

# picoRing *dual*: ultralow-power bimanual ring controllers for everyday AR

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Figure 1: Overview of picoRing *dual*.

## Abstract

Advances in AR glasses and HMD enable digital XR (AR/VR) vision even in outdoor and public situations. However, traditional handheld XR controllers for hand interactions remain too bulky and socially awkward for these everyday contexts, failing to match the portability and subtlety required for mobile use. Ring-based input controllers offer a reliable finger-sensing solution; however, continuous operation with a tiny, battery-constrained ring remains a challenge. Here, we present picoRing *dual*, an ultra-low-power bimanual interface with a pair of ring-wristbands based on inductive coupling. Unlike the original picoRing *mouse* limited to uni-manual ultra-low-power trackball interaction at approximately 50 bps, picoRing *dual* uses an NFC-based ring-to-wristband link to capture fast index-finger motions and thumb-to-index microgestures reliably at approximately 1.4 kbps. By tuning the ring's coil geometry, our system achieves stable NFC against finger bending while complying with NFC's ultra-low power profile. Therefore, picoRing *dual* with approximately 0.86 mW on the ring side can last approximately 100 continuous hours on a single charge of the

ring's 20 mAh battery. picoRing *dual* has the potential to bridge the gap between powerful XR control and the social requirements of everyday wearable technology, offering ubiquitous finger input for everyday AR.

## CCS Concepts

• Human-centered computing → Interaction devices; Ubiquitous and mobile computing; Gestural input; • Hardware → Wireless devices.

## Keywords

ultralow-power wearables, everyday AR, dual ring, NFC, coil, bimanual, ubiquitous finger input

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## 1 INTRODUCTION

Advances in smart glasses, such as head-mounted displays (HMDs) and AR glasses, allow us to use digital information in our daily lives, but how we interact with these devices during our daily lives remains challenging. Handheld VR controllers are too bulky for public use, and camera-based hand-tracking systems in AR glasses have issues with continuous use due to 10 mW-class relatively high power

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**Table 1: Technical comparison of wearable devices for XR interaction. To the best of our knowledge, picoRing *dual* is the first ultralow-power bi-manual dual-ring interface below 1 mW.**

	Device form factor	Power consumption (mW/device)	Wireless connection	Micro finger movement	Micro finger gesture
<b>Dual-handheld, glove, wristband, or fingertip</b>					
Quest Controller [1]	Bi-manual by two handhelds	Approx. 27	BLE	Pointing	Click and joystick
TapType [28]	Bi-manual by two wristbands	Approx. 10	BLE	-	Tap
DigiTouch [39]	Bi-manual by two gloves	-	Gazell	-	Tap and slide
BiTipText [42]	Bi-manual by two fingertips	-	× (Wired)	-	Tap
<b>Dual-ring</b>					
DualRing [19]	Uni-manual by two rings	-	× (Wired)	Pointing	Tap and slide
DRG-Keyboard [18]	Uni-manual by two rings	Approx. 120	BLE	-	Tap and slide
MouseRing [27]	Uni-manual by two rings	Approx. 10	BLE	-	Tap and slide
<b>picoRing <i>dual</i></b>	Bi-manual by two rings	<b>0.86</b>	Ring-to-wrist NFC	Pointing	Press and scroll

consumption and a restricted field of view. Ring-worn interfaces offer a promising alternative because they can reliably capture nearby finger actions while keeping the palms free [17, 32, 38]. In particular, dual-ring systems by using both hands can replicate the control of handheld VR controllers, such as grabbing and stretching 3D objects, or navigating a system menu with one hand while aiming at a target with the other. However, achieving high-fidelity sensing within the tiny, battery-constrained form factor of a ring remains a significant engineering challenge. While picoRing *mouse* [17, 32] have demonstrated the feasibility of ultra-low-power interaction using inductive coupling, its application is limited to low-bandwidth tasks like cursor navigation. The data rate of approximately 50 bps is insufficient for capturing the rapid, nuanced finger movements required for immersive XR manipulation.

To address these challenges, we propose picoRing *dual*, a dual-ring-based bimanual interaction that supports high-fidelity finger sensing within an ultra-low-power framework. Our system employs an enhanced near-field communication (NFC) between a ring sensor coil and a wristband reader coil on each hand. By optimizing the coil geometry and utilizing an NFC-based communication scheme, picoRing *dual* achieves a data rate of approximately 1.2 kbps—a 24-fold increase over the previous picoRing series [17, 32], enabling the reliable capture of fast index-finger motions and thumb-to-index microgestures on both hands simultaneously. With this configuration, the ring consuming approximately 870  $\mu\text{W}$  ( $\approx 4.2\text{ V} \times 208\ \mu\text{A}$ ) can last approximately 100 hours on a single 20 mAh charge. Therefore, picoRing *dual* provides a privacy-preserving and power-efficient alternative to bulky handheld controllers, paving the way for ubiquitous finger input in everyday AR environments. To facilitate replication and provide implementation details, we have open-sourced the current picoRing *dual*: [https://removed\\_for\\_review](https://removed_for_review).

Our contribution is summarized as follows:

- The design of an ultralow-power bimanual dual-ring interface using ring-to-wristband NFC channel and simple angle optimization of the ring coil.

- The demonstration and technical evaluation of 860  $\mu\text{W}$ -class wireless ring controller named picoRing *dual* toward everyday AR interaction.

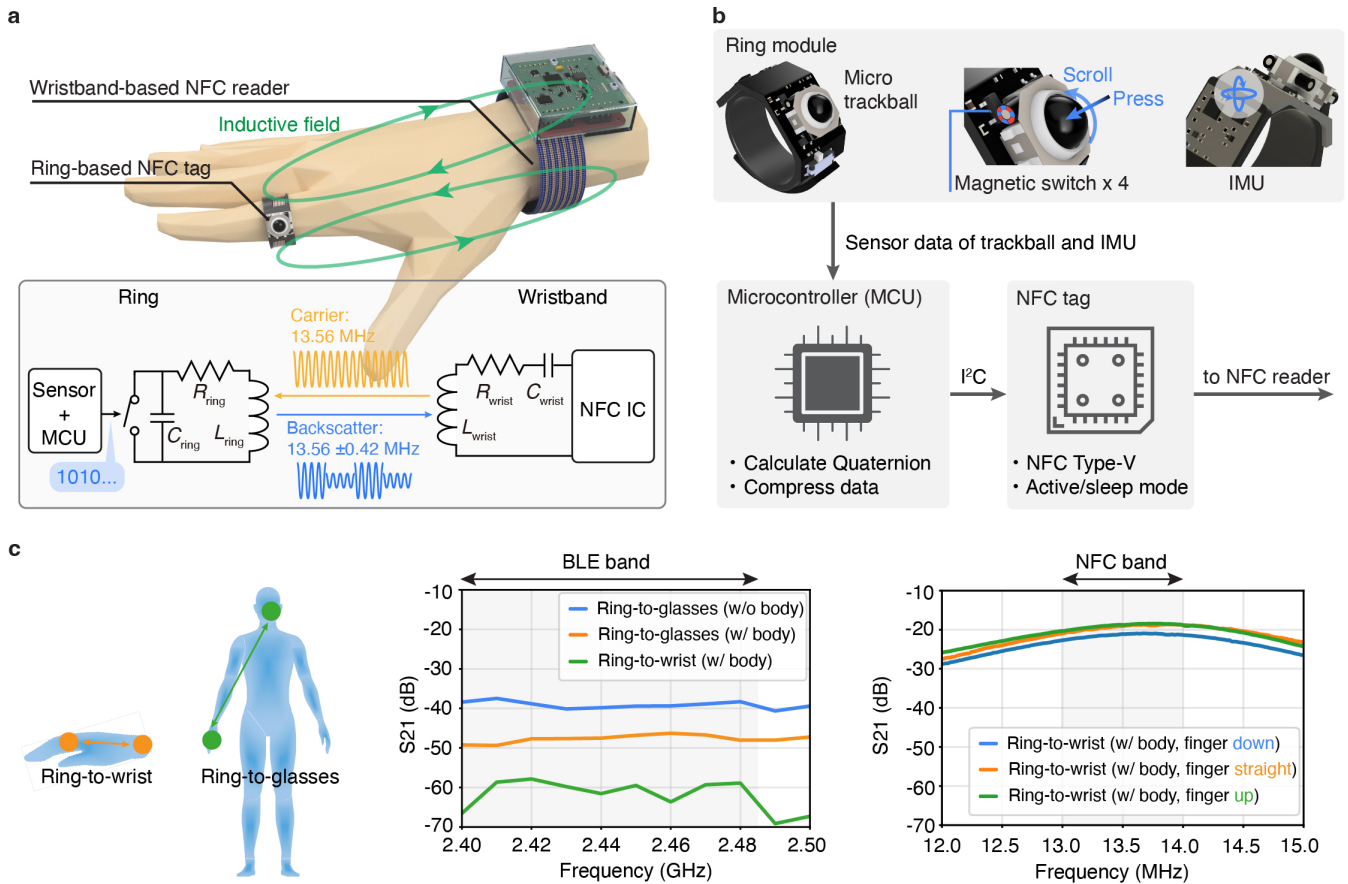
## 2 RELATED WORK

### 2.1 XR controller

As XR shifts from specific gaming usage to all-day usage, there is a growing demand for subtle and socially acceptable interaction techniques [4, 25]. Traditional XR interaction relies on handheld controllers or optical hand tracking to track mid-air hand poses. However, handheld controllers are cumbersome for hands, while optical tracking suffers from occlusion, often failing to capture subtle interactions outside the line of sight [22, 40]. Unlike dynamic mid-air hand poses, subtle inputs allow users to engage in XR interactions in public settings without drawing attention or causing arm fatigue. To address these limitations, wrist-worn devices such as smartwatches [14] and smart wristbands [24] have been investigated for always-available XR interaction, employing IMU [2, 5], EMG [3, 9], optical [8, 24], pressure [21], and acoustic [49] sensing. Nevertheless, the physical distance between the wrist and the fingers restricts the stable, continuous capture of subtle micro-gestures. In contrast, smart rings place sensors directly on the finger, enabling reliable, seamless detection of subtle inputs suitable for everyday use [17, 30, 32].

### 2.2 Dual-ring

Rings for XR can provide subtle input techniques, including (i) rapid finger pointing [12, 48], and (ii) micro-gestures such as scrolling and clicking [29, 32, 36]. To support these interactions, prior rings utilize motion sensors to enable finger pointing [19, 27], in addition to using miniature touchpads [13] or trackballs [17] to support microgestures. Building on single-ring research, dual-ring usage has emerged to support bimanual interactions. By equipping both hands with a ring, users can operate XR environments similarly to traditional handheld VR controllers, eliminating the need for bulky



**Figure 2: Design overview of picoRing *dual*.** (a) Schematic of picoRing *dual*, consisting of a pair of a ring-based NFC tag and a wristband-based NFC reader on the user’s both hands. (b) Illustration of the working principle of the ring-based NFC tag to convert the mouse input or motion data into an NFC packet. (c) Communication channel efficiency in the BLE and NFC bands, showing the influence of the human body and varying communication paths (ring-to-wrist and ring-to-glasses).

hardware [7]. While other form factors such as fingertips [42], wristbands [28], and gloves [39] have been explored for bimanual subtle input, the finger-covered devices often obstruct natural tactile sensations, or wristbands need to rely on external surfaces. In contrast, dual rings keep the sensitive fingertips entirely unobstructed, ensuring that users can maintain their everyday tactile feedback and seamless hand-to-object interactions while still enabling robust bimanual input in XR. The dual-ring has two kinds of configurations: two rings on a single hand [47] or one ring on each hand [7]. For example, two motion rings on the index fingers can detect finger joints such as handwriting [11] and typing [41], while placing one ring on each hand mimics the familiar setup of standard dual VR controllers for applications like gaming [7]. However, achieving the low-power ring controller for everyday XR interaction is still challenging due to power-hungry wireless communication against a ring’s tiny battery (see Tab. 1).

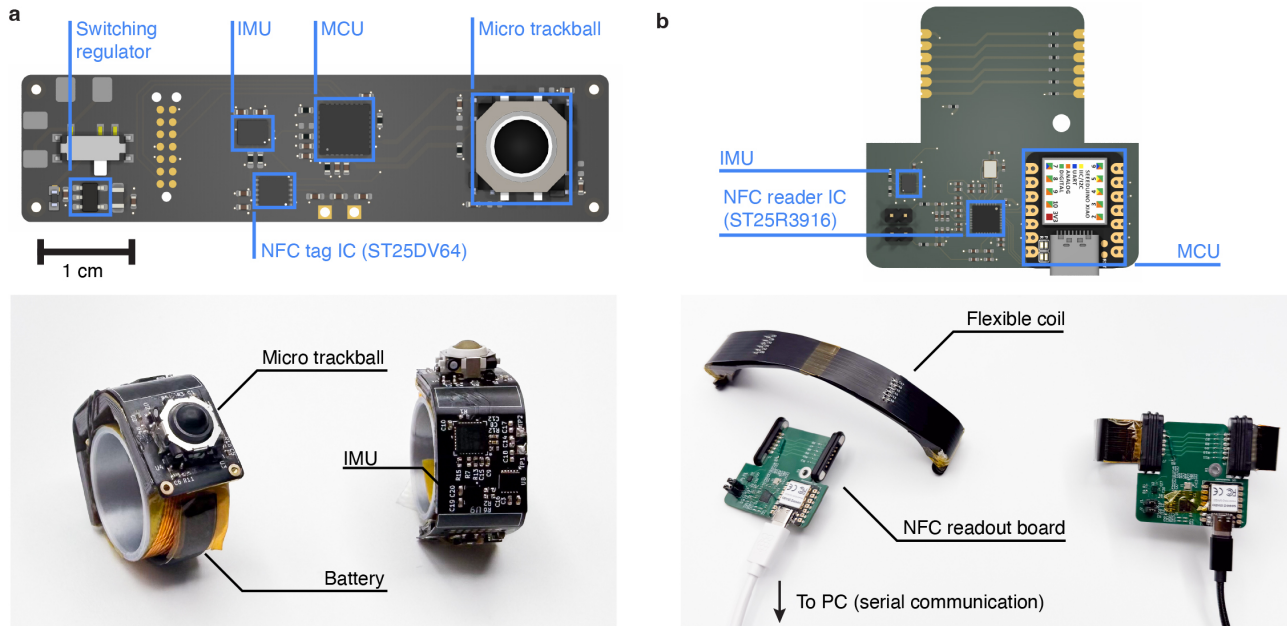
### 2.3 Near-field communication

NFC, which is one of the RFID technologies, is designed for short-range identification and payment by wirelessly powering up tags

and sending data through load modulation. Unlike active protocols like BLE that require internal power to constantly broadcast signals, NFC operates through passive inductive coupling and load modulation. Instead of emitting its own radio waves, the NFC tag simply alters its impedance to reflect the reader’s magnetic field, allowing the tag side to achieve near-zero power consumption or a completely battery-free form factor. While early HCI research focused on simplified pairing and tangible interfaces [6, 10], recent work has expanded the NFC’s utility by embedding tags into everyday accessories and toys, ranging from jewelry [15, 46], clothing [31, 33, 34, 44], furniture [23, 37], capsule [45], patch [26, 43], and gadgets [16, 20]. These integrations enable battery-free wireless sensing, specifically for on-demand gesture recognition and physiological monitoring [50]. Building on these NFC works, picoRing *dual* introduces an ultralow-power bimanual interface that addresses the battery constraints of ring-sized controllers.

## 3 DESIGN AND IMPLEMENTATION

picoRing *dual* consists of a ring-based NFC tag module and a wristband-based NFC reader on each hand (see Figure 2a). The



**Figure 3: Prototype photograph of our (a) ring-based NFC tag with a  $60 \times 14$  mm flexible PCBs including a micro trackball, mouse sensor module, MCU, IMU, NFC tag IC, and switching regulator, and (b) wristband-based NFC reader implemented with the coil fabricated by flexible PCBs. The flexible PCBs are mounted to the 3D-printed wristband, and the wristband coil is connected to the NFC readout board, composed of NFC reader IC and MCU.**

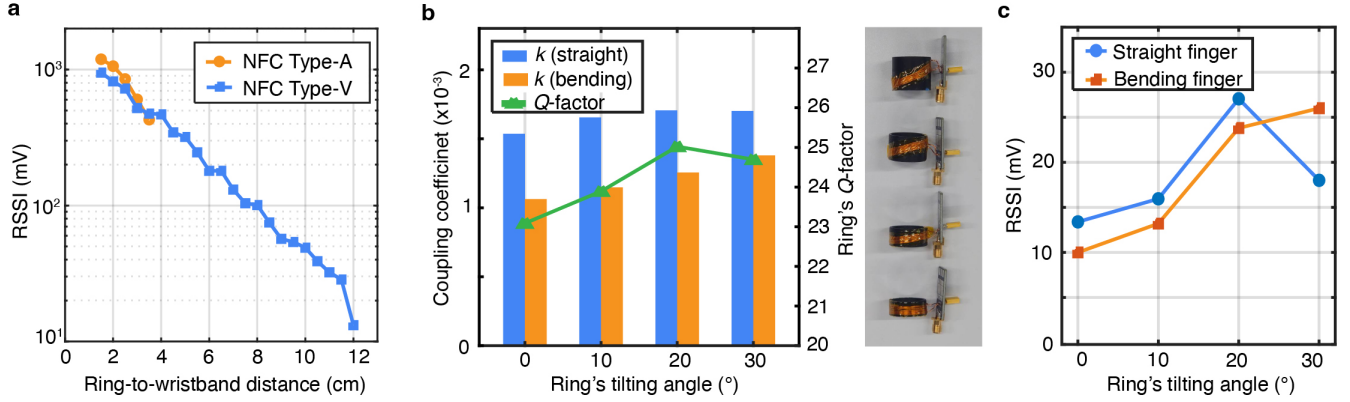
ring module integrates a micro trackball, magnetic switches, an IMU, a low-power microcontroller (MCU), and a custom coil. The ring’s MCU continuously samples data from the trackball and IMU, calculates quaternions, and compresses the payload before transferring it via I2C to an NFC tag, which transmits the data via passive backscatter through inductive coupling ( $13.56 \pm 0.42$  MHz) (see Figure 2b). By limiting the NFC transmission distance to a nearby wristband, each ring on both hands can utilize NFC protocol for ultralow-power communication. Since the wristband can accommodate a relatively large battery, it acts as a power-sufficient hub that relays the captured interaction data to other devices (e.g., AR glasses) via BLE, allowing the rings to focus entirely on the short-range NFC link.

To confirm the feasibility of the ring-to-wrist inductive link, we evaluated the communication channel efficiency by measuring the  $S_{21}$  scattering parameter (the ratio of received to transmitted power) across both the NFC (13.56 MHz) and BLE (2.45 GHz) bands. Specifically, we connected the chip antennas (EB\_NN03-320-M-BT, Ignion) and custom coils to a vector network analyzer (PicoVNA 108) to test two configurations: ring-to-wrist and ring-to-glasses (see Figure 2c). The results showed that while the BLE ring-to-glasses channel maintains  $-40$  dB in free space, the nearby dielectric human body causes severe attenuation, dropping the  $S_{21}$  to  $-70$  dB. Even at the short ring-to-wrist distance, BLE exhibits low efficiency at around  $-50$  dB due to body-induced loss. In contrast, the short-range NFC ring-to-wrist channel achieves a robust  $S_{21}$  of  $-20$  dB, outperforming BLE by over 30 dB, though the ring-to-glasses channel becomes noisy below  $-70$  dB due to far-away distance. Furthermore, the NFC link exhibits high tolerance to dynamic hand postures; even when the

finger moves up or down, the channel stably sustains an  $S_{21}$  between  $-20$  dB and  $-25$  dB. These results validate that the short-range inductive link is highly effective for ultra-low-power ring operation. Note that, while the most similar work, *picoRing mouse* [17] uses ring-to-wristband inductive coupling for ultralow-power operation, *picoRing mouse* is restricted to a slow 50 bps datarate due to its frequency-sweeping readout. In contrast, *picoRing dual* uses a load-modulation-based binary phase shift keying (BPSK) via the single carrier frequency of 13.56 MHz to increase the datarate by 30 times to approximately 1.5 kbps. This enhanced bandwidth enables the rings to continuously stream high-throughput IMU motion data while maintaining only 0.86 mW power consumption on the ring side.

### 3.1 Ring

The ring coil consists of an 8-turn resonant coil wound by  $\phi 0.5$  mm copper wire and a flexible PCBs including NFC tag IC (ST25DV64, STM), MCU (STM32U375, STM), IMU (ICM-45605, TDK), switching regulator (LM3670MF, TI), trackball (EVQWJN007, Panasonic), and 3D-printed ring base (see Figure 3a). The ring’s MCU samples the raw interaction data from the IMU and micro trackball at 20 Hz, applies a Madgwick filter to compute the finger orientation as a quaternion, and compresses the data payload from float-type 16 bytes to int-type 8 bytes (2-bytes  $\times$  4 quaternion) with 1-byte trackball state to minimize transmission overhead before transferring it via I2C to the NFC tag IC. We selected NFC Type-V (ISO/IEC 15693) over standard Type-A or Type-B because Type-V is optimized for mid-range communication. Its narrow bandwidth of ( $13.56 \pm 0.42$ ) MHz



**Figure 4: Evaluation of picoRing *dual*.** (a) Received Signal Strength Indicator (RSSI) profiles of NFC Type-A and Type-V protocols as a function of the ring-to-wristband distance, demonstrating the extended operating range of Type-V under weak inductive coupling. (b) Measured inductive coupling coefficient ( $k$ ) for straight and bending finger postures alongside the ring's quality factor ( $Q$ -factor) across various coil tilting angles ( $0^\circ$ ,  $10^\circ$ ,  $20^\circ$ , and  $30^\circ$ ). (c) RSSI performance under straight and bending finger postures across different ring tilting angles, validating that a tilting angle of  $20^\circ$  shows the optimal balance of signal strength for natural hand gestures.

increases receiver sensitivity to weak magnetic fields, allowing the system to maintain a stable ring-to-wristband link.

Furthermore, the coil is wound with an inclination of  $20^\circ$  relative to the ring's horizontal plane. Because most mid-air finger gestures are performed with slightly bent fingers, a parallel coil design would misalign with the wristband reader during interaction. Tilting the coil ensures that the loop remains parallel to the wristband when the finger is naturally flexed. This angle optimization increases the inductive coupling coefficient ( $k$ ) by a factor of 1.2, as described in § 4.2. As a result, the system maintains a stable link even at a ring-to-wristband distance over 10 cm, which is sufficient for standard hand size [32]. The resonant frequency of the ring coil is adjusted to 13.56 MHz by connecting the chip capacitor of 30 pF in parallel. In total,  $Q$ -factor, inductance, power consumption, and data rate of the ring are 25, 2.4  $\mu$ H, 0.86 mW ( $= 4.2$  V  $\times$  205  $\mu$ A), and 1.44 kbps ( $= 9$  byte  $\times$  20 Hz), respectively.

### 3.2 Wristband

The wristband coil consists of a 5-turned flexible resonant coil mounted on a 3D-printed flexible wristband and the NFC read-out board including MCU (XIAO SAMD21, Seeed Studio) and NFC reader IC (ST25R3916, STM) powered by USB PD cable connected to an external PC (see Figure 3b). To recognize the ring's data, the wristband coil captures the load-modulated backscatter signals generated by the ring. The NFC reader IC demodulates the 13.56 MHz carrier to extract the 424 kHz subcarrier with 26.48 kHz data rate, decoding the BPSK-encoded sensor packet. Once decoded, the onboard MCU processes the incoming stream and immediately transmits the compressed orientation and trackball data to the host device via USB cable. Standard wristband reader coils are typically implemented with a low number of turns and low self-inductance ( $L_{\text{wrist}}$ ) to prioritize matched impedance over standard short ranges. In contrast, we need to increase the number of turns to maximize  $L_{\text{wrist}}$ , thereby boosting the reader's sensitivity to subtle load changes

**Table 2: Power consumption of the ring coil hardware.**

Component	NFC ( $\mu$ W)	BLE ( $\mu$ W)
MCU (STM32U375)	169	169
Trackball module ( $4 \times$ CT8132)	7.9	7.9
IMU (ICM-45605)	396	396
Power management (LM3670MF)	63	63
<b>Wireless communication</b>	<b>130</b>	<b>11,520</b>
	<b>(ST25DV64)</b>	<b>(nRF52840)</b>
<b>Estimated total</b>	<b>&gt; 765</b>	<b>&gt; 12,200</b>
<b>Measured total@4.2 V</b>	<b>860</b>	<b>28,000</b>

caused by the ring. When the ring tag modulates its impedance ( $\Delta Z_{\text{ring}}$ ), the input impedance looking into the wristband coil ( $Z_{\text{in}}$ ) changes according to the mutual inductance ( $M = k\sqrt{L_{\text{ring}}L_{\text{wrist}}}$ ), expressed as:

$$Z_{\text{in}} = Z_{\text{wrist}} + \frac{(\omega M)^2}{Z_{\text{ring}}} \quad (1)$$

where  $Z_{\text{wrist}}$  and  $Z_{\text{ring}}$  the inherent impedance of the wristband and ring coil, respectively,  $\omega$  the angular frequency of the carrier signal. By maximizing  $L_{\text{wrist}}$ , the  $(\omega M)^2$  scales significantly higher. This amplification ensures that even when the  $k$  is low due to distance or misalignment, the variation in  $Z_{\text{in}}$  remains large enough to stably detect and demodulate. In total,  $Q$ -factor, inductance, and power consumption of the wristband are 9, 3.2  $\mu$ H, and 170 mW ( $= 3.3$  V  $\times$  51 mA), respectively.

## 4 TECHNICAL EVALUATION

### 4.1 Operation Time using BLE vs NFC

Based on the measured power consumption of the ring hardware (Table 2), we evaluated the operational ring lifetime when powered by a miniature 20 mAh lithium-ion curved battery designed for

smartring. When configuring the ring for continuous active tracking, the measured power consumption at 4.2 V significantly differs between the two wireless protocols (BLE and NFC). Operating the device entirely over a standard BLE active connection with the transmission power of 0 dBm consumes approximately 28.000  $\mu$ W (28 mW), draining the 20 mAh battery in just 4 h. Even though we decrease the input power to  $-40$  dBm, the power consumption remains almost the same as that of 0 dBm. In contrast, NFC drastically decreases the power below 900  $\mu$ W, enabling the continuous operation over 100 hours. Therefore, *picoRing dual* allows the ring to achieve an operational lifespan comparable to conventional handheld controllers, supporting 4 to 5 days of continuous use on a single charge. Furthermore, under a typical daily usage of 3 to 4 hours, the battery life extends to approximately one month, making it highly practical for long-term everyday applications.

## 4.2 Tilted Ring Optimization for NFC Type-V

To maximize communication range between ring and wristband, we selected NFC Type-V over standard Type-A after evaluating their Received Signal Strength Indicator (RSSI) profiles across distances from 1.5 cm to 12.0 cm (Figure 4a). While the Type-A protocol loses connection beyond 3.5 cm due to its high RSSI demodulation threshold around 400 mV<sub>rms</sub>, Type-V successfully maintained a stable wireless link up to 12.0 cm, operating reliably down to a minimal RSSI threshold of only around 10 mV<sub>rms</sub>. This 3.4-fold increase in communication distance is driven by Type-V's narrow signal bandwidth, which significantly lowers the receiver's noise floor and threshold sensitivity. As a result, Type-V can successfully decode attenuated signals, making it ideal for the restricted, low-coupling finger-to-wrist path.

To further stabilize the link during dynamic hand movements, we optimize the ring's coil geometry by evaluating four prototypes with tilting angles ( $\phi$ ) from  $0^\circ$  to  $30^\circ$  under straight and bent finger postures (see Figure 4bc). Increasing the angle generally increases the coil's area, increasing the ring's  $L$  or  $Q$ -factor besides the  $k$  (see Figure 4b). The increase in  $k$  is also owing to the geometric alignment between the ring and the wristband. Because the positional relationship between the finger and the wrist is inherently asymmetric, the magnetic flux lines emitted from the wristband pass through the finger at an angle. We confirm that  $\phi = 20^\circ$  is the best among the three tilting angles because  $\phi = 20^\circ$  shows high RSSI over 20 mV<sub>rms</sub> for the straight/bending posture. With this ring's angle optimization, the RSSI of the ring coil with  $\phi = 20^\circ$  is increased by approximately 2 over the ring coil with  $\phi = 0^\circ$ .

## 5 APPLICATION EXAMPLES

*picoRing dual* offers a significant advantage in providing long-term continuous operation on a single charge, while reliably detecting subtle thumb-to-index microgesture and index finger movements. Therefore, its main application is ubiquitous finger input for AR/XR, particularly when integrated with augmented reality (AR) glasses. AR glasses often rely on dynamic hand gestures or smartphone touch control for interactions, which can lead to fatigue or discomfort over time. In contrast, *picoRing dual* offers subtle bimanual inputs that enable comfortable, long-term interactions while preserving user privacy.

Figure 5 shows some application examples of *picoRing dual*. First, *picoRing dual* can function as a pair of ring controllers for XR gaming like first-person shooting, which requires reliable detection of continuous inputs from both hands without occlusion issues. *picoRing dual* allows a user to use one hand's trackball for smooth character locomotion while simultaneously using the other hand's IMU for weapon aiming. This dual-ring delivers handheld-grade control precision while maintaining a completely wearable form factor. Next, *picoRing dual* enables hands-free multitasking during everyday activities like cooking. While the user's hands are physically occupied such as holding a spatula, the rings allow them to manage background digital tasks (e.g., checking e-mail) without disrupting their workflow. If the ring's IMU detects no hand movement for an extended period while the user is distracted by other tasks, the ring can provide alerts to refocus the user's attention. Lastly, *picoRing dual* is available for outdoor mobile scenarios, such as interacting with an AR navigation map while walking. Traditional camera-based hand tracking often fails outdoors due to dynamic ambient lighting, and holding a smartphone while walking introduces safety and ergonomic concerns. In contrast, *picoRing dual* enables private, subtle interactions directly inside a pocket or at the user's side. Users can effortlessly zoom, scroll, or pan the AR map with micro-finger gestures while walking naturally.

## 6 CONCLUSION AND DISCUSSION

This paper presented *picoRing dual*, a dual-ring-based ultralow-power bimanual interaction designed to overcome the severe power and form-factor constraints of finger-worn devices. By constructing a short-range data communication between the ring and a nearby wristband through the NFC-based inductive link, we shifted the heavy power burden of long-range active radios away from the smartring. Driven by an optimized high- $L$  coil and a low-overhead data compression scheme, the ring module achieves a continuous tracking frame rate of 50 fps at an ultra-low power consumption of just 0.86 mW. Powered by a miniature 20 mAh battery, *picoRing dual* extends the ring's operational runtime to 100 h (4 days), enabling a 30-fold increase compared to standard BLE setup. Lastly, *picoRing dual* demonstrates its feasibility for ubiquitous, everyday AR/VR interactions through three types of application examples.

Future work will focus on several key areas. First, we plan to conduct user studies to quantitatively evaluate the spatial input accuracy of the trackball and IMU configurations across various mobile contexts. Second, while the current wristband readout board can operate for a full day on a standard wearable battery charge, which is sufficient for standard smartwatch applications, we aim to further optimize its power management to match the multi-day operation of the rings. Finally, we envision upgrading the higher-level link between the wristband and AR glasses. By replacing standard BLE with metamaterial textile networking, signal propagation can be guided efficiently over the body surface [35]. Wireless charging-enabled e-textiles would be the other option, which can transfer watt-class power to the smartwatches or glasses [34]. Integrating this with our ring-to-wristband energy-efficient inductive link will push the entire ecosystem among rings, wristbands, and glasses.



Figure 5: Application examples of picoRing dual.

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