Collisionless Multi-Tag NFC Sensing for Indoor Activity Recognition Using Meander E-Textiles

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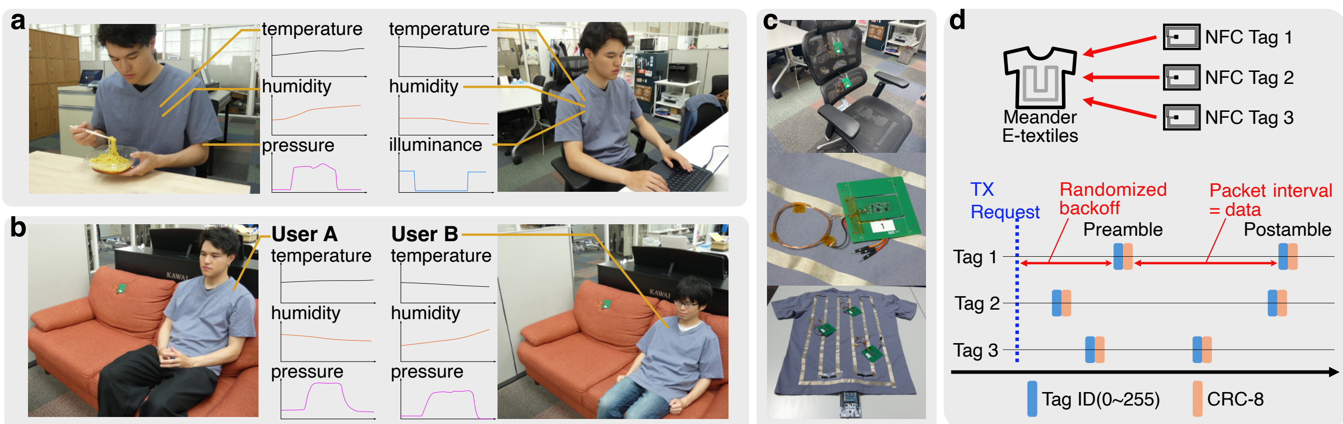

Figure 1: Overview of packet-interval-NFC-based e-textile sensing. (a) Scenarios: when a user sits on a chair equipped with NFC sensor tags, NFC reader garment identifies the location and receives sensor data from the tags. (b) Multi-user scenario: sensor tags know who triggers them and transmit data to the user. (c) Equipment: sensor tags are installed on a chair without battery. Sensor tags are custom circuit with small sized PCB and an loop antenna. (d) Overview of packet interval NFC: each tag autonomously transmits preamble and postamble, whose time interval represent the data sent from the tag.

Abstract

This paper presents a low-maintenance indoor activity sensing based on the interaction between user-worn meander e-textiles and a battery-free near-field communication (NFC) environmental sensor tag. Conventional smart homes rely on a dense deployment of active IoT sensors, which suffer from severe battery maintenance overhead and the multi-user association problem—the difficulty of mapping sensor triggers to specific individuals. To address these challenges, we invert the traditional sensing paradigm: we deploy low-cost, passive, and battery-free NFC tags across the indoor environment (e.g., floors, furniture) while the user wears clothing integrated with a meandered textile coil that functions as an active near-field reader. As the user interacts with daily items such as furniture, the meander e-textile powers and interrogates the nearby NFC sensor tags. By customizing NFC protocol based on packet interval modulation, our system achieves near-collisionless data transmission from multiple NFC tags, unlike conventional NFC constrained to one-to-one proximity interactions. Here, we demonstrate that a user wearing the meander e-textile can stably aggregate data from multiple battery-free sensor tags affixed to a single chair.

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CCS Concepts

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

Keywords

E-textiles; Asynchronous NFC; Packet Interval Modulation; Indoor Activity Recognition; Smart Home; Meander Coil

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1 Introduction

Smart homes usually need many active IoT sensors installed everywhere to track indoor activities. However, this traditional approach has two big problems. First, maintaining these sensors is difficult and costly because hundreds of devices need periodic battery replacements. Second, these sensors cannot tell who triggered them. When multiple people live in the same house, it is very hard to connect a sensor reaction to a specific person. Therefore, we need a new indoor sensing system that requires no battery maintenance and can automatically identify the user.

To solve these problems, we change the traditional setup. We place low-cost, battery-free NFC tags on everyday surfaces like floors and furniture, while the user wears clothing with a built-in meander textile coil that acts as a reader. As the user moves and touches daily items, the clothing powers and reads the nearby tags. While normal NFC only works between one reader and one tag, our system uses a custom protocol based on packet interval modulation (PIM) [1]. By combining this protocol with the meander textile coil [2–5], the clothing can efficiently power a wider area and communicate with multiple tags near the user without data collisions. As a proof of concept, we show that a user wearing the meander clothing can stably collect data from multiple battery-free tags on a single chair without any collisions (Fig. 1a-b).

2 Packet-interval-based NFC

Unlike centralized protocols where the NFC reader manages every transmission window, packet-interval-NFC allows NFC tags to transmit data autonomously and unidirectionally. The NFC reader garment simply provides a continuous magnetic field to power up the tag, and then the NFC tags broadcast two independent short packets when sending sensor values. Instead of encoding data within long bitstreams, NFC PIM represents sensor values through the temporal distance between two consecutive packets. This interval-based design naturally prevents data collisions from multiple tags. Because each packet is extremely short, the transmission time in the air is almost zero, making the chance of packets overlapping highly unlikely.

The packet-interval-NFC system can be implemented through three modifications of the standard NFC in addition to the use of meander e-textiles (Fig. 1c-d). First, we eliminate all downlink commands from the reader to the tags, which saves bandwidth and allows us to increase the uplink data rate to a high-speed 424 kbps. Second, each transmitted packet is made extremely compact, containing only a 1-byte tag ID and a 1-byte CRC-8 for error detection, resulting in a total size of just 2 bytes. The actual sensor value is mapped directly onto the time interval between two consecutive packets. Third, to ensure precise interval measurements and prevent clock drift, the tags dynamically synchronize their internal clocks with the stable 13.56 MHz carrier frequency provided by the reader garment.

3 Context-Aware Chair Scenarios

We construct a sensing system based on context-aware chair scenarios. The sensing system targets three different placements: a laboratory, a cafeteria, and a relaxation space. In each environment, chairs are equipped with multiple NFC tags to perform multi-modal sensing. Specifically, the multiple NFC tags are deployed on a single chair, such as a pressure sensor on a seat surface and a temperature sensor on a back of a seat. When a user wearing the NFC reader garment moves between the laboratory, the cafeteria, and the relaxation space, and sits on the chairs, the number of NFC tags within the communication range of the NFC reader garment changes dynamically and rapidly. Even during such dynamic changes in the number of NFC tags, the sensing system achieves seamless data collection from the NFC tags without complex communication control. Based on the collected data, the sensing system successfully demonstrates real-time context estimation of user behavior and environmental sensing of each location.

4 Demonstration Plan

We demonstrate the reception of sensor data from NFC tags using two chairs equipped with multiple NFC tags. A participant wears the NFC reader garment and sits on the chairs. When the participant sits on a chair, sensor data obtained from the NFC tags attached to the chair are displayed on a laptop screen in real time. When the participant stands up from the chair, the reception of sensor data stops. When the participant sits on the other chair, the chair where the participant sits changes, and both the types and the number of the obtained sensor data change.

Acknowledgments

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