

Research Statement

[Tengxiang Zhang](#)

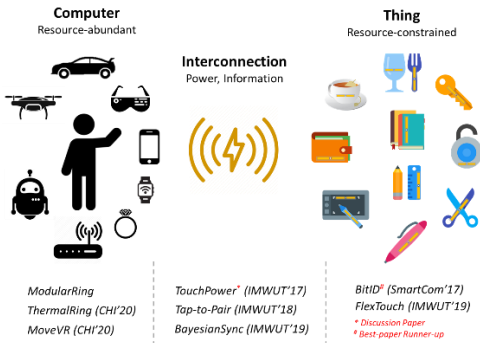


Figure 1: A Thing-computer interconnection paradigm for sustainable computing and interaction.



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



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

My research lies in the technical side of ubiquitous computing and human computer interaction. I adopt a human-centered perspective to build self-sustainable sensing and interactive systems. The key to weave technologies into the fabric of everyday lives is spontaneous 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.

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].

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 constraints. The small size further limits the available computing, I/O, and power resources on such computers.

To overcome the constraints, 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].

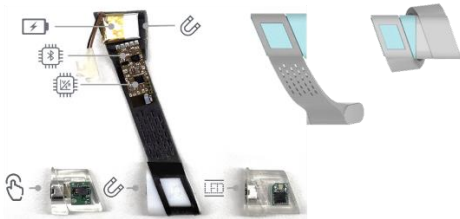


Figure 4: ModularRing adopts a modular design for smart rings.

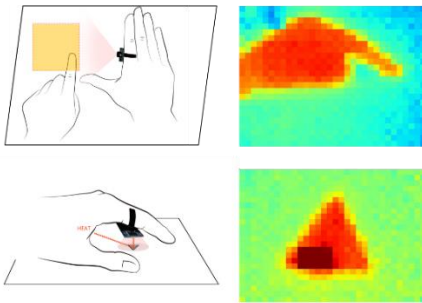


Figure 5: Thermal imaging of a hand and a passive tag.

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-words 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].

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.

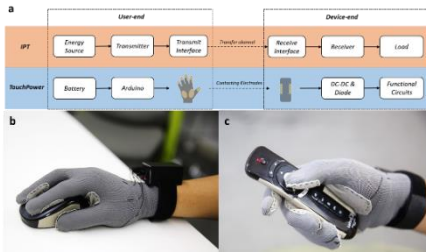


Figure 6: Components of IPT systems (a). TouchPower used with a mouse (b) and a remote control (c).

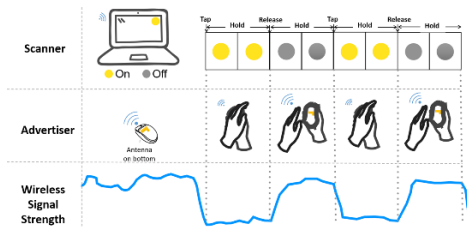


Figure 7: Tap-to-Pair associates two wireless devices by synchronous tapping.

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.

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 fully-functional Tap-to-Pair application for Linux systems is open sourced [6].

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

1. Self-sustainable Sensors and Sensing Materials

I am developing ultra-low-power backscatter wireless sensors that can be continuously powered by energy harvesting techniques. Such self-sustainable sensors do not require user maintenance, thus are suitable for ubiquitous deployment. I also plan to leverage my metamaterials background to build chipless and passive wireless sensing materials that can be applied to everyday surfaces. I will focus on designing sensing features on things for fast and robust signal processing on computers.

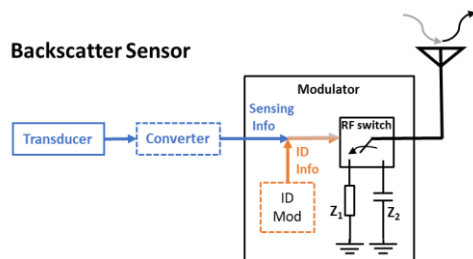


Figure 8: A side-band modulation backscatter sensor

2. Pervasive Interaction Techniques for Resource-constrained Devices

The ubiquitous sensors can form pervasive input interfaces. However, their computing and input/output capabilities are extremely limited due to power and cost constraints. To address the challenge, I plan to focus on synchronization-based and semantic-based pervasive interaction techniques. I will also continue to develop power and information transfer techniques. In this way, existing powerful computers like wearables, robots, and drones can work together with ubiquitously deployed sensors for an immersive interaction experience.

3. Intelligent Human-machine Systems and Theories

Ubiquitous sensors enable new ways to build intelligent human-machine systems. I plan to leverage such accurate and robust sensors to automatically collect and label training data for personalized intelligent human-machine systems. I will also explore methods to quantify subjective feelings by analyzing biosignals, which can further reduce user efforts. I am also interested in theories on interpretation and optimization of such human-machine systems. I believe the key is to quantify the difficulty of the task for human and machine separately. I am utterly curious about the sweet spot (Figure 9) where it is optimal for users (in terms of naturalness, efficiency, etc.) and for machines (in terms of expense, lag, etc.) to collaborate on various tasks.

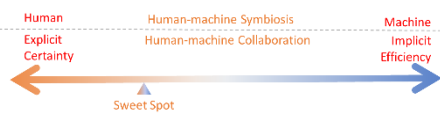


Figure 9: Human-machine collaboration

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