# Demo of Z-Ring: Context-Aware Subtle Input Using Single-Point Bio-Impedance Sensing


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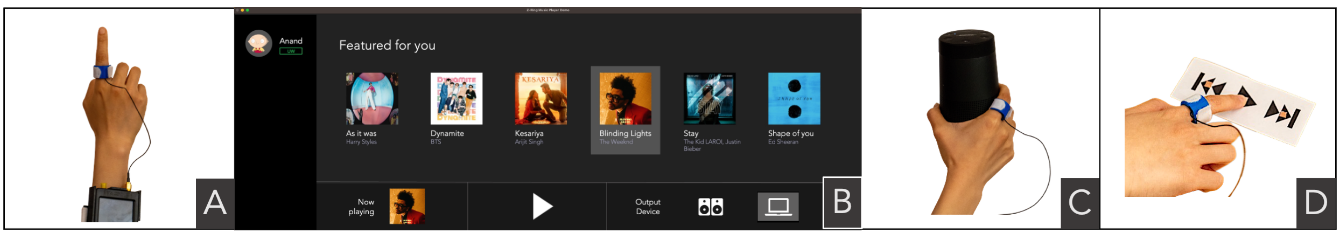


**Figure 1: Z-Ring is a ring wearable (A) that employs RF sensing for context-aware interactions, demonstrated through a music player app (B) featuring interactions like audio redirection to a Bluetooth speaker by grabbing it (C) and seamless control using passive copper sheet-based tangible buttons (D).**


## ABSTRACT

This paper presents Z-Ring, a novel wearable device that uses radio frequency (RF) based sensing to offer unique capabilities for human-computer interaction, including subtle input, object recognition, user identification, and passive surface interaction. With only a single sensing modality, Z-Ring achieves diverse and concurrent interactions that can enhance the user experience. We illustrate the potential of Z-Ring to enable seamless context-aware interactions via a custom music player application. In the future, we plan to expand Z-Ring's functionality with user customization and explore usage for additional applications.



## CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile devices**; **Interaction devices**; **Interaction techniques**.

## KEYWORDS

Wearable Computing; Context Aware; RF Sensing; Human-Computer Interaction




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## 1 INTRODUCTION

In the dynamic landscape of immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR), user input mechanisms are fundamental to the quality of interaction and overall experience. Current interaction mechanisms, often featuring more prominent hand movements or voice commands, can be fatiguing over extended periods of use [5, 7]. For these immersive technologies to be practical and comfortable, especially for prolonged durations, the development of subtle input methods is indispensable. By reducing the gap between the user's physical movement and the digital response, such input can deliver a more comfortable and engaging experience.

In addition, integrating context awareness with subtle input can make experiences more immersive and intuitive [4, 6]. If the input modality knows the user's current activity, it can automatically provide relevant responses and take appropriate action.

As our primary interface for interaction with our environment, the human hand offers immense potential for providing such a context. Wearable devices equipped with the ability to detect and interpret what our hands are holding or touching can provide valuable insights into our ongoing activities and possible intentions, enabling interactions tailored to the user's immediate needs and actions.

We introduce Z-Ring, a ring-based wearable device designed to empower users with four distinct functionalities: subtle input, object recognition, user identification, and passive surface interaction. Using these capabilities in tandem facilitates an experience that is subtle (via subtle input), contextually aware (via object recognition), ubiquitous (via passive user interfaces), and mindful of privacy (with user identification). Compared to existing work, which requires separate sensing modalities to detect different interactions, Z-Ring uses a single sensing modality to enable multiple concurrent interactions, enabling richer experiences.

Z-Ring models the hand as an electrical antenna[8] using RF-based sensing.The impedance of this hand antenna is affected by the pose of the hand and what the hand is holding or touching. By analyzing hand impedance, measured by performing an S11 measurement, Z-Ring can employ a machine learning backend to predict the hand's activities accurately. This approach leverages a single sensing modality for comprehensive hand activity recognition.

In this paper, we demonstrate the capabilities of Z-Ring in the context of a music player application (Figure 1). We feature the music player application as a representative example, where Z-Ring's subtle input functionality lets users control and navigate through tracks with small finger movements. At the same time, its object recognition enables users to change the device from which the music is playing. The user identification feature offers personalized playlists, and passive surface interaction helps users play, pause, or change music tracks simply by tapping on a passive surface.

## 2 IMPLEMENTATION

The Z-Ring system comprises a 3D printed ring that incorporates gold-plated copper electrodes on a flexible printed circuit board (PCB) affixed to the inner surface of the ring. These electrodes remain in contact with the user's finger and are connected to a portable Vector Network Analyzer (VNA) [1] that conducts the S11 measurements. These measurements involve a frequency sweep from 1 MHz to 1 GHz, yielding a 51-point measurement of complex numbers that signify magnitude and phase at various frequencies. On the outer side of the ring is a 6-degree-of-freedom Inertial Measurement Unit (IMU), operating at a frequency of 100 Hz. Both the VNA and IMU interface with a Raspberry Pi board to read the measurements and transfer them wirelessly over WiFi to a computer for further processing. A battery powers all electronic pieces and is situated on the user's wrist, together with the VNA and Raspberry Pi.

The computer on the receiving end of the wireless data analyzes the incoming data to make inferences about the hand interactions. These inference outputs control a music player application running on the same computer. The application uses OpenCV for the music player interface, while Scikit-learn[2] and TensorFlow[3] support the machine learning backend.

## 3 INTERACTIONS

In the context of the music player application, Z-Ring enables the following interactions:

**Song Navigation and Selection via Thumb-to-Index Gestures.** Z-Ring facilitates navigation through the song list using simple swipe gestures in the up, down, right, and left directions performed with the thumb and index finger. Tapping the thumb and index finger together allows song selection. Additionally, pinch-and-rotate gestures enable volume adjustment.

**Audio Redirection Using Held Object Recognition.** Z-Ring redirects the audio simply by touching the intended output device. For example, holding or touching a Bluetooth speaker directs the audio output to that speaker, while touching a laptop redirects the audio output to the laptop's speakers. Similarly, touching near the ear activates the headphones for audio output.

**Seamless Control with Ubiquitous Passive Music Buttons.** Z-Ring enables music control using copper-based buttons to operate the music player. These buttons facilitate functions such as play/pause, volume adjustment (up/down), and song navigation (next/previous). Touching a specific button triggers the corresponding action in the music player.

**User Profile Access Through User Identification**. Z-Ring incorporates a user identification mechanism to load personalized user profiles, including favorite songs. The interaction is enabled simply by wearing the ring, which causes the system to perform a background user identification check; if the user is in the database, their profile is retrieved and loaded. For new users, the system creates a system profile and saves their preferences, including their favorite songs, for future reference.

## 4 CONCLUSION AND FUTURE WORK

The Z-Ring is a wearable device that leverages rich RF-based sensing to facilitate subtle input, object recognition, user identification, and passive surface interactions. Using the example of a music player, a common application, we illustrate how Z-Ring's capabilities facilitate seamless, context-aware interactions. As we look toward the future, we will explore Z-Ring's full potential through user customization, personalization, and exploring a broader range of applications. This involves developing easily understood interfaces that let users define their own gestures, preferences, or interaction mappings based on their individual needs and preferences.

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