Poster Abstract: CapTag: Toward Printable Ubiquitous Internet of Things

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ABSTRACT

Many human activities involve interactions with passive objects. By wirelessly sensing human interactions with such "things", one can infer activities at a fine resolution, enabling a new wave of ubiquitous applications. This forms the basis of the tangible user interface allowing individual to use omnipresent objects as a control interface to the digital world. Existing works have tendencies to create such interface with complicated circuitry, leading to overwhelm complexities. To conquer these, we propose the inkjet printable capacitive tags (CapTags), empowering a new paradigm of printable communications and sensing modality. We use discrete capacitive and inductive components to simulate the tag-interrogator system, and prove the feasibility of proposed hardware featurization and high frequency sweeping strategy where the information can be encoded in the resonating spikes. This enables the touch points to be detected by searching resonating detune effects. Although this work only includes the designs and simulations, we believe this new sensing modality would truly realize the vision of printable ubiquitous computing.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**.

KEYWORDS

Capacitive Sensing, Tags, Internet of Things

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1 INTRODUCTION

Many human activities involve interactions with passive objects. By wirelessly sensing human interactions with such "things", one can infer activities at a fine resolution, enabling a new wave of ubiquitous applications. The ability to sense touch in the physical world can form the basis of the tangible user interface allowing individual to use omnipresent objects as a control interface to the digital world [1, 7].

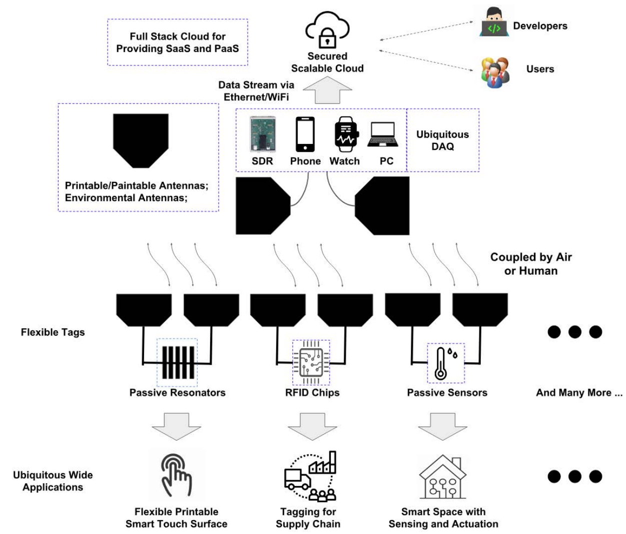

Figure 1: Vision of *CapTags* powered IoT systems.

To harvest these benefits, a practical system needs to satisfy two requirements. *First*, such system needs to *sense touches* on different spots of the same object, and be able to *distinguish touches* on different objects. *Second*, it requires to be simple, flexible and cheap enough so that users are able to fabricate them using the Off-the-shelf (OTS) inkjet printer or paints in large scale without professional skills. Although existing sensors can detect object usages and touch interactions using vision and deep learning algorithms [3], they often require augmenting the objects with circuits, or may provoke visual privacy concerns. Technologies enabled by RFID can overcome these by attaching energy-harvesting tags on objects [7]. However, their antennas are typically made of metal pieces using screen printing approach, and therefore these approaches are suffered from performance degrading while being attached on non-flat surface of irregular objects. Beside, they are barely used in common consumers' daily life due to relatively high costs compared to printed barcodes [6]. To address these, we propose the inkjet printable ***Cap****acitive* ***Tags*** (CapTags), empowering a new paradigm of communications and sensing modality for future *printable* IoTs.

2 SYSTEM DESIGN

Figure 1 shows our long-term vision where CapTag is a passive paper-like tag, comprised of chipless or chip-based capacitive communication/sensing components, together with printable electrodes (capacitive "antennas"). Owing to its passive nature and thin form factor, CapTag can be attached on everyday objects and even woven into clothes. Generally, We target two fundamental challenges:

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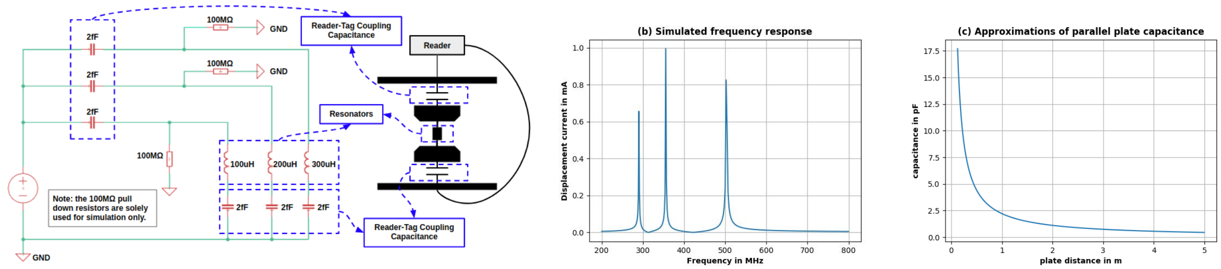

(a) Schematics for simulating tag responses (b) Simulated frequency response (c) Coupling capacitance

Figure 2: Simulation results of preliminary feasibility study

❓ **Tag Design and Fabrications:** How to **design the printable capacitive-coupled tags** and interaction surfaces, such that any user can customize and print the tags to accommodate their own sensing/identification applications?

❓ **Sensing and Communication Algorithms:** How to **extend the capacitive sensing range** for both air-coupling and body-coupling communications?

To address these challenges, we design the tag structure to ensure easy fabrication on OTS inkjet printers without professional skills. Compared to standardized inductive and RF coupled approaches, we propose to use *capacitive coupling* [8] as the sensing and communication method because it does not have strict requirements on the resistance and shape of antenna, indicating conductive inks having moderate resistance can be more than sufficient to fabricate the antennas [4, 6]. Based on chipless passive RFID and Capacitive Wireless Power Transfer (CWPT) [1, 2], we introduce novel approaches to achieve *hardware featurization* where the patterns of resonating frequencies induced by passive printable resonators on the tag are used to encode information which can be read and decoded remotely by an interrogator.

To enable reliable long range sensing, we propose a novel sensing approach, named as *High Frequency – Swept Frequency Resonating Sensing* (HF – SFRS). Unlike prior works examining spectrum less than 5 MHz [5], the spectrum features of CapTag will be sensed up to 800 MHz frequencies. Evidence from high pass characteristics of capacitors and Personal Area Network (PAN) [8] supports the intuitions that higher frequency allows more displacement current passing through the coupling region, leading to long sensing range and higher reliability. Furthermore, we will introduce a mixture of *closed-form* and *data-driven* approaches, as part of future work, to identify human-tag interactions and environmental sensing. This means the *constant resonating properties* created by resonators of CapTag can be used to mark unique touch points, while the *dynamic resonating properties* reveal the characteristics resulting from diverse surroundings and movements. This allows us to interpret the physical environment and identify human-tag interactions under the same settings.

3 PRELIMINARY STUDY

To evaluate the feasibility, we used discrete components to simulate the capacitance coupling impacts by customized designed resonators. We used 2 fF parallel-plate capacitors to model the tag-reader coupling as a conservative choice [8]. Practically, the value may be even smaller due to the unpredictable shunting effects result from surroundings, *e.g.,* metal surfaces of the furniture. Figure 2a shows the schematic used to model the system and Figure 2b shows the SPICE simulation results where three *spikes* can be observed visually due to the tag resonating characteristics. Similar to [1], these resonating "spikes" would be designed to map to each touch points. Figure 2c shows the theoretical relations between coupling capacitance and distance between parallel plate (equation 1), where we choose 40 cm^2 as the effective area and the relative dielectric constant to be 1 (when air is used to fill the space between two parallel plate).

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \quad (1)$$

4 CONCLUSION

We propose the paradigm enabled by inkjet printable CapTags. With simulations, we demonstrate the feasibility of creating resonating spikes using tag resonating characteristics that can then be mapped to different touch points. We leave the experimental evaluations and explorations as part of future work. We believe this new sensing modality truly realize the vision of printable ubiquitous computing.

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