**: To handle real-world tasks effectively, enabling multi-modal perception is essential. For instance, the human sensory system integrates diverse inputs from balance (equilibrioception) to touch (haptic perception). In contrast, emerging technologies may only use a limited well-studied sensing modality, thus severely confining the applicability. For example, virtual reality interactive applications are often restricted to bright indoor scenarios due to the lighting condition requirement of the camera. (2) **Unnecessary cost and overhead**: Relying heavily on limited sensing modalities can be inefficient and cumbersome. For example, detecting fine-grained hand gestures solely with the computer vision approach may require sophisticated and expensive training. (3) **Privacy and security threat**: When only a few of sensing modalities are used, adversaries can exploit their well-known characteristics, making it easier to launch effective attacks against these systems.

Driven by these pressing limitations, I have been focusing on expanding the horizon of **sensing intelligence** for future human-machine interaction. **By exploring novel sensing modalities and processing paradigms, my goal is to enhance the ability of computing platforms (e.g., smartphones, vehicles, and robots) to understand and interact with us and the world**, which is very challenging for the following reasons:

1. The methodologies for developing and using novel sensing modalities **remain largely un/under-explored, requiring persistent efforts** to integrate these technologies into real-world applications. For example, to achieve accurate motion sensing, using magnetic field may not seem to be the most straightforward modality. With series of research, I was able to demonstrate magnetic sensing can achieve millimeter-level, zero-drift accuracy --- a significant advantage compared with state-of-the-art camera and IMU-based sensing.
2. Unlike well-investigated vision-based sensing, alternative sensing modalities often lack specialized, low-cost devices. This issue leads to unique challenges for this line of research. To explore the feasibility of a new sensing modality, one may have to explore **off-the-shelf sensing devices** that are not designed for that task. That is, one has to perform out-of-box thinking, carefully address various new factors (e.g., energy consumption, cost, and form factor) to make the new sensing modality feasible and practically usable.
3. Tackling potential privacy and security concerns is a pressing requirement. Specifically, we need to address key questions: Would adversaries leverage these new sensing techniques? How to design new privacy and security standards and practices for emerging sensing technologies?

To address these core challenges, my research philosophy aims to explore sensing technologies for real-world problems, identify novel technical challenges and develop their solutions, build human-centric solution with a security mindset, and conduct **end-to-end tests** to verify the system. I am strongly motivated by **problems that connects people** and often reside in healthcare and robotics domains. My current research at Shanghai Jiao Tong University, and my earlier PhD research at the University of Michigan, Ann Arbor cover a wide range of emerging sensing modalities. These works lead to **startup efforts and series of opensource tools**.

Specifically, I have been exploring ambient, ubiquitous sensors such as IMU sensors (e.g., accelerometer and gyroscope) and magnetic sensors (e.g., magnetometers). Compared to other sensing modalities, these sensors are more accessible thanks to their low cost, compact form factor, and privacy-preserving features. I have built driving behavior fingerprinting to characterize driving patterns and crowdsourcing-based risk analysis. Achieving this objective involved a substantial data collection initiative. In 2020, I integrated my work into a refined smartphone app and co-founded a telematics startup called DriverX (<https://driverx.net/>). Recently, my research also explored sensing subtle movements with novel magnetic sensing technologies. This line of research enables **drift-free**, high-precision tracking, pushing the boundaries of what is possible with legacy sensing modalities. I

have led and **secured competitive funding as the leading PI**. Specifically, my works in magnetic sensing were awarded for two National Natural Science Foundation of China (NSFC) grants with the **acceptance rates around 15% and 11.2% in 2021 and 2024**, respectively. My works also recognized by external collaborations, e.g., joint seed grant from SJTU – Cornell collaboration with Prof. Cheng Zhang. My research results have been presented at top conferences such as MobiSys (2015, 2022), MobiCom (2021, 2022, 2024), UbiComp (2019, 2021, 2023, 2024, and 2025), SenSys (2023), CCS (2014, 2019), CoNEXT (2017), and VehicleSec (2023). My works received the **Distinguished Paper Award** from UbiComp 2025 and the **Best Paper Award** from VehicleSec 2023.

In this statement, I will first demonstrate how novel sensing modalities would expand the scope and possibility of human-machine interaction. Next, I will elaborate my efforts on securing sensing systems. Finally, I will present the overview of my future research agenda.

Research Areas

Magnetic Sensing

Tracking fine-grained motion is crucial for rehabilitation and humanoid robot teleoperation. However, existing methods has unique limitations their applicability in practice. For example, for neurological patients, providing their kinesiologists with their high-accuracy body movement is extremely important. However, existing goniometer solutions are often not user friendly. The IMU-based approach incurs severe drifting error, and vision-based methods may be hindered by occlusion and are privacy-intrusive.

My recent works demonstrate that even off-the-shelf magnetometers can tackle challenging tasks, e.g., millimeter-level motion tracking. To enable magnetic sensing for fine-grained motion sensing, I invented a fully untethered, accurate, and wearable sensing system using passive magnets and a new magnetic sensing array (MagX [6]). Since passive magnets require no maintenance, they can be worn indefinitely. Our experiments have demonstrated millimeter-level accuracy in 5-DoF tracking of two independent magnets. The core of MagX can be used for diverse application scenarios. Specifically, I co-lead an international effort with Prof. Alanson Sample's team from the University of Michigan, Ann Arbor to introduce MagDesk [14], which enable high-accuracy, 3D interaction in the office desk setting. This work received the **Distinguished Paper Award** from UbiComp 2025. Moving forward, I investigated the feasibility of applying magnetic sensing for tracking body motion, e.g., motion capture. The major challenge is, accurate motion tracking that usually incurs high cost. For example, existing methods rely on (1) multiple professional optic cameras in a confined space, or (2) specialized IMU (e.g., xSens) that has smaller drifting error. To guarantee both low-cost and high-accuracy features, I invented MagDot [11] tracking system. To facilitate MagDot on different body joints, I tackled a unique challenge --- **how to ensure tracking accuracy given various moving patterns of different joints, e.g., wrist, knee, and shoulder**. The major contribution of MagDot is **symmetrical tracking**. Thus, users can freely attach/remount the tracking unit to facilitate moving patterns for different joints. MagDot demonstrates zero-drift, accurate tracking performance in both indoor and outdoor scenarios, paving the path toward practical and affordable motion tracking.

Despite these promising applications, magnetometer is **sensitive to real-world disturbances**, which can be caused by everyday objects such as smartphones, earphones, and even metal furniture. These disturbances traditionally require users to undertake a frequent, cumbersome calibration process, affecting the practicality of magnetic tracking. I introduced MAGIC [7], which automatically calibrates various disturbances in magnetometer arrays. A key innovation of MAGIC is its novel auto-triggering module, which minimizes user involvement. The demo of MAGIC can be found here: <https://www.youtube.com/watch?v=EEMWb0cUsrc>.

The technical principle underlying my work is transferrable to interdisciplinary areas, e.g., robotics. My work, METRO [12], **allows self-driving cars to interpret road markings even when the road is covered by heavy snow**; POLARIS [13] demonstrated that one can use passive magnets to build invisible fiducial tags --- **granting robotic systems to navigate in messy environments without relying on vision-based sensors**. In the context of interacting with robots, the major challenge is how to encode rich information, e.g., thousands of road markings or even posture calibration messages, into magnetic tags that can be read by fast-moving cars and/or robots? I proposed solutions for **using magnets' distances and polarities** to achieve this goal. Specifically, METRO uses the distance between magnets to encode road marking information. POLARIS uses diametrically magnetized disc magnets, allowing designers to modulate information with magnetic polarities for robotic systems. As the result, METRO can identify various road markings with over 96% accuracy in diverse weathers, at a substantially lower cost (about \$0.17 per meter) compared to conventional road markings (\$0.21 to \$7.70 per meter). POLARIS enabled the world-first magnetic fiducials to achieve an accuracy of up to

0.58 mm and 1° in posture estimation with extremely low energy overhead, thus even compatible with solar-powered miniature robots.

IMU Sensing

Sensing driving patterns is safety-critical and attracts extensive research efforts to improve safety and efficiency. However, existing sensing facilities may fall short in practice. For example, existing methods usually use camera to sense the on-road markings, thus inferring the relative motion of the car. Ubiquitous sensing, such as gyroscope and accelerometers in smartphone IMUs are capable of capturing linear and angular inertia, thus hinting potential of understanding motion even without visibilities.

My works explore the spatial-temporal features of IMU data, overcome poor data fidelity and connect them with real-world applications via **extensive field tests**. When drivers turn the steering wheel, they either intentionally perform lane change, left/right turn. In VSense [1], I proposed a unique feature vector for capturing the angular changes recorded by low-quality smartphone gyroscope. Moving forward, I noticed that the traffic signal types at intersections are poorly documented, even in developed regions, e.g., the downtown area in Chicago. Specifically, the unprotected left turn signal (left-turning traffic and oncoming traffic share the same time phase) is not recorded by transportation department not digitized by navigation service providers, e.g., Google Maps. Handling these unprotected left turns is a challenging task for both human drivers and self-driving vehicles as the ego car has to carefully examine the oncoming traffic. Based on the collected IMU data from VSense' field tests, I noticed that **when drivers encounter an unprotected left turn, s/he may perform a sudden brake**, pause the turning behavior to wait for the oncoming vehicles. My TurnsMap [3] project leverages this pattern, thus automatically detecting unprotected left turns based drivers' motion. To achieve high sensing accuracy, TurnsMap **used the crowdsourced IMU data collected by VSense**. TurnsMap discovered some unexpected results. For example, protected intersections close to schools can have burst brakes in the morning hours, indicating that intersection safety can be a dynamic pattern. Revealing this information can include the dynamic safety factor as a new dimension for navigation applications.

I further pushed my inventions to a larger audience by co-founding DriverX (<https://driverx.net/>). DriverX is a mobile telematics startup aimed at revolutionizing road safety through driving behavioral biometrics. One of our flagship innovations is 'driver fingerprinting'. Based on the data analytics techniques we proposed in VSense and TurnsMap, I turn the IMU-based turning data into behavioral biometrics that **can authenticate driver identity**. This is application offers a unique, camera-free approach for authenticating drivers, which is pressing problem during the COVID-19 pandemic, as car-hailing services like Uber and Lyft suffered from verifying driver identities due to face mask. DriverX was invited to submit a full proposal to the NSF SBIR/STTR Phase I program.

Sensing System Security and Privacy

I believe security and privacy mindset is indispensable for inventing new sensing technologies, as these new modalities can open doors to novel and stealthy attacks. In my recent work DualStrike [16] (to appear in NDSS 2026), we explored a crucial security loophole in a fast-emerging interactive device – Hall-effect keyboards. We discovered, for the first time, that these essential devices may **both** leak the victim's keystrokes and susceptible to remote keystroke injection. This loophole can allow attackers to remotely eavesdrop essential information (e.g., passwords) thus implementing more destructive attacks. In my ViFi study [10], I demonstrated that seemingly innocuous IMU sensor data could inadvertently disclose highly sensitive information, such as a person's income status or political inclinations. Specifically, ViFi discovered that IMU sensors can pick up vehicles' vibration patterns, which is closely correlated with vehicle's engine and body types (e.g., pickup vs. compact cars). As IMUs are zero-permission, de facto sensor for modern smartphones, if leveraged by malicious entities, this issue could impact billions of devices. This work received the **Best Paper Award** at VehicleSec 2023. My work in LibreCAN [4] proposed an automated translator of proprietary vehicular data, largely lowered the barrier of remote in-vehicle data access, thus may reveal new security threats for vehicular security.

Future Directions

Unleashing the Power of Multi-modal Sensing with Machine Learning. I think the SIGMOBILE community and wearable technologies can make unique contributions to the grand vision of AI and robotics. Specifically, (1) the multi-modal sensing framework can provide indispensable solution for perception tasks. For example, using the magnetic sensing for enabling tactile sensing for robots and high accuracy motion teleoperation. (2) Automated sensing system design and optimization. For example, building foundation model that can efficiently leverage different modalities, thus facilitating end applications. In particular, how to optimize various parameter, e.g., type, sample rate, and even sensor model, of various sensing tasks. (3) Aggregating crowd intelligence to address challenging

tasks. For example, my existing work on crowdsourcing IMU data from drivers' smartphones revealed critical safety information. However, different models of sensing units can lead to discrepancies in sensing data, thus severely undermining the end-to-end results. Compared with other sensing modalities, this is a unique challenge for wearable and mobile systems. Looking forward, I am excited in developing new inference engines for overcoming the heterogeneity of sensing nodes.

Bridging New Sensing Technologies with Cross-disciplinary Experts. To connect these novel techniques with existing problem spaces, it is crucial to invite cross-disciplinary efforts. (1) I would like to continue end-to-end system-building efforts to assess our sensing modalities' usability in different domains. The principles of our magnetic tracking can apply to critical applications, e.g., capsule endoscopy and humanoid robotic teleoperation. I plan to collaborate with researchers and experts from different fields, e.g., medical, sports, and robotics, to tackle these problems. (2) Similar to computer vision in its infancy, applying new sensing modality to other problem spaces requires a long and steep learning curve. A practical principle would be inventing novel form factors. For example, in magnetic sensing, the system should limit the distance between the sensor and magnet without burdening users. I plan to collaborate with experts from human computer interaction to invent new wearable form factors. (3) I believe **accessibility and transparency** are the bedrock for expanding external engagement. We are also open-sourcing MagX, METRO, and POLARIS for research communities and already received inquiries about leveraging our systems for achieving drift-free, low-cost motion tracking. Moving forward, I will organize international workshops at academic conferences to build communities that invite researchers from interdisciplinary domains to share emerging problems and new sensing technologies.

Security and Privacy Models for Emerging Sensing Modalities. My works also covers other sensing modalities such as Bluetooth low-energy (BLE) beacons [2], battery voltage [5], and vehicular control units [9]. These emerging sensing capabilities, while offering significant advancements, can lead to intrusive data collection. Conversely, overly cautious privacy measures might impair the practical utility of these technologies. Consider the examples of TurnsMap – while they have proven useful in real-world scenarios, their potential for misuse, such as unauthorized driver identification or location tracking, cannot be ignored. Facing this entangled problem, I aim to develop usable data collection form factors that users would feel comfortable to use, even in their everyday lives. I believe these efforts would be crucial for better connecting humans with fast-emerging technology landscapes.

Selected Publications and Outputs

(Underlined authors are my direct advisees, “*” denotes co-primary authors)

- [1] **Dongyao Chen**, Kyong-Tak Cho, Sihui Han, Zhizhuo Jin, and Kang G. Shin. “Invisible Sensing of Vehicle Steering with Smartphones”. In *Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys 2015)*.
- [2] **Dongyao Chen**, Kang G. Shin, Yurong Jiang, and Kyu-Han Kim. “Locating and Tracking BLE Beacons with Smartphones”. In *Proceedings of the 13th International Conference on emerging Networking EXperiments and Technologies (CoNEXT 2017)*.
- [3] **Dongyao Chen** and Kang G. Shin. “TurnsMap: Enhancing Driving Safety at Intersections with Mobile Crowdsensing and Deep Learning”. In *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (UbiComp 2019)*.
- [4] Mert D. Pesé, Troy Stacer, C. Andrés Campos, Eric Newberry, **Dongyao Chen**, and Kang G. Shin. “LibreCAN: Automated CAN Message Translator”. In *Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security (CCS 2019)*.
- [5] Liang He, Yuanchao Shu, Youngmoon Lee, **Dongyao Chen**, and Kang G. Shin. “Authenticating Drivers Using Automotive Batteries”. *ACM International Conference on Ubiquitous Computing (UbiComp 2020)*.
- [6] **Dongyao Chen**, Mingke Wang, Chenxi He, Qing Luo, Yasha Irvantchi, Alanson Sample, Kang G. Shin, and Xinbing Wang. “Wearable, untethered hands tracking with passive magnets”. *The ACM International Conference on Mobile Computing and Networking (MobiCom 2021)*.
- [7] Mingke Wang*, Qing Luo*, Yasha Irvantchi, Xiaomeng Chen, Alanson Sample, Kang G. Shin, Xiaohua Tian, Xinbing Wang, and **Dongyao Chen**. “Automatic Calibration of Magnetic Tracking”. *The ACM International Conference on Mobile Computing and Networking (MobiCom 2022)*.
- [8] Fengyuan Zhu, Mingwei Ouyang, Luwei Feng, Yaoyu Liu, Xiaohua Tian, Meng Jin, **Dongyao Chen**, and Xinbing Wang. “Enabling Software-defined PHY for Backscatter Networks”. *ACM International Conference on Mobile Systems, Applications and Services (MobiSys 2022)*.
- [9] Mert D. Pesé, **Dongyao Chen**, C. Andrés Campos, Alice Ying, Troy Stacer, and Kang G. Shin. “DETROIT: Data Collection, Translation and Sharing for Rapid Vehicular App Development”. *IEEE International Conference on Sensing, Communication and Networking (SECON 2022)*.

- [10] **Dongyao Chen**, Mert D. Pesé, and Kang G. Shin. “Guess Which Car Type I Am Driving: Information Leak via Driving Apps”. The Inaugural Symposium on Vehicle Security & Privacy (VehicleSec 2023). **[Best Paper Award]**
- [11] **Dongyao Chen**, Qing Luo, Xiaomeng Chen, Xinbing Wang, and Chenghu Zhou. “MagDot: Drift-free, Wearable Joint Angle Tracking at Low Cost”. In Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT/UbiComp) 2024
- [12] Jike Wang, Shanmu Wang, Yasha Iravantchi, Mingke Wang, Alanson Sample, Kang G. Shin, Xinbing Wang, Chenghu Zhou, and **Dongyao Chen**. “METRO: Magnetic Road Markings for All-weather, Smart Roads”. The ACM International Conference on Mobile Computing and Networking (MobiCom 2023).
- [13] Jike Wang, Yasha Iravantchi, Alanson Sample, Kang G. Shin, Xinbing Wang, **Dongyao Chen**. “POLARIS: Accurate, Vision-free Fiducials for Mobile Robots with Magnetic Constellation”. The ACM International Conference on Mobile Computing and Networking (ACM MobiCom), 2024
- [14] Kunpeng Huang, Yasha Iravantchi, **Dongyao Chen**, and Alanson P. Sample. “MagDesk: Interactive Tabletop Workspace based on Passive Magnetic Tracking”. In Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT), 2025. **[Distinguished Paper Award]**
- [15] Runtong Zhang, Yijie Li, Dian Ding, Yi-Chao Chen, Yida Wang, **Dongyao Chen**, Jingxian Wang, Jiadi Yu, Ling Ma, and Guangtao Xue. “Bridge: Enabling BLE Direction Finding Feature Compatible with All Bluetooth Devices”. The ACM International Conference on Mobile Computing and Networking (ACM MobiCom), 2025
- [16] Xiaomeng Chen, Jike Wang, Zhenyu Chen, Xinbing Wang, Alfred Chen, and **Dongyao Chen**. “DualStrike: Accurate, Real-time Eavesdropping and Injection of Keystrokes on Commodity Keyboards”. To Appear in Network and Distributed System Security (NDSS) Symposium, 2026
- [17] DriverX. <https://driverx.net/>
- [18] MagX Demo. https://www.youtube.com/watch?v=KH2tZ0x_HuM
- [19] MAGIC Demo. <https://www.youtube.com/watch?v=EEMWb0cUsrc>
- [20] MagX GitHub repository. <https://github.com/dychen24/magx>
- [21] METRO GitHub repository. <https://github.com/wjk5117/METRO/>
- [22] POLARIS GitHub repository. <https://github.com/wjk5117/Polaris>
- [23] V-Sense Demo. https://youtu.be/OwgWmU_cgI4
- [24] LocBLE Demo. <https://youtu.be/556lo5MoJso>