Demo of picoRing *mouse*: ultra-low-powered wireless mouse ring with ring-to-wristband coil-based impedance sensing

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Abstract

Wireless mouse rings offer subtle, reliable pointing interactions for wearable computing platforms. However, the small battery below 27 mAh in the miniature rings restricts the ring's continuous lifespan to just 1-2 hours, because current low-powered wireless communication such as BLE is power-consuming for ring's continuous use. The ring's short lifespan persistently disrupts users' mouse use with the need for frequent charging. This interactivity demonstrates picoRing *mouse*, enabling a continuous ring-based mouse interaction with ultra-low-powered ring-to-wristband wireless communication. picoRing *mouse* employs a coil-based impedance sensing named semi-passive inductive telemetry, allowing a wristband coil to capture a unique frequency response of a nearby ring coil via a sensitive inductive coupling between the coils. The ring coil converts the corresponding user's mouse input into the unique frequency response via an 820 uW mouse-driven modulation module. Therefore, continuous use of picoRing *mouse* can potentially last over 92 hours on a single charge of a 20-mAh small battery.

CCS Concepts

• **Human-centered computing → Ubiquitous and mobile computing**; **Pointing devices**; • **Hardware → Wireless devices**.

Keywords

wireless mouse ring, coil-based impedance sensing, semi-passive inductive telemetry, wearables

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1 INTRODUCTION

Mouse devices are basic tools for simple, fast pointing with computers. Integrating mouse functionality into wearable form factors such as wristbands, glasses and rings (*e.g.,* Apple Watch, Galaxy Ring) promises always-available essential interactions with wearable computing platforms [4, 9, 15]. Especially, the wireless ring-formed input devices worn on the index finger offer reliable detection of even subtle, privacy-preserved thumb-to-index finger inputs such as pressing and scrolling, unlike the wristband and glasses [5, 8, 12]. However, the physical constraint of the tiny ring structure requires the equipment of tens of mAh small battery, challenging the continuous operation of power-consuming tens of mW-class wireless communication modules such as Bluetooth Low Energy (BLE). For example, prior wireless rings support only $1-2$ hours of continuous wireless communication with BLE, limiting the ring's communication usage to intermittent data transfer [1, 5, 8]. Such an operation is suitable for periodic healthcare monitoring around the rings (*e.g.,* Oura Ring, Galaxy Ring), but not appropriate for ring-based input interface that requires both continuous interaction and real-time communication with other wearables (*e.g.,* smartwatch, HMD).

This Interactivity demonstrates picoRing *mouse*, enabling an ultra-low-powered wireless mouse ring with a ring-to-wristband coil-based impedance sensing (see Figure 1a). picoRing *mouse* is inspired by a sensitive coil-based impedance sensing named passive inductive telemetry (PIT) [10, 12, 13]. Unlike long-range electromagnetic communication such as BLE and RF backscatter, PIT constructs a short-range but ultra-low-powered inductive link between a pair of a ring coil and a wristband coil. Since the ring coil can send its sensor information to the wristband coil by simply modifying the inductive field generated from the wristband coil, the ring coil does not need active signal transmission with power-hungry

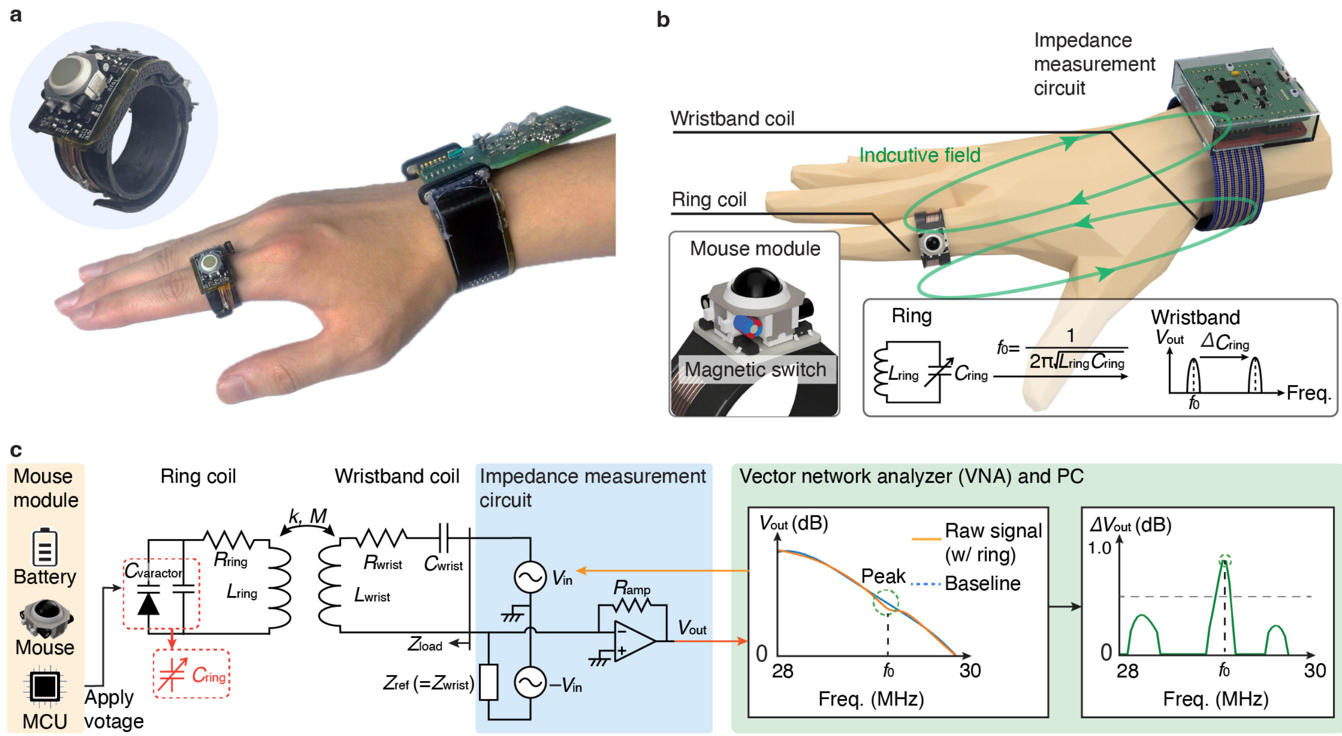

Figure 1: Design overview of picoRing *mouse*. (a) Prototype photograph, (b) illustration, and (c) circuit diagram of picoRing *mouse*.

communication modules. With the combination of PIT with the ring-based mouse module, picoRing *mouse* enables the ultra-low-powered mouse ring that achieves 800 µW power consumption at most and weighs as little as 5 g, possibly enabling continuous operation of over 92 hours on a single charge of a 20 mAh curved small battery.

2 RELATED WORK

Ring-formed mouse devices have long been investigated within HCI community. The exploration of the previous mouse ring can be divided into two categories: i) ring-based sensing techniques such as computer vision, pressure, and inertial sensors to track the fine-grained finger movement [2] and ii) low-powered wireless ring design using antenna- or coil-based low-power wireless communication such as RF backscatter and near-field communication (NFC) [12, 16] to continuously operate the ring devices during daily life. The former demonstrates high-fidelity microgesture recognition compared to the wristband- and glasses-based finger sensing [4]. However, the latter is still challenging since µW-class RF backscatter needs a large and unsuitable antenna in the ring [7], and mW-class NFC offers a few centimeter-scale short communication that cannot construct ring-to-wristband link [6, 17]. picoRing, which is most similar to this paper, extends the coil-based communication distance by using coil-based sensitive impedance sensing for a ring-to-wristband low-powered wireless connectivity [12]. While picoRing proposes a battery-free wireless ring, the input modality of the passive ring is limited to a few interfaces such as pressing [12] or tapping [10]. By contrast, picoRing *mouse* can support multi-modal inputs in a single ring by integrating semi-passive communication architecture into the prior, as will be described in § 3.1.

3 SYSTEM DESIGN

picoRing *mouse* consists of two main components (see Figure 1b): 1) a ring coil with a mouse module, which changes its frequency response based on the mouse inputs, and 2) a wristband coil that detects the peak in the frequency response corresponding to the ring's resonant frequency. The working principle of picoRing *mouse* is as follows: First, the wristband coil generates a weak inductive field to couple with the nearby ring coil. When the user scrolls the mouse module mounted on the ring, the MCU connected to the mouse module detects the scrolling direction via magnet switches, transforming the mouse direction into a unique frequency response (*i.e.,* the change in the ring's resonant frequency). Through the inductive coupling, the wristband coil connected to a sensitive impedance measurement module obtains the frequency response. Since the ring's frequency response is appeared as the frequency peak in the frequency characteristics of wristband's impedance, the wristband coil enables to recognize the mouse direction as a unique peak frequency shift.

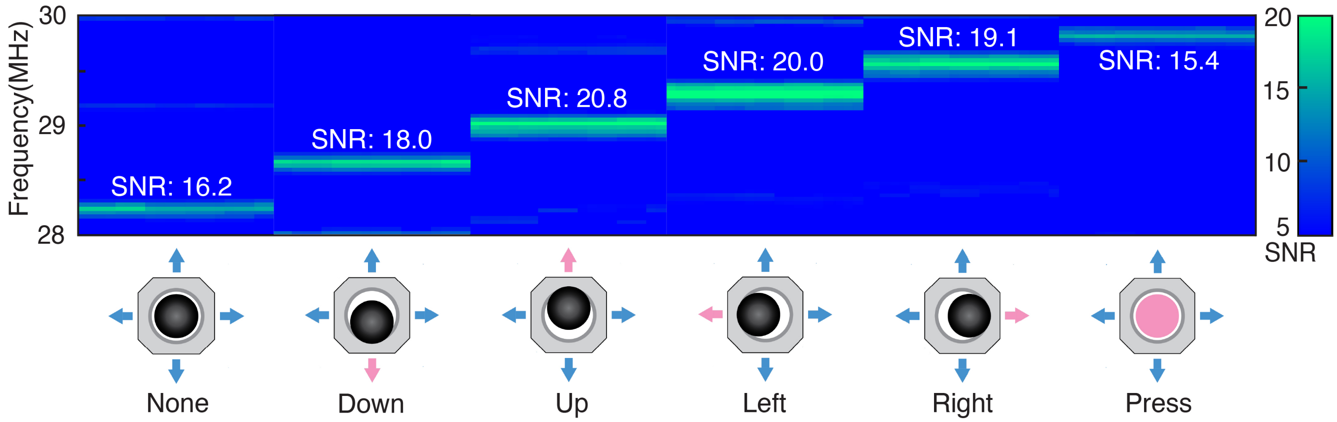

Figure 2: Gesture recognition capability of picoRing *mouse*. We evaluate time-series and average SNR for scrolling and pressing interactions. SNR over 10 **indicates the high-fidelity recognition [12].**

3.1 Semi-passive inductive telemetry

picoRing *mouse* needs ultra-low-powered wireless communication for the long-term operation of the wireless ring mouse. Among low-powered wireless communication, picoRing *mouse* uses PIT similar to picoRing [12]. PIT, which consists of a pair of a fully-passive ring coil and a wristband coil, allows the wristband to detect the passive response of the ring coil. Since the ring-to-wristband inductive coupling is too weak, prior picoRing increases the PIT sensitivity by developing both a sensitive coil with distributed capacitors and a sensitive impedance measurement circuit named balanced bridge circuit. The sensitive coil, which has a large turn number or large inductance at a high resonant frequency (MHz) by inserting multiple chip capacitors into a single long coil, can increase the passive response from the ring coil. By contrast, the bridge circuit, which uses a differential circuit structure, can be sensitive to the small impedance change from the wrist coil. For more detail, please refer to [12] (see Figure 1c). Note that the fully-passive features of the prior PIT requires the ring coil to modify the inductive field with a battery-free analog modulation circuit such as tactile switches. In contrast, our semi-PIT approach, which modifies the inductive field via electrical switch, allows the ring coil to use digital modulation and digital signal processing, embedding the programmable, multi-modal interactions like our mouse-based scrolling and pressing into the inductive modulation. Specifically, picoRing *mouse* uses a simple frequency-shift keying based on a voltage-controlled varctor, which encodes the mouse inputs into a unique shift of ring's peak frequency (f_0) by the applied voltage magnitude. Note that f_0 is a ring's resonant frequency determined by the ring's inductance (L_{ring}) and capacitance (L_{ring}) as follows: $f_0 = 1/(2\pi\sqrt{L_{\text{ring}}C_{\text{ring}}})$.

3.2 Ring

The ring coil consists of a 8-turned resonant coil with distributed capacitors and the mouse module equipped with a small trackball (EVQWJN007, Panasonic) supporting up, down, right, left scrolling and pressing interactions. When users scroll or press the trackball in the mouse module, the trackball either converts the scroll rotation into rotation of cylindrical magnets with alternating polarity distribution or turns on the tactile button. The magnetic switch (CT8132BL, Allegro MicroSystems) below each magnet sends the magnet rotation data to an ultra-low-power MCU (STM32L011F4U6, STM), and then, according to the input type, the MCU applies a different corresponding voltage to a varactor (SMV1253, Skyworks) by a digital-potentiometer-based voltage divider circuit (AD5160, Analog Devices). The varactor, which changes its capacitance ranging from 27 pF to 69 pF based on the applied voltage, changes the C_{ring} or f_0 by being connected in parallel to one of the distributed capacitors in the ring coil. In total, the ring coil provides five physical interface 1-D/2-D inputs: scroll up, down, left, right, scroll and press, and its resonance frequency for each interaction is tuned to 28.0 MHz,28.4 MHz, 28.8 MHz, 29.2 MHz, 29.6 MHz, respectively. The inductance (L_{ring}) and resistance (R_{ring}) of the ring coil are 2.6 µH and 3.5 Ω, respectively. Note that the ring coil is tilted with approximately 20°, mitigating the misalignment between the ring and wristband coils when the hand is grasped for thumb-to-index finger input. With this tilted ring, the measured inductive coupling coefficient (k) increases from 0.0031 to 0.0039.

The ring coil has two types of operation modes: ACTIVE mode and STANDBY mode. In the ACTIVE mode, the ring coil continuously streams data to the wristband coil. By contrast, in the STANDBY mode, the timer in the MCU periodically awakens to check the receiving data from the connected magnet switch. picoRing basically waits in the STANDBY mode and transits to ACTIVE mode when the user inputs to the mouse module. When there is no signal change in the magnet switch for 5 s, picoRing backs to the STANDBY mode. The power consumption is approximately 800 µW (=1.8 V×430 µA) and 50 µW (=1.8 V×28 µA) in the ACTIVE and STANDBY modes, respectively. The continuous ACTIVE operation time of picoRing *mouse* is estimated to be approximately 92 hours with the 20 mAh curved Lipo battery (UFX150732). Assuming the standard mouse operation time as about four hours per

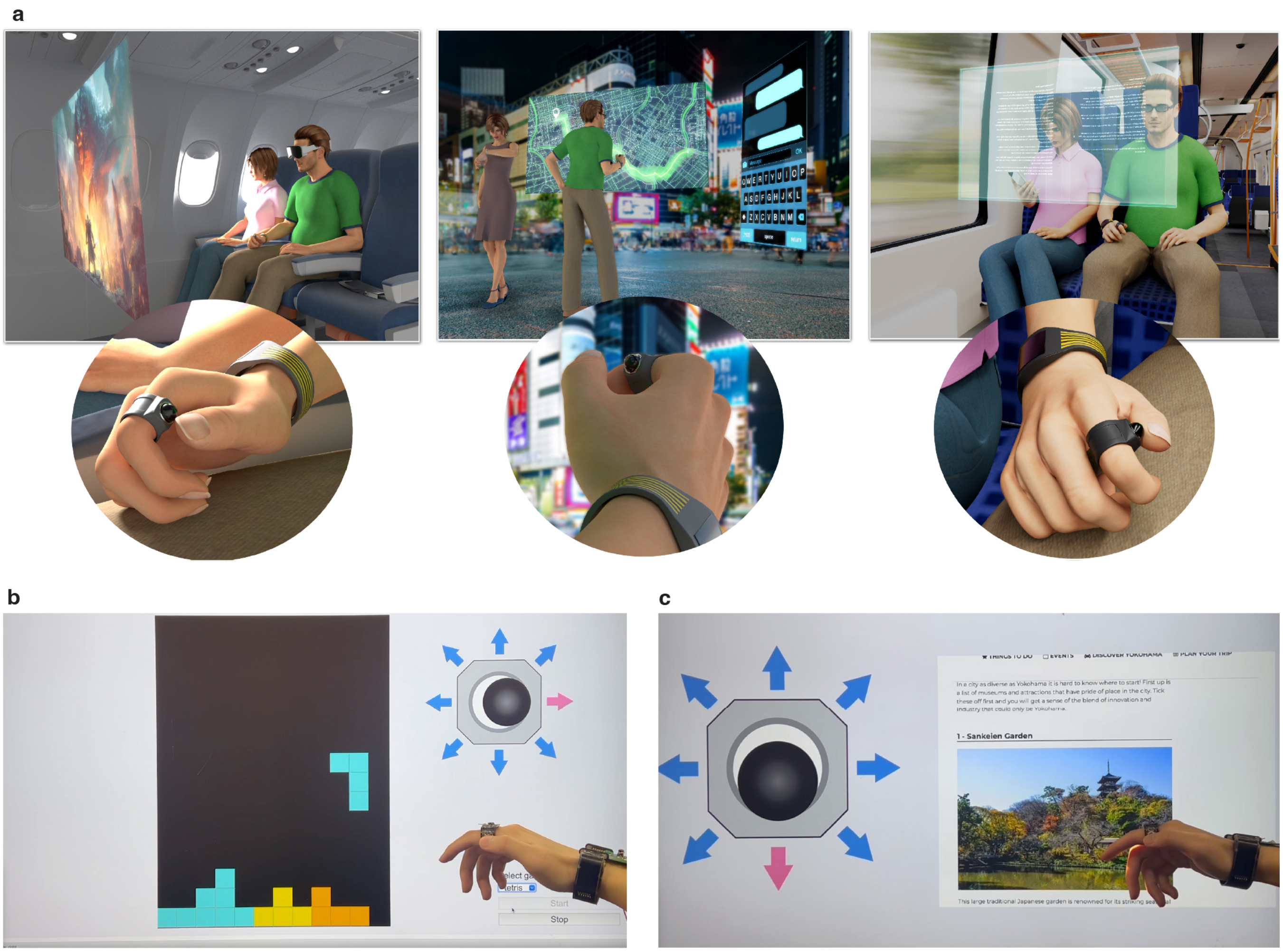

Figure 3: Application examples of picoRing *mouse*. (a) Illustration of potential usage of picoRing *mouse* during daily lives. (b) Photograph of two types of demonstration by picoRing *mouse*. Wearable game controller for tetris playing and page scroll controller for web viewing.

day, picoRing can potentially operate over a few weeks on a single charge.

3.3 Wristband

The wristband coil consists of a 6-turned flexible resonant coil mounted on a 3D-printed flexible wristband and the impedance measurement circuit connected to a mobile vector network analyzer (VNA) (NanoVNA-H4, AURSINC). To recognize the ring's mouse state, the wristband coil detects the ring's frequency peak (f_0) by monitoring the frequency sweep signal ranging from 27.8 MHz to 29 MHz with an input power of 0.2 mW. The coil is connected to the impedance measurement circuit via a magnetic connector. In total, the resonant frequency, inductance (L_{wrist}) and resistance (R_{wrist}) of the wristband coil connected with seventeen 140 pF distributed capacitors and a 50 Ω resistor in series are 27 MHz, 4.0 μH, and 53 Ω, respectively, and the measured power consumption of the circuit and VNA are 0.46 W and 3.9 W, respectively.

4 PRELIMINARY EVALUATION

To characterize the input accuracy of picoRing *mouse*, this section evaluates the signal-to-noise ratio (SNR) of picoRing *mouse* for user's scrolling and pressing interactions. The SNR is measured similar to [12]. Figure 2 shows the time-series SNR and the average SNR for the first author. The result shows that the average SNR for each input is over 10 dB, indicating that picoRing *mouse* can support high-fidelity recognition, according to [12].

5 DEMONSTRATION

picoRing *mouse*, an ultra-low-powered wireless mouse ring, has the advantage of long-term operation with a single charge, unlike the prior wireless ring. Therefore, picoRing *mouse* can enable ubiquitous, seamless, finger inputs during prolonged daily life including VR/AR interactions in the airplane and train or outside (see Figure 3a). This Interactivity demonstrates three application examples to highlight the effectiveness of picoRing *mouse* (see Figure 3bc). The first demonstration allows users to play and pause music by using a subtle pinch gesture on the ring's scroll ball. Because the picoRing *mouse* can reliably detect subtle finger inputs over extended periods, users can frequently and naturally use the mouse ring without worrying about battery life. The second demo shows wearable game controller experience (see Figure 3b). Here, the user can control the rotation of various falling blocks in Tetris even for a day. Owing to semi-PIT, picoRing *mouse* can support complicated user interactions in addition to an ultra-low-powered operation. Lastly, the user scrolls the screen in AR/VR anywhere. While the AR glasses and HMD support the scrolling interactions based on hand gestures, the gestures are relatively dynamic, causing fatigue in the continuous usage. In contrast, the subtle finger input by picoRing *mouse* allows the long-term privacy-preserving interactions.

6 CONCLUSION

This paper demonstrates picoRing *mouse*, an ultra-low-power ring-based finger input device. By combining semiPIT-based ring-to-wristband low-powered wireless communication with the low-powered mouse module, picoRing *mouse* achieves the 800 μW wireless ring mouse, supporting multi-modal, thumb-to-index, subtle finger inputs with long-term operation times of about 92 hours. As for the future works, picoRing *mouse* could be used for spatial interaction in VR/AR by mathematically converting the user's subtle mouse input to extended 3D hand posture [3]. Moreover, the power transmission of wireless charging-enabled clothing [11, 14] can enable picoRing *mouse* to work while being charged, allowing always wearing of a pair of the ring and wristband coils as fashion accessories. We strongly believe picoRing *mouse* could provide a new class of wearable computer mouse, seamlessly interconnecting itself with daily HCI devices.

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