Research Statement

[Tengxiang Zhang]

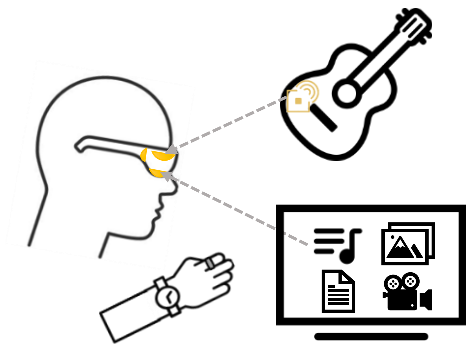

Figure 1: Head, wrist and finger mounted wearable devices facilitate interaction with digital content and tagged physical objects.

Digital content is breaking out of the screens into the physical world with the help of augmented reality and IoT technologies. How do we transition into the new computing paradigm and interact with digital content and physical objects in a natural, consistent, and spontaneous way? I build smart wearables (*e.g.*, glasses, rings), develop sensing algorithms (*e.g.*, for gestures/facial actions), and design interaction interfaces (*e.g.*, with AR/MR) to understand and merge the tagged physical world, the digital metaverse, and the humans. Finally, I apply the research outputs to benefit humans (Figure 1). Thus, my previous work falls into three categories: **Smart Wearables, Digital and Physical Resources Integration Techniques**, and **Pervasive Sensing and Interaction**. Such efforts have led to over ten publications at top venues, including SIGCHI and IMWUT, with two paper awards.

1. Head, Wrist and Finger Mounted Wearable Devices

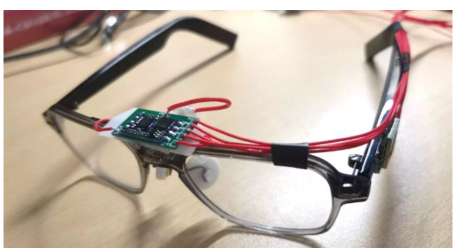

Figure 2: Smart glasses support novel interaction via EOG and IMU sensing.

I focus on smart rings and smart glasses to sense both explicit and implicit interaction intent. Our smart glasses prototype (Figure 2) deploys electrooculography (EOG) electrodes on the nose pads and between the eyebrows to sense upper facial activity. It also places two inertial measurement units (IMUs) close to the skin below the ears to sense lower facial movement. The project was demonstrated at the MobileHCI 2022 Student Design Competition and later invited for video demonstration at the Huawei Developer Conference 2022.

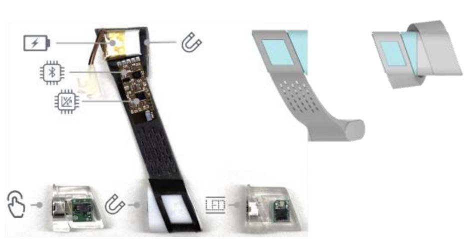

Figure 3: ModularRing adopts a modular design for smart rings.

Finger wearables can support accessible and subtle gesture inputs. However, finger wearables are challenging to design due to the inherent size constraints which limit the available computing, I/O, and power resources. To overcome these limitations, I designed a modular smart ring (Figure 3). Instead of integrating all functionality into a single piece of hardware, the novel design of **ModularRing** [1] separates the I/O module from the wireless MCU and battery. Users can then switch the module and combine multiple rings with different I/O modules to support the desired interaction. For example, one ring with a microphone module and one with a speaker module can work together as an audio interface to make audio calls. ModularRing won the Finalist in the 2018 Global Innovation Competition, leading to three patents. The hardware design is open-source [1].

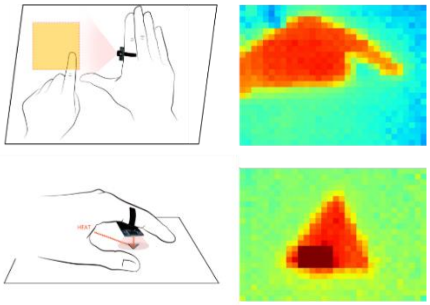

Figure 4: Thermal imaging of a hand and of a passive tag (which reflects the hand's thermal emissions)..

In **ThermalRing** [2], I use a low-power, low-resolution thermal camera to support gestural and tag-based input. ThermalRing analyzes the heat silhouette of the hand to recognize drawing gestures on flat surfaces (Figure 4). A bag-of-words model is trained to recognize gestures based on movement distance and the angle of the hand. I also proposed ThermalTags, passive tags that can be easily made using materials with high heat reflectivity such as copper tape. When covered by a hand, ThermalTags reflect 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, enabling more interaction possibilities. The firmware of the project is open-source [2].

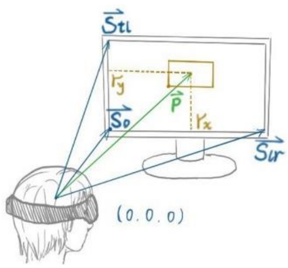

Figure 5: ScreenJump localizes on-screen resources like windows by detecting the screen itself and on-screen positions.

2. Integrating Digital and Physical Resources

As our digital and physical worlds become increasingly entwined, we should be able to interact with both digital content and physical objects seamlessly. This often calls for unified characteristics, such as digital identities for physical objects and spatial coordinates for digital content. **ScreenJump** [3] (Figure 5) uses an AR headset to calculate the spatial coordinates of on-screen digital resources (e.g., images, text) by localizing the screen and retrieving pixel positions of such resources from the corresponding computing device. Users can thus select and manipulate such fine-grained digital resources by intuitive gazes and gestures.

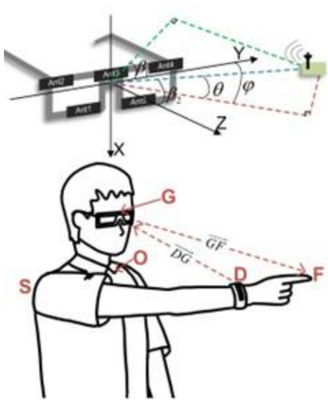

Figure 6: BLEselect deploys an antenna array on a pair of smart glasses to detect AoA from wearables and tags to make gestural selection of physical objects more intuitive.

BLEselect [4] (Figure 6) enables intuitive head and hand gestural selection of physical objects. A compact antenna array is fitted on a pair of smart glasses to estimate the angle of arrival (AoA) of advertising signals from wrist-worn devices and Bluetooth tags. A sensing pipeline supports three selection gestures—nodding, pointing thand encircling—with lightweight machine-learning models trained in real-time. Extensive evaluations show our system is accurate, low-power, and privacy-preserving despite the small-size antenna array.

Figure 7: Bluetooth-compatible backscatter sensing tag (33x22mm, 800uA).

Since the use of battery-powered tags in BLEselect doesn't scale well due to financial and environmental cost, I developed maintenance-free backscatter wireless tags that offload many hardware components (e.g., power source, RF oscillator) to resource-abundant edge devices. This minimizes communication power consumption and makes it possible to power such tags with harvested energy. I have built a Bluetooth-compatible backscatter tag (Figure 7) that broadcasts the IMU data as Bluetooth advertisements, which commercial devices like smartphones and laptops can receive. The average broadcasting current is only 800uA, a four-fold improvement on commercial Bluetooth chips (3.5mA).

3. Pervasive Sensing and Interaction Techniques

In **BitID** [5], I modify commercial-off-the-shelf (COTS) low-cost passive ultra-high frequency (UHF) radio-frequency identity (RFID) tags to behave as binary sensors. The tag's readability is modulated by externally switching the antenna matching impedance (Figure 8). Users can easily make and deploy BitID sensors to detect the binary states of various objects. Codes for a complete BitID system, including sensor registration, definition, and event recognition, are open-sourced [5].

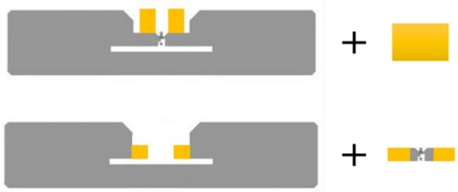

Figure 8: BitID tags work by selectively shorting and separating the IC with the antenna (top and bottom respectively).

How to power up pervasively deployed tags? **FlexTouch** [7] powers sensing structures with existing smart phones. I also invented the concept of **Interaction-based Power Transfer (IPT)** [7], 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 9), which transfers DC power through contacts of electrodes on the glove and objects.

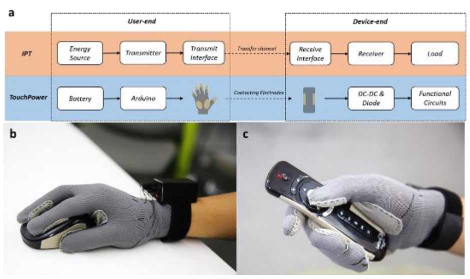

Figure 9: (a) IPT system components. TouchPower used with (b) a mouse and (c) a remote control (c).

Can we use such tags for interaction? **Tap-to-Pair** [8] supports spontaneous device association based on the temporal correlation of two signals. Users can tap on an IoT device to induce periodic wireless signal strength changes, which are then correlated with the blinking patterns of target devices for association (Figure 10). A follow-up work [9] proposes a 2D design space and 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 is open-sourced [9].

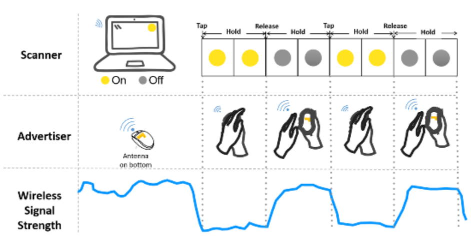

Figure 10: Tap-to-Pair associates two wireless devices by synchronous tapping.

Future Research Directions

I am eager to collaborate with colleagues with various backgrounds to apply my HCI, computer science, and engineering skills to new application domains, including but not limited to smart buildings and cities, education, healthcare and accessibility. New topics that I am actively working towards include:

1. Radar-based Gesture Sensing and Tag Localization

The Bluetooth smart glasses and backscatter tags have limited localization precision. I plan to deploy a miniature 60GHz FMCW radar and Bluetooth transceivers on smart glasses for power-efficient and accurate tag localization. I also plan to leverage the Van Atta array (Figure 11) to estimate tag orientations, which makes it possible for wireless tag-based simultaneous localization and mapping (SLAM). Such radar also has the potential to detect macro and micro gesture inputs.

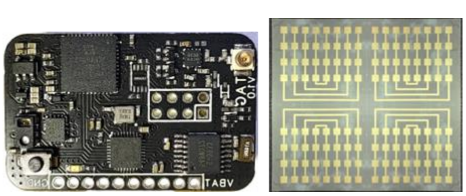

Figure 11: Backscatter tag with two-way communication (left) and Van Atta array based tag antenna for monostatic 60GHz FMCW radar (right).

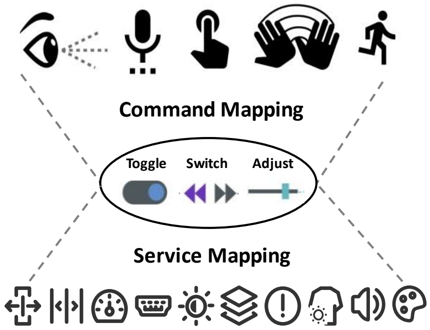

Figure 12: Multi-modal intentions map to available services through a command set.

2. Modalily-agnostic Cross-device Interaction

A world with more tightly integrated physical and digital content calls for a new interaction paradigm. I have been exploring abstracting user interaction intent to a command set, then recommending services accordingly. **BoldMove** [10] experimented with three commands (*Toggle, Switch, Adjust)* on a ubiquitous touch interface (Figure 12). A general interaction framework can bring a new interaction paradigm that better suits the mixed world.

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