EarLume: Nonverbal Self-Expression Through Light-Based Earable

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Fig. 1. Demonstration of Earlume's functionality and interactivity: The left image shows a real-world usage scenario, the right image sequence illustrates the user interaction and functionality that the light will illuminate in the same order upon playback.

This paper presents Earlume, an on-skin earable designed to explore non-verbal self-expression through customizable light-based interactions. Inspired by the symbolic role of ear adornments in self-expression and the usage of on-skin interfaces as media for self-expression, Earlume aims to provide functional wearables with aesthetic customization. Inspired by the braille texture input and Morse Code, the device enables users to record and replay personalized input patterns, offering an interface for playful and expressive interactions. This paper details EarLume's interactive process, fabrication, and system functionality. Earlume emphasizes the potential for integrating interactive wearables with design features to create new forms of digital and personal expression.

Additional Key Words and Phrases: On-Skin, Wearable, Self-expression, Human Computer Interaction

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1 Introduction

Wearable devices are currently at the heart of human-computer interaction (HCI) topics, driven by the increasing development of new technology that can replace bulky and stationary equipment. In between, Earables, which are ear-worn devices with sensors located in the vicinity of the ear [11, 21] are an emerging form factor. The ear, with its proximity to the face and complex neural structure experiences less movement during daily behavior, and thus it has a natural advantage as a sensor placement location. Many researchers have explored its usefulness for functions realization such as biometric [4–7, 22] and behavior monitoring [1, 10]. These technologies utilize the ear's stable and hidden nature for data collection, and show good performance, while these products seldom consider customization for personal expression.

The ear has long been a medium for self-expression across cultures and historical periods, and decorating the ear can communicate personal identity and emotion — from the societal symbolization in South Asia [15], group affiliation identities [8] long ago, to authority and gender expression in the modern city [14]. Earrings are valued for their subtle appearance, making them suitable for various occasions. Larger and more intricate designs can enhance confidence and personal characteristics. Unconventional accessories, such as asymmetrical designs or mixed materials, challenge traditional norms and promote inclusiveness in fashion [2]. These examples highlight the potential of the ear as a canvas for meaningful and diverse forms of self-expression.

At the same time, the seamless material experimented in the on-skin interfaces offer a novel approach by combining wearable technology as body extension [9, 12, 20, 23]. In addition to their functional use, the researchers also explored their possible connection to emotion [17], personalized expression[16]. For example, ThermOn [3] enables users to measure dynamic body feelings corresponding to the sound of music, and Tattio [13] allows individuals to design, make, and wear their own skin technology creations. More research work on epidermal electronics and interactive skin-worn devices has explored capacitive tattoos, flexible circuits, and LED-based skin displays, demonstrating their potential for functionality and aesthetic expression[18, 19].

Thus, we proposed the prototype of Earlume, a non-verbal self-expression interface that allows a user to fully customize light pattern for output display using natural behavior of tapping as input. Unlike existing wearables that primarily focus on functionality or passive display, EarLume integrates an interactive light-based system that transforms personal expression into a dynamic, programmable medium. Earlume works with a TinyLily microprocessor, LED lights, and a capacitive on-body interface to create a seamless and interactive user experience. This combination of components ensures a lightweight, flexible, and personalized device that meets a user's expectations. The development process behind Earlume focuses on creating an innovative body extension that supports playful and expressive interaction. Earlume extends this vision by integrating customizable, interactive, and expressive elements into an earable, further enhancing both personal and social engagement through on-skin interfaces.

2 Design Methodology

2.1 Iterative Design Process

During the design iteration of EarLume, we primarily conducted internal testing with members of our research team. Each iteration focused on refining key aspects of the earable, including LED placement, color combinations, input sensitivity, and overall comfort. We tested multiple LED placements and different color combinations using LED0402 and LED1206, as shown in Figure 2, and found that the in-parallel yellow-green LED0402 combination provided the best balance between brightness and design aesthetics. For input sensitivity, we experimented with different location

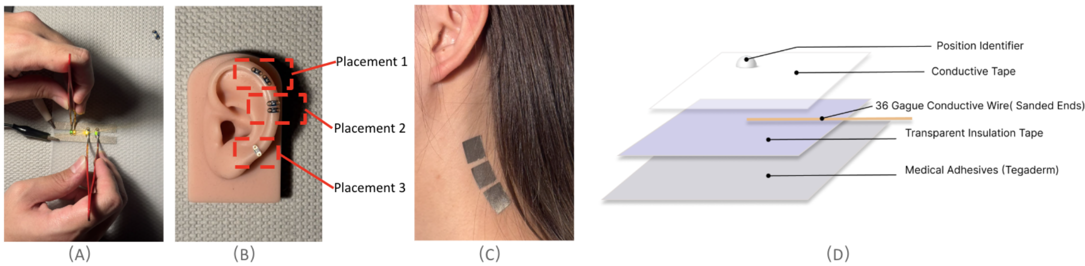

Fig. 2. In the iteration process, we tested: (A) Color combination of the LED light set in yellow and green; (B) Placement of ear position and light set alignment; (C) Input location around back neck area; (D) Layered structure with conductive tape, wires, insulation, and medical adhesives.

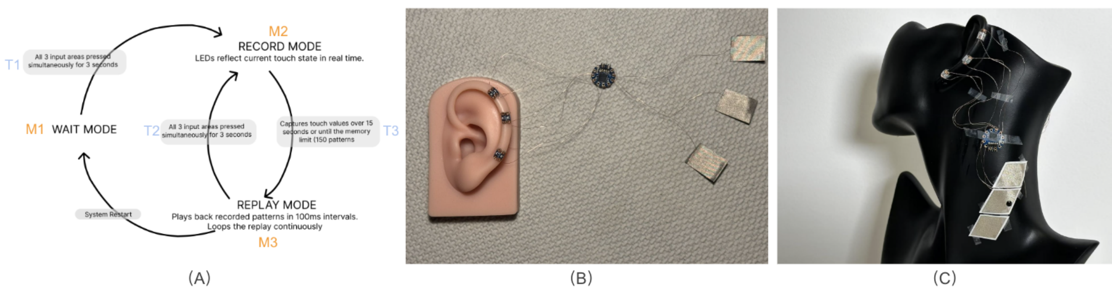

Fig. 3. In the final design, we implemented a touch-sensitive wearable system with the following components: (A) Technical framework of the system; (B) Tested prototype on an artificial ear model; (C) Final design and layout demoed on human model.

of input area and on-skin materials such as DuoSkin, conductive thread, and conductive tape. By evaluating the tactile responsiveness and wearability, we determined that conductive tape with layered insulation provided the best combination of sensitivity and skin safety. This decision also factored in its adaptability to different placements on the ear model, ensuring comfort and enhancing overall user experience, and then placing the device on a human ear to evaluate and demonstrate real use cases. Since our testing was conducted within the team, we relied on expert evaluations and iterative adjustments.

2.2 Fabrication

The fabrication process for EarLume used conductive tape, transparent insulation tape, 36-gauge conductive wire, and medical adhesive, with consideration for sensitivity, usability, and skin safety. The layered structure of our final input areas is shown in Figure 2. To ensure user safety and comfort, we incorporated a medical adhesive, Tegaderm, as a protective layer between the device and the skin. Conductive wires were prepared with ends sanded for electrical conductivity and placed on the adhesive side of the conductive tape to form the input area. On the other side of the conductive tape, a position identifier made of a black diamond sticker was placed at the corner to better help users identify the location of the input area. This design is inspired by Braille bumps, which help visually impaired individuals identify key locations on surfaces. Finally, the conductive tape was applied to the transparent insulation tape, forming the layered structure of the input area. The composition of the input area prevents accidental touch from skin and guarantees skin safety by forming a rectangular pyramid structure, in which the size of materials decreased gradually from the medical adhesive to conductive tape.

2.3 System Functionality

The circuitry for Earlume was created with a TinyLily micro-controller and TinyLily LED0402 sets, and the layered input area was connected to these with conductive wires. The system consists of three capacitive touch input areas made with conductive tape and three lighting modules, controlling LED0402s based on user input. It runs through three main modes in one cycle and fast LED blinking for 2 seconds signals the switch between modes. The modes include:

(1) WAIT Mode: Monitors user touch inputs; LEDs flash every 500 ms to indicate readiness.
(2) RECORD Mode: Activates when all three input areas are pressed for 2 seconds; then it captures and records touch input for up to 15 seconds, with LEDs lighting up to reflect input in real time.
(3) REPLAY Mode: Starts once Record Mode ends; replays the stored pattern, updates LEDs every 100 ms and loops until a new input is detected.

Through the fabrication of capacitive touch input, hardware connection and the logic written in the code, the EarLume captures input signals, processes them with corresponding algorithm, and controls the state of LED through connected pins.

3 Discussion

We designed an on-skin interface that enables users to freely manage the physical input and output of personal expression by digital means. Drawing inspiration from the hand actions of tapping Morse code and playing the piano, we use light patterns for non-verbal communication. The self-defined input and output connection transforms the device from a passive display into an active medium of personal creativity. Our work seeks to tackle the limitations of traditional verbal and textual expression through personalized light patterns and gestural inputs, creating new possibilities for conveying complex emotional and psychological states in the future. Furthermore, the new interface is comfortable and seamlessly integrated with the user's body. The technological components should be lightweight, flexible, and nearly imperceptible during everyday interactions. The technological design prioritizes user comfort and bodily integration.

The design and functionality of EarLume present opportunities for various applications beyond shining light patterns. As an expressive wearable, EarLume extends the concept of digital fashion by allowing users to personalize and modify the appearance dynamically. Future adaptations of EarLume could incorporate context-aware functionality by mapping different light patterns to specific notifications that cound realize hands-free, non-intrusive communication.

While EarLume presents a novel approach to on-skin earable interaction, our internal usability testing revealed that certain limitations remain, particularly in terms of usability and hardware constraints. Applying the EarLume interface to the ear requires precise alignment and positioning, making the installation process not so friendly, especially for a non-expert user in this field. Additionally, with the battery and microprocessor exposed in the current hardware setup, the system is vulnerable to disconnections and environmental factors. Ideally, these components should be integrated into a single, enclosed module for better durability and usability. Future improvements should focus on tackling these insights gained on modularization and easier application methods to improve usability and durability.

4 Conclusions

In this paper, we introduce Earlume, an earable designed to facilitate non-verbal self-expression through on-skin interaction. We refer to the piano-playing and Morse-typing actions, using an LED light set to create a seamless user input experience on the skin. The main contribution of this paper is the implementation of a full-cycle automation for user-defined modules, which bridge the gap in the current market and research that primarily focuses on functional earable applications or non-technical and less seamless methods of self-expression. EarLume shows great potential in various scenarios like emotional expression, assistive communication and interactive digital fashion, offering new possibilities for wearable technology integration.

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