Research Statement

[Tengxiang Zhang](https://)

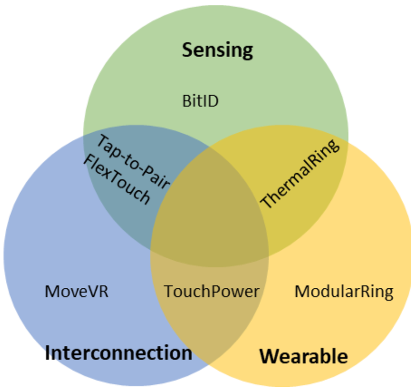

Figure 1: Taxonomy of my previous works.

My research lies in the technical side of ubiquitous computing and human computer interaction. I adopt a human-centered perspective to build a pervasive interface to bridge the digital and physical. I believe the key to build such an interface is to enable 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

Existing interactive everyday things are usually expensive and require extra maintenances (e.g. charging). Users can also be reluctant to replace existing objects with the 'smart' version for aesthetic or sentimental reasons. To overcome such limitations, I develop passive wireless sensing tags that can be easily deployed on existing everyday objects. The sensor's many hardware components (e.g. power source, RF oscillator) and processing steps (e.g. signal digitalization) are offloaded to a remote device. The cost, size, and power consumption of such sensors are then minimized. The small and thin form factor and the passive nature make them suitable for ubiquitous deployment on existing infrastructure and objects.

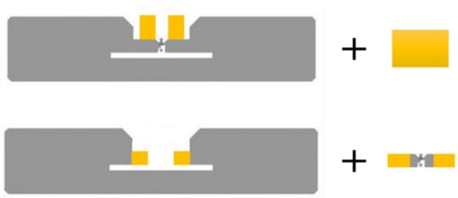
Figure 2: BitID tags enabled by shorting the IC (top) and separating the IC with the antenna (bottom)

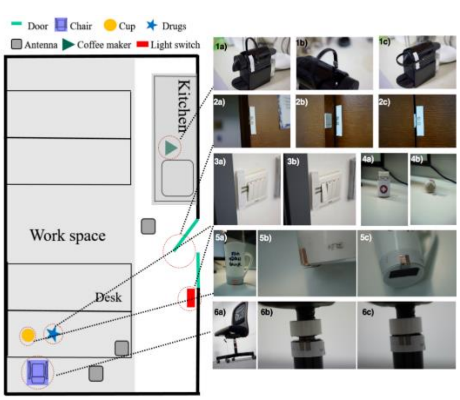

Figure 3: BitID deployed on six objects in an office room.

In **BitID** [1], I modify commercial-off-the-shelf (COTS) low-cost and passive UHF RFID tags to detect binary object states. By attaching shorting stubs to exposed antenna around the chip (Figure 2), the tag's readability is modulated by the connection status of the shorting stubs. Users can easily make BitID sensors using everyday tools like copper tape and scissors. We deploy BitID sensors on various objects (Figure 3) to show its potential and scalability. The codes for the BitID sensing system is open sourced on GitHub. The RFID reader used in BitID can be expensive and is 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] extends the capacitive sensing ability of a smart phone to everyday things. With one end of conductive ITO-coated PET films applied on its touch screen, the smart phone can detect and process capacitive changes on the other end of the films. The smart phone can then recognize human behaviors and different object states.

2. Developing finger wearables for more interaction possibilities

Finger wearables can support a rich set of input gestures thanks to the dexterity of fingers. They are also close to the interacting object, which makes them ideal candidates for resource sharing. However, finger wearables are challenging to design due to the size constrains. The small size further limits the available computing, I/O, and power resources.

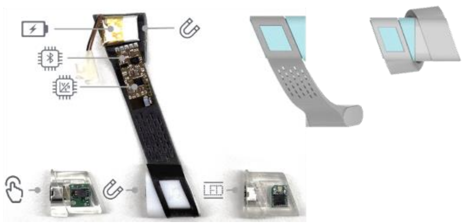

Figure 4: ModularRing adopts a modular design for smart rings.

To overcome such resource constrains, I explore modular design for a smart ring (Figure 4). Instead of integrating various I/O 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 I/O module based on needs, and combine multiple rings with different I/O modules to create advanced interfaces. For example, a ring with a microphone module and a ring with a speaker module can work together as an audio interface to make a call. ModularRing won Finalist of 2018 Global Innovation Competition and led to three patents.

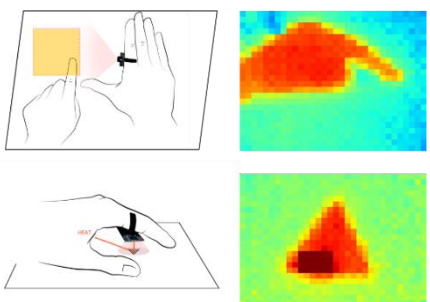

Figure 5: Thermal imaging of a hand and a passive tag.

In **ThermalRing** [4], I proposed a novel I/O 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). 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.

3. Establishing Interconnections for Resource Distribution

Currently, most interaction interfaces are centered around powerful and independent computing devices. A human-centered pervasive interface, however, requires seamless interconnection among devices for resource redistribution. By allocating energy, computation, and I/O resources based on needs, the design of the interfaces can be more flexible and thus be truly woven into the fabric of everyday life.

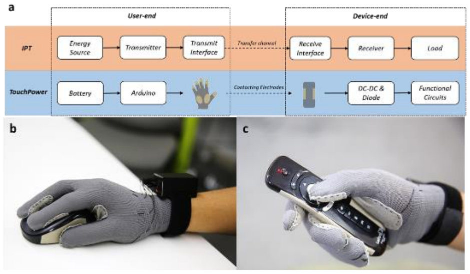

Figure 6: Components of IPT systems (a). TouchPower used with a mouse (b) and a remote control (c).

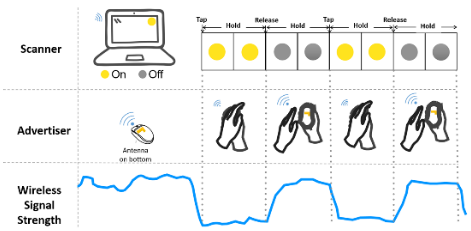

Figure 7: Tap-to-Pair associates two wireless devices by synchronous tapping.

Powering off-body objects with on-body energy sources can significantly reduce user maintenance efforts. I invented the concept of **Interaction-based Power Transfer (IPT)** [5], which leverages the contact and closeness between user and object during interaction to establish power transfer channel. 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 redistributed without affecting the original interaction.

IoT devices are usually resource constrained and thus can only support limited interaction. **Tap-to-Pair** [6] provides a spontaneous device association experience based on temporal correlation of two signals. Users can tap the initiating 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 from more targets.

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 and improve the existing work. 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 electronics to new application domains, including but not limited to smart building, smart city, education, etc. Topics that I plan to work on include

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, just like how different text colors make it easier for human eyes to read. The sensors and features will be designed so that users can easily deploy them on everyday objects.

2. Generation of everyday AI models with minimal user efforts

User generated and customized AI models can better satisfy individual user needs with lower computing cost. However, the cost to build such AI models on the human side is generally high. I plan to leverage ubiquitously deployed sensors to automatically collect and label the training data, thus reducing human efforts. I will also explore methods to quantify subjective feelings by analyzing biosignals, which can also enable easier building and evaluation of such user-generated AI models.

3. Human-AI symbiosis theory and applications in HCI

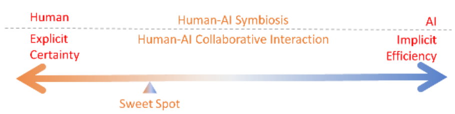

Figure 8: Human-AI collaborative interaction

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 8), 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.

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