Earlume: On-Skin Earable Prototype For Nonverbal self-expression

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Fig. 1. Demonstration of Earlume's functionality and interactivity: The left image shows a real-world usage scenario, the top-right image highlights the application of EarLume on human body, and the bottom-right image illustrates the user interaction.

This paper presents Earlume, an on-skin earable device designed to explore non-verbal self-expression through customizable light-based interactions. Inspired by the symbolic role of ear adornments in self-expression and usage of on-skin interface as medium for self-expression, Earlume aims to bridge functional wearables with aesthetic customization. The device enables users to record and replay personalized input patterns, offering an interface for playful and expressive interactions. This paper details the interative process, fabrication, and system functionality. Earlume emphasizes the potential of integrating interactive wearables with design principles 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 HCI topics, driven by the increasing development of seamless material used to replace bulky and stationary equipment. In between, earables, which are ear-worn devices with sensors located

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in the vicinity of the ear [12, 22] are an emerging form factor. There has been extensive research in the functional use of earables, especially for healthcare applications [24], there is less focus in their exploration as personalized and interactive tools for creative self-expression. Thus we proposed the prototype of Earlume, an non-verbal communication interface that allows user to fully defined input and output display as a way of hidden self-expression. Earlume works with TinyLily microprocessor, LED lights, and capacitive on-body interface to create a seamless and interactive user experience. This combination of components ensures a lightweight, flexible, and personalized device that fits user' expectation. The development process behind Earlume focuses on creating an innovative bodily extension that supports playful and expressive interaction.

2 Related Work

The ear has long been a medium for self-expression, with adornments such as earrings, piercings, and ear cuffs representing cultural symbols and personal identity among various societies [15] [1]. In modern contexts, ear accessories continue to reflect individuality and subcultural affiliations, yet the emergence of earables are closely related to sensor usage [21] [5]. Ear-worn smart devices largely focused on its function realization such as biometric sensing[23][4][6][7][9] and behavior monitoring [11] [2], [25]. While these technologies utilize the ear's stable and hidden nature for data collection, they often lack aesthetic personalization and expressive interaction. On-skin interfaces offer a novel approach by combining wearable technology with self-expression [3], allowing users to integrate dynamic, interactive elements directly onto their bodies[13][10][16] [20]. Peng explored the system's ability to fuel social dialogue, amplifying positive emotions [17], and Kao's work, Tattio[14], allow individuals to design, make, and wear their own skin technology creations. Research in epidermal electronics and interactive skin-worn devices has explored capacitive tattoos, flexible circuits, and LED-based skin displays, demonstrating their potential for both functionality and aesthetic expression[18, 19]. Earlume extends this vision by integrating customizable, interactive, and expressive elements into earable, further enhancing both personal and social engagement through on-skin interfaces.

3 Design Methodology

3.1 Iterative Process

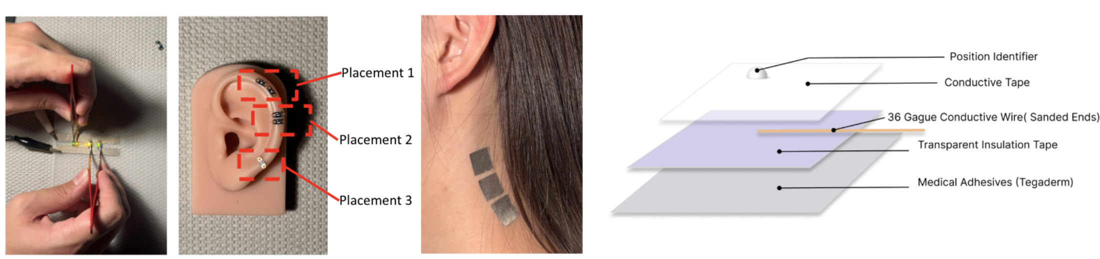

Fig. 2. In the experiment process, multiple LED placement configurations (Placement 1, 2, 3) and color combinations (yellow-green, yellow-yellow, green-green) are tested for aesthetic use; different input positions and sizes to align with natural hand movements behind the neck; EarLume finalized with a layered structure of an on-skin electronic interface, incorporating conductive tape, 36-gauge conductive wire, insulation tape, and medical adhesives for flexible and durable connectivity, and a diamond sticker as position identifier.

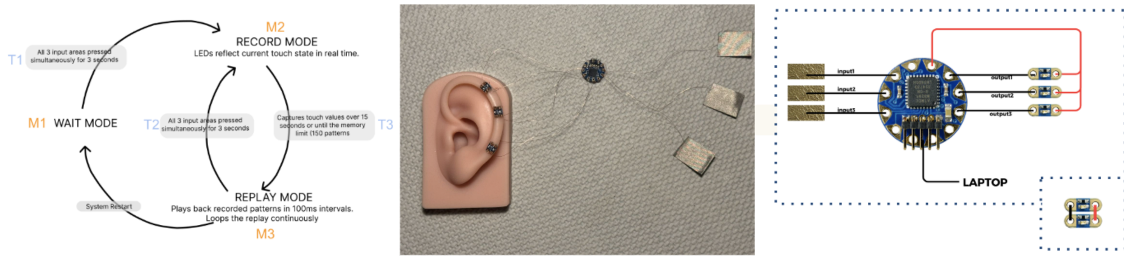

Fig. 3. The interaction model consists of three modes: wait, record, and replay, enabling dynamic touch input capture and playback, with two transition modes in between; Fully functional integrated prototype was first applied and tested on ear model; System circuit diagram illustrating the circuit consists of touch input, microcontroller, and LED sets.

We explored various LED placement options and tested different color combinations using two LED types: LED0402 and LED1206, as shown in Figure 2, and the in-parallel yellow-green LED0402 combination was chosen, as it provided the ideal balance between brightness and design aesthetics. Different on-skin materials were tested such as DuoSkin [13], conductive thread in weaving, conductive tape that would contribute to the touching sensitivity and aesthetic visual of the wearable. We also experimented with various positions and sizes for the input area following the natural mapping principles of hand movements behavior behind the neck. This decision also factored in its adaptability to different placements on the ear model, ensuring comfort and enhancing overall user experience, and then apply on human ear [8] to evaluate and demonstrate real use cases.

3.2 Fabrication

The fabrication process for EarLume used conductive tape, transparent insulation tape, 36-gauge conduct wire, and medical adhesive, with consideration of sensitivity, usability, and skin-safety. The layered structure of our final input areas is shown in Figure 5. To ensure user safety and comfort, we incorporated medical adhesives, 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 conductive tape to form the input area. On the other side of the conductive tape, a position identifier made of diamond sticker was placed at the corner to better help user identify the location of input area. This design is inspired by Braille bumps, which help visually impaired individuals identify key locations on surfaces. Finally, conductive tape was applied to the transparent insulation tape, forming the layered structure of the input area. The composition of 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.

3.3 System Functionality

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

(1) WAITING Mode: Monitored user touch inputs. LEDs flash every 500 ms to indicate readiness.

(2) RECORD Mode: Activated when all three input areas are pressed for 2 seconds. Then captured and recorded touch input for up to 15 seconds, with LEDs lighting up to reflect input in real time.
(3) REPLAY Mode: Started once Record Mode ends, replayed the stored pattern, updated LEDs every 100 ms and looped until a new input is detected.

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

4 Discussion

We designed an on-skin interface that enables users to freely do the physical input and output personal expressions in digital ways. Drawing inspiration from tapping the Morse code and hand actions of piano playing, we use light patterns for non-verbal communication. Our work seeks to tackle the limitations of traditional verbal and textual communication by articulating complex emotional and social states through personalized light patterns and gestural inputs. The self-defined input and output connection transforms the device from a passive display into an active medium of personal creativity. 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.

While EarLume presents a novel approach to on-skin earable interaction, 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 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 modularization and easier application methods to improve usability and durability.

5 Conclusions

In this paper, we introduce Earlume, an earable device designed to facilitate non-verbal self-expression through on-skin interaction. We refer to the piano-playing and Morse-typing actions, using LED light set to create a seamless user input experience on the skin. The main contribution of this paper is the implementation of a fully-cycles automation for user-defined modules, which bridge the gap in the current market and research in which primarily focuse on functional earable device applications [17, 24] or nontechnical and less seamless methods of self-expression [18, 19].

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