Battery-free Wireless Sensing and Beyond

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The future of Internet-of-Things (IoT) demands seamless interaction between users and devices. The vision is also of one, where sensing and actuation interfaces blend into everyday objects. If all these interaction and sensing interfaces are realized without the need of any integrated power source, and built upon hardware so cheap and simple that it can be installed or discarded easily; then, any physical space can become truly context-aware.

Firstly, to achieve this vision of IoT-enabled smart space, we first design and develop RIO, a novel battery-free touch sensing user interface (UI) primitive. With RIO, any surface can be turned into a touch-aware surface by simply attaching RFID tags to them. RIO is built using the technique of impedance tracking: when a human finger touches the surface of an RFID tag, the impedance of the antenna changes. This change manifests as a variation in the phase of the RFID backscattered signal, and is used by RIO to track fine-grained touch movement over both of-the-shelf and custom built tags.

We further develop a novel system called RTSense, which enables low-cost RFID tags to sense room temperature. Our key insight is that the impedance of the RFID tag changes with the temperature and such a change can be reflected in the tag reading. Thus, we can piggy-back communication channel with sensing information. However, it is challenging to achieve high accuracy and robustness against environment changes. To address these challenges, we first develop a detailed analytical model that captures the impact of temperature change on the tag impedance. We then build a system that leverages a pair of tags that respond differently to the temperature change to cancel out the environmental changes.

Finally, we build an end-to-end system which analyzes ball motion using similar commercial passive RFID tags. Despite significant work on wireless sensing, most existing works focus on sensing translation movement or absolute localization. However, rotational movement is also important especially in sports analytics (*e.g.*, tracking ball movement), yet has been under-explored. Motivated by the need, we use RFID tags to sense a ball's speed, direction, spin, and rotation axis. In particular, we exploit the polarization in RFID to enable motion sensing using a single RFID antenna. We develop an analytical model to capture the impact of polarization on the received signal and an optimization framework to incorporate the model to estimate the ball movement. We implement our system, Tag based Inertial Measurement Unit (*TIMU*), and demonstrate its effectiveness through extensive evaluation.