Research Statement

[Tengxiang Zhang](#)

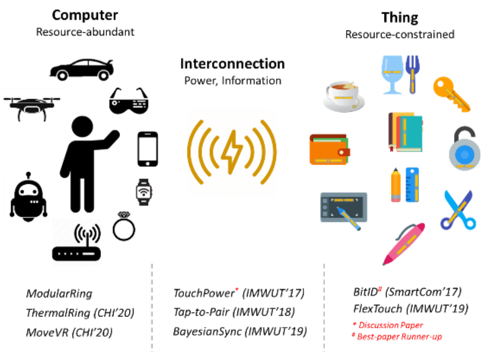

Figure 1: A Thing-computer interconnection paradigm for sustainable computing and interaction.

My research lies in the technical side of ubiquitous computing and human computer interaction. I adopt a human-centered perspective to design sustainable sensing and interactive systems, which form a pervasive interface to merge the digital and physical world. I believe the key for such an interface is spontaneous and smooth flow of information and energy among computers and everyday things. Thus, my previous work falls into three categories (Figure 1): **Sensing Tags**, **Finger Wearables,** and **Interconnection Techniques**. Such efforts have led to over 10 publications at top-venues including SIGCHI and IMWUT with two paper awards.

1. Augmenting Everyday Things with Sensing Tags

Interactive everyday things are essential for ubiquitous sensing and interaction. Replace existing things with battery-powered 'smart' things is not sustainable, since the large amount of batteries would introduce huge maintenance efforts and cause significant damage to the environment. So, I develop maintenance and battery free wireless sensing tags that can be easily deployed on existing everyday things. The sensor's many hardware components (e.g. power source, RF oscillator) and functions (e.g. signal digitalization) are offloaded to a remote resource-abundant computer. The cost, size, and power consumption of such sensors are then minimized, which makes them suitable for ubiquitous deployment on existing infrastructure and objects.

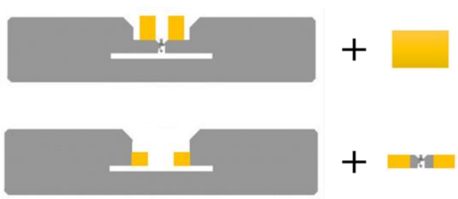

Figure 2: BitID tags enabled by shorting the IC (top) and separating the IC with the antenna (bottom)

In **BitID** [1], I modify commercial-off-the-shelf (COTS) low-cost and passive UHF RFID tags to behave as binary sensors. The tag's readability is modulated by externally switching the antenna matching impedance, which is achieved by changing the electrical connection around the chip as shown in Figure 2. Users can easily make and deploy BitID sensors to detect binary states of various objects (Figure 3). Codes for a complete BitID system including sensor registration, definition, and event recognition are open sourced [1].

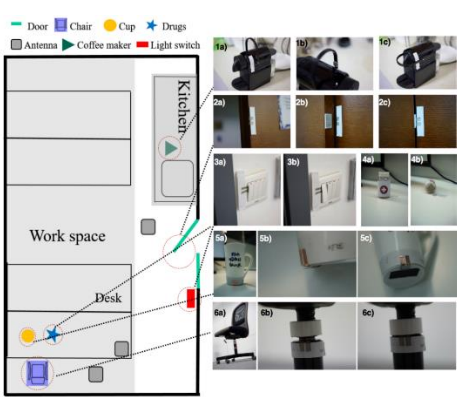

Figure 3: BitID deployed on six objects in an office room.

The RFID reader used in BitID is expensive and not widely available yet. So, I look into opportunities to leverage more accessible computers to power and compute for the resource-constrained tags. **FlexTouch** [2] uses conductive strips to extend the sensing range of the capacitive touch screen on a smart phone to a larger area (e.g. a Yoga mat). I am also developing ultra-low-power backscatter touch sensors that can broadcast touch events to unmodified Bluetooth devices like smart watches.

2. Designing Novel Finger Wearable Computers

Finger wearables can support accessible and subtle gesture inputs. They are also close to the interacting object, which makes them ideal for resource sharing. However, finger wearables are challenging to design due to their size constrains. The small size further limits the available computing, I/O, and power resources on such computers.

To overcome the constrains, I apply modular design on a smart ring (Figure 4). Instead of integrating all functions into one piece of hardware, **ModularRing** [3] uses switchable I/O modules for interaction. The novel wearing design allows the I/O module to be separated from the wireless MCU and battery. Users can then switch the module and combine multiple rings with different I/O modules to form the desired interaction interface. For example, one ring with a microphone module and one with a speaker module can work together as an audio interface to make calls. ModularRing won Finalist of 2018 Global Innovation Competition and led to three patents. The hardware design is open sourced [3].

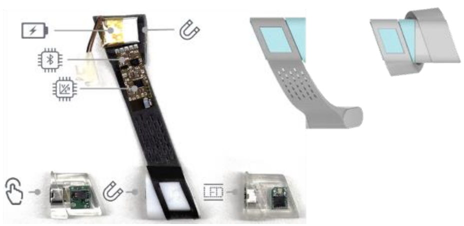

Figure 4： ModularRing adopts a modular design for smart rings.

In **ThermalRing** [4], I use a novel input module-a low-power low-resolution thermal camera for gesture and tag inputs. ThermalRing analyzes the heat silhouette of the hand to recognize drawing gestures on flat surfaces (Figure 5). A bag-of-word model is trained to recognize gestures based on movement distance and angle of the hand. I also proposed ThermalTag, passive tags that can be easily made using materials with high heat reflectivity (e.g. copper tape). When covered by hand, ThermalTag reflects the heat radiated from the hand and thus can be imaged. This demonstrates how the on-body wearables can work together with off-body tags to enable more interaction possibilities. The firmware of the project is open sourced [4].

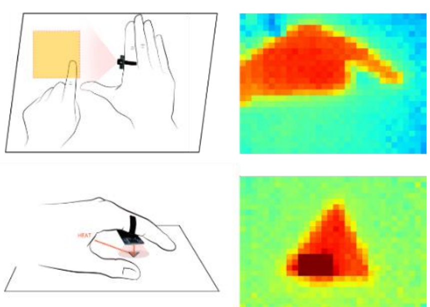

Figure 5: Thermal imaging of a hand and a passive tag.

3. Establishing Human-centered Thing-computer Interconnections

Currently, interactions are typically centered around powerful and independent computing devices. A pervasive interface requires interactive everyday things, which will introduce unacceptable deployment and maintenance efforts. Interconnection techniques reduce such efforts by enabling users to redistribute energy, computation, and I/O resources among computers and everyday things. Only necessary functions like sensing and feedback are kept on the resource-constrained things, while demanding functions like computing and power are offloaded to the resource-abundant computers.

Powering off-body objects with on-body energy sources can greatly reduce power maintenance efforts. I invent the concept of **Interaction-based Power Transfer (IPT)** [5], which leverages the contact and closeness between user and object during interaction to transfer power. IPT is especially suitable for devices that only need to be powered during interaction (e.g. mouse, remote controller). The concept was validated with a glove-based IPT prototype **TouchPower** (Figure 6), which transfers DC power through contacts of electrodes on the glove and objects. With careful design of the transfer interface, energy can be transferred with little impact on the original interaction.

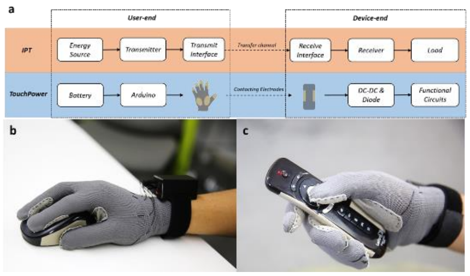

Figure 6: Components of IPT systems (a). TouchPower used with a mouse (b) and a remote control (c).

I also develop human-centered association techniques to initiate interaction from the more available everyday things. **Tap-to-Pair** [6] supports spontaneous device association based on temporal correlation of two signals. Users can tap on an IoT device to induce periodic wireless signal strength changes, which is then correlated with the blinking patterns of target devices for association (Figure 7). A follow up work [7] proposes a 2D design space and design guidelines for blinking patterns by applying Bayesian models of user tapping behaviors. Such optimization enables the technique to support robust selection among more targets. A functional Tap-to-Pair application for Linux systems is open sourced [6].

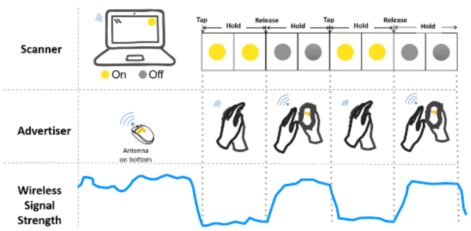

Figure 7: Tap-to-Pair associates two wireless devices by synchronous tapping.

Future Research Directions

My previous work focus on building sensing and interactive systems for pervasive interaction. In the future, I plan to continue the effort to connect computers and things. Aside from that, I will explore how to enable users to build applications that take full advantages of the interconnected things and computers. I am also eager to collaborate with colleagues with various backgrounds to apply my skills in HCI, computer science, and electrical engineering to new application domains, including but not limited to smart building, smart city, education, etc. Topics that I plan to work on include

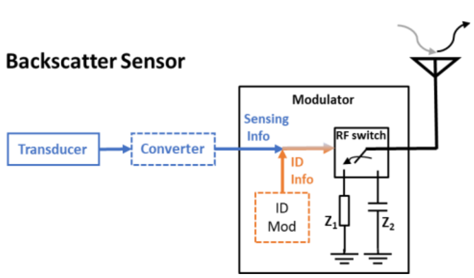

Figure 8: A side-band modulation backscatter sensor

1. Low-maintenance and easily deployable sensing systems

I plan to build backscatter wireless sensing systems with ultra-low-power sensors that leverage existing wearable devices, robots, and drones for signal processing. I also plan to design sensing features on everyday things to create signals that are easier to detect and process. This is similar to how different text colors make it easier for human eyes to read. The sensors and features will be designed so that they can be easily deployed on everyday objects.

2. Generation of everyday AI models with minimal user efforts

User generated and customized AI models are accurate, robust, private, and versatile for the diverse and varied user needs. However, it is not practical for users to collect and label all data, as well as evaluate and iterate the models. I plan to leverage ubiquitously deployed sensors to automatically collect and label the training data to reduce human efforts. I will also explore methods to quantify subjective feelings by analyzing biosignals, which can also reduce user efforts involved in data labeling and system evaluation.

3. Human-AI symbiosis theory and applications in HCI

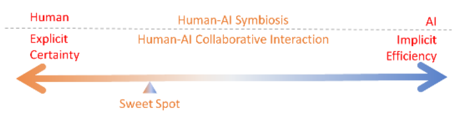

Figure 9: Human-AI collaborative interaction

My previous research focus on pure explicit interactions, for which users fully express their intention by completing gestures. A pure implicit interaction predicts and auto-completes the task for the user. I'm utterly curious about the sweet spot between the two extremes (Figure 9), where it is optimal (in terms of naturalness, efficiency, etc.) for users and practical (in terms of expense, lag, etc.) for AI to collaborate on various tasks. I will both formulate fundamental theories and develop human-in-the-loop interactive AI systems to take advantages of the strengths of both human and AI.

REFERENCES

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3. *Yuanchun Shi, Yinshuai Zhang, and Tengxiang Zhang. 2018. CN Patent 108926081.A Smart Ring and Its Wearing Method.* ***Codes****: https://github.com/saintnever/ModularRing*

4. *Tengxiang Zhang, Xin Zeng, Yinshuai Zhang, Ke Sun, Yuntao Wang, and Yiqiang Chen. 2020. ThermalRing: Gesture and Tag Inputs Enabled by a Thermal Imaging Smart Ring. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20), 13.* ***Codes****: https://github.com/saintnever/thermalring*

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6. *Tengxiang Zhang, Xin Yi, Ruolin Wang, Yuntao Wang, Chun Yu, Yiqin Lu, and Yuanchun Shi. 2018. Tap-to-Pair: Associating Wireless Devices with Synchronous Tapping. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 2, 4: 201:1–201:21.* ***Codes****: https://github.com/starsjf/Tap2pair*

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