Research Statement

[Tengxiang Zhang]()

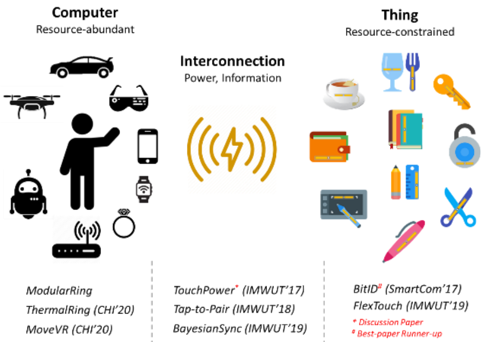

Figure 1: A Thing-computer interconnection paradigm for sustainable computing and interaction.

My research lines in the technical side of ubiquitous computing and human computer interaction. I adopt a human-centered perspective to design sustainable sensing and interaction systems to bridge the physical and the digital world. More specifically, I develop power and information **interconnection** techniques to offload energy and computing intensive tasks and components from resource-constrained **things** to resource-abundant **computers**. Such efforts have led to consecutive publications at top-venues including SIGCHI and IMWUT with two paper awards. My previous work falls into three categories (Figure 1): **Sensing Tags**, **Finger Wearables,** and **Human-centered Interconnection Techniques**.

1. Augmenting Everyday Things with Sensing Tags

Augmented everyday things are key to enable pervasive ubiquitous sensing and interaction. Replace existing things with battery-powered 'smart' things is not sustainable, since the large amount of batteries will introduce huge maintenance efforts and can 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 device. The cost, size, and power consumption of the sensors are then minimized, which makes them suitable for ubiquitous deployment.

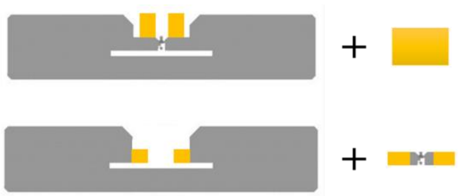

Figure 2: BitID tags enabled by shorting the IC (top) and separating the IC with the antenna (bottom)

In **BitID** [3], I modify commercial-off-the-shelf (COTS) low-cost and passive UHF RFID tags to behave as binary sensors. By externally switching the antenna matching impedance, the tag's readability is modulated by the contact status of the two parts (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 registration, definition, and recognition are open sourced [here]().

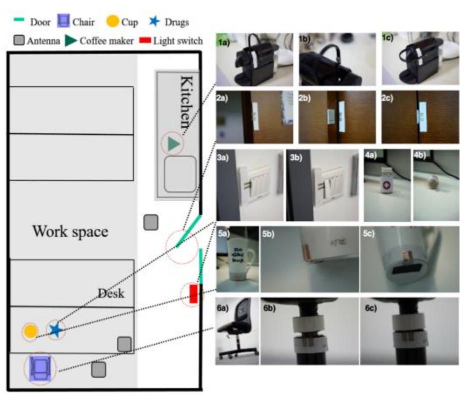

Figure 3: BitID deployed on six objects in an office room.

I also leverage more accessible computers to power and compute for tags. **FlexTouch** [2] uses conductive strips to extend the sensing range of the capacitive touch screen on a smart phone, which can detect large-scale activities like Yoga postures. ThermalTags in [7] reflect heat from human hands for thermal imaging, which are used for quick access purposes.

2. Novel Design of Finger Wearable Computers

Finger wearable computers can support a rich set of input gestures thanks to the dexterity of fingers. Also, they are usually in close proximity to the interacting object, which makes them ideal candidates as computers in the Thing-computer interconnection paradigm. However, finger wearables are challenging to design due to size constrains. The small size further limits the available computing, I/O, and power resources.

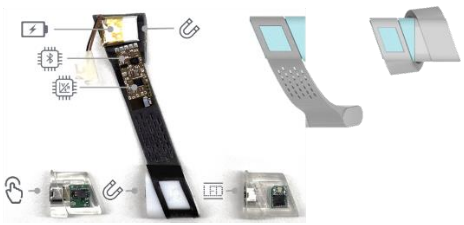

Figure 4: ModularRing adopts a modular design for smart rings.

To overcome such constrains, I apply modular design on a smart ring (Figure 4). Instead of integrating all functions into one piece of hardware, **ModularRing** [1] uses switchable I/O modules for interaction. The novel wearing method allows the I/O module to be separated from the wireless MCU and battery. Users can then switch the module and combine multiple rings to form desired interaction interfaces. For example, a ring with a microphone module and a ring with a speaker module can work together as an audio interface. ModularRing won Finalist of 2018 Global Innovation Competition and led to three patents. The hardware design is open sourced [here](#).

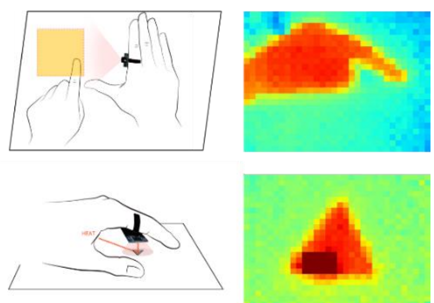

Figure 5: Thermal imaging of a hand and a ThermalTag.

In **ThermalRing** [7], 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 its drawing gestures on flat surfaces (Figure 5). The movement distance and angle of the hand are calculated from its side thermal image. A bag-of-word model is trained to recognize gestures based on movement features. The ring can also recognize ThermalTags, which shows how on-body wearables and off-body tags together can enable more spontaneous and convenient interaction. The firmware of the project is open sourced [here](#).

3. Human-centered Interconnections for and by Interaction

The resource-constrained things need to be associated with resource-abundant computers for power and information transfer. The user should be able to initiate the interconnection from both computers and things. The user-thing interaction itself can be leveraged to establish power interconnection between on-body computers and off-body things, thus eliminating the need for batteries on things.

Currently, users usually interact with computers (e.g. smart phone). However, it is impractical for users to access such powerful computers anytime anywhere. I develop human-centered association techniques to enable initiating interaction from the more available everyday things.

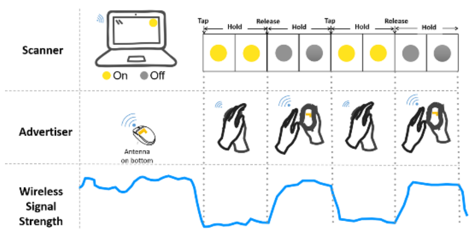

Figure 6: Tap-to-Pair associates two wireless devices by synchronous tapping.

Tap-to-Pair [5] supports a spontaneous device association based on temporal correlation of two signals. Users can tap on the thing to induce periodic wireless signal strength changes, which is then correlated with the blinking patterns of target devices for association (Figure). I then propose a 2D design space and design guidelines for blinking patterns by applying Bayesian models of user tapping behaviors [4]. Such optimization enables the technique to support robust selection among more targets. A ready-to-use Tap-to-Pair program is open sourced [here]().

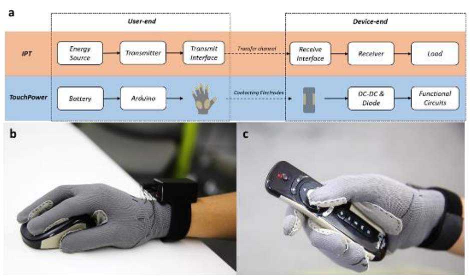

Figure 7: Components of IPT systems (a). TouchPower used with a mouse (b) and a remote control (c).

Power transfer from one on-body wearable to off-body things can significantly reduce user maintenance efforts since only the wearable computer need to be charged. I invent the concept of **Interaction-based Power Transfer (IPT)** [6], which transfers on-body energy to off-body devices leveraging the proximity and contact between the user and the object during interaction. IPT is especially suitable for devices that only need to be powered during interaction (e.g. mouse, remote controller). I build a glove-based IPT prototype **TouchPower** (Figure) to validate the concept. TouchPower transfers DC power through contacts of electrodes on the glove and the object. With careful design of the transfer interface, energy can be distributed with little impact on the original interaction.

Future Research Directions

My previous work focus on enabling sustainable ubiquitous sensing and interactive systems. In the future, I plan to continue working on such sustainable systems based on the Thing-computer interconnection paradigm. Aside from that, I will also start formularizing the general theory and design guidelines for such sustainable sensing and interaction systems. I'm also eager to collaborate with colleagues with various backgrounds to apply my skills in HCI, electronics, and computer science to new application domains, including but not limited to smart building, smart city, education, etc. Specifically, I plan to

1. Develop backscatter sensors and wireless sensing algorithms

I plan to build backscatter sensors both with and without chips, which can leverage resources from computers including wearable devices, robots, and drones. At the same time, I will develop wireless sensing algorithms for activity detection and prediction. I plan to combine sensing data from multiple sources with backscattered wireless signals to improve sensing accuracy and reduce training efforts.

2. Design digital resource redistribution mechanisms

My previous work investigates physical resource distributions. Digital resources should also be able to flow freely among things and computers, following the user for a truly human-centered interaction experience. I plan to design AR-assisted solutions to request and transfer digital resources with a finer gratuity among computers and between computers and things.

3. Human-AI symbiosis theory and applications in HCI

My previous research focus on pure explicit interactions, for which users fully express their intentions by performing gestures. A pure implicit interaction predicts and auto-completes the task without any explicit expressions from users. I'm utterly curious about the sweet spot between the two extremes (Figure 6), where it is optimal (in terms of naturalness, efficiency, etc.) for users and practical (in terms of expense, lag, etc.) for AI to collaborate. I plan to take a bottom-up approach to search for the optimal human-AI collaboration model for daily interaction tasks.

Figure 6: Human-AI collaborative interaction

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