EarPut: Augmenting Behind-the-Ear Devices for Ear-based Interaction

Roman Lissermann
Telecooperation Group
Technische Universität Darmstadt
lissermann@tk.informatik.tu-darmstadt.de

Jochen Huber
Telecooperation Group
Technische Universität Darmstadt
jhuber@tk.informatik.tu-darmstadt.de

Aristotelis Hadjakos
Telecooperation Group
Technische Universität Darmstadt
hadjakos@tk.informatik.tu-darmstadt.de

Max Mühlhäuser
Telecooperation Group
Technische Universität Darmstadt
max@tk.informatik.tu-darmstadt.de

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Abstract

In this work-in-progress paper, we make a case for leveraging the unique affordances of the human ear for eyes-free, mobile interaction. We present EarPut, a novel interface concept, which instruments the ear as an interactive surface for touch-based interactions and its prototypical hardware implementation. The central idea behind EarPut is to go beyond prior work by unobtrusively augmenting a variety of accessories that are worn behind the ear, such as headsets or glasses. Results from a controlled experiment with 27 participants provide empirical evidence that people are able to target salient regions on their ear effectively and precisely. Moreover, we contribute a first, systematically derived interaction design space for ear-based interaction and a set of exemplary applications.

Author Keywords

Ear-based interaction; mobile interaction; eyes-free; device augmentation; touch, multi-touch; experiment

ACM Classification Keywords

H5.2. User interfaces: Graphical user interfaces (GUI), Input devices and strategies, Interaction styles.

General Terms

Human Factors

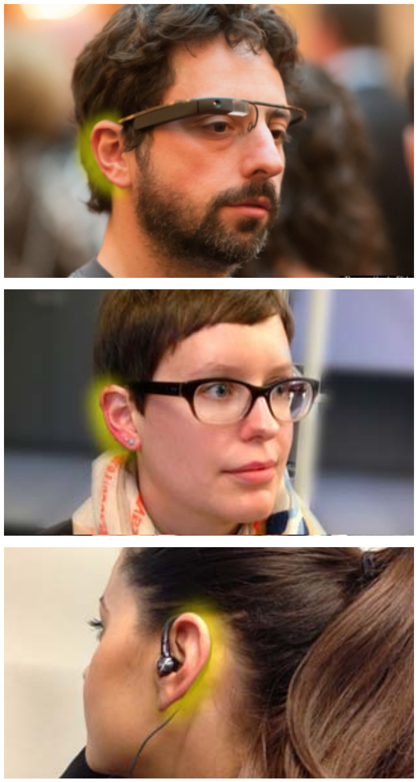

Figure 1. The ear hook of devices that are placed or worn behind the ear can be augmented to instrument the human ear as an interactive surface for touch-based interaction.

Introduction

Alice is an avid jogger and usually listens to music on her runs. Today, she has her iPod with her and is listening to one of her favorite albums through earphones. From time to time on her run, she skips to the next song in the playlist. But instead of fiddling with her iPod or looking for the remote attached to the cable of her earphones, she simply taps her ear once to advance to the next song. She is also used to adjusting the playback volume, depending on the environmental noise around her. And again, she just swipes across her ear helix to do so. When she returns from her run back home, she takes off the earphones and puts her glasses back on. She enters the living room and switches on the TV by double tapping on her ear. She then skims channels by touching either the upper or lower part of her ear helix to advance or go back in the channel list.

The scenario above illustrates how the human ear can be beneficial for eyes-free, mobile interaction. Ears are particularly interesting for that purpose due to three reasons: (1) we can interact with each of our ears using *just one hand*, (2) the human sense of proprioception [12] allows us to do so reliably *without visual attention* and (3) the *ear as an interactive surface* provides more degrees of freedom for interaction than e.g. ear- or headphones with integrated controls. These observations lead to the central question of this work-in-progress: how can these characteristics be capitalized for *precise* and *effective* eyes-free, mobile interaction?

A large body of research is concerned with instrumenting body parts as interactive surfaces [2–6]. These rely primarily on heavy and complex instrumentation. Another field of research focuses on lightweight instrumentation of specific mobile devices with additional functionality, such as touch interaction on earphone cables [10], on headsets [1], with fabric [7] or hover gestures around devices [8, 9]. In the same vein, recent commercial products such as Google's "Project Glass" provide touch input on the side of the glasses frame. Compared to body-part instrumentation, these approaches have the drawback of device-based interactions: users either have to look for the device (e.g. earphone cable) or are unaware of precise absolute positioning of interface elements due to the lack of visibility (e.g. headsets).

In this paper, we propose to augment accessories that are placed or worn behind the ear (such as glasses, ear hook earphones or headsets, cf. Figure 1) with *EarPut*: a novel interface concept, which unobtrusively instruments the ear as an interactive surface. This way, arbitrary ear-worn accessories can be augmented to enable eyes-free, mobile interaction with the ear.

The contribution of this paper is three-fold, which is reflected by the remainder of this paper. We first present the concept of EarPut and illustrate its hardware implementation. We used the prototypical implementation of EarPut in a controlled experiment to assess both *precision* and *effectiveness* of touch-based interactions and contribute the results. Moreover, we provide first insights into the design space for ear-based interactions and conclude by exemplifying future application scenarios.

EarPut: Concept and Implementation

In order to track and identify touch-based interactions with the ear, we use capacitive sensing based on electrodes that are placed onto an arc-shaped area. The combined device is then used to augment the ear hook of existing wearable accessories (see Fig. 2), allowing for touch-based interactions on the *ear arc* (i.e. on both ear helix and lobe).

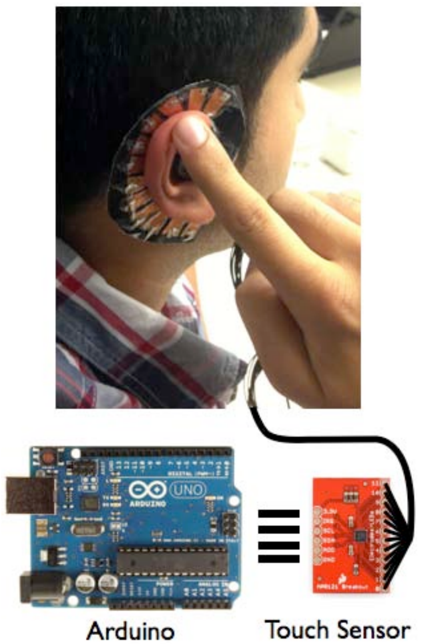

Figure 2. EarPut hardware overview.

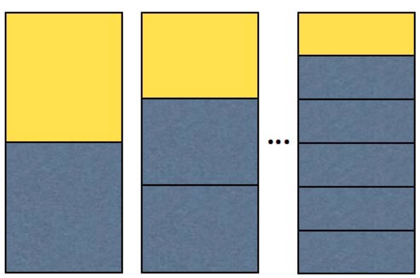

Figure 3. Region-based user interfaces used in the experiment. The UIs were subdivided into 2 to 6 areas, requiring the participants to touch the highlighted areas.

EarPut employs an MPR121 Capacitive Touch Sensor [11] to sense touch events. The sensor is connected to 12 electrodes. The electronic capacity increases when either a finger or parts of the ear arc approach an electrode. Thus, EarPut can sense touch input within 12 distinctive areas. The communication between the capacitive sensor and the microcontroller is based on the i2c serial protocol and performs measurements, as well as the signal analysis. Moreover, EarPut utilizes a breakout board (red in Figure 2) for the MPR121 Capacitive Touch Sensor, which is connected to an Arduino board, forwarding the sensor data.

Controlled Experiment

Although the sense of proprioception allows us to reliably touch our own ear, it is unclear how (1) precisely and effectively users can touch certain areas, and equally important, (2) how many different areas can be targeted at all. We thus used EarPut to explore these questions in a controlled experiment with 27 participants. As a first step, we measured both precision and effectiveness of single touch interactions as a crucial basis for more advanced interactions. Moreover, we conducted semi-structured interviews to obtain qualitative user feedback.

Experiment Setup and Methodology

The tasks consisted of simple touch tasks, where the participants had to map a visualized 1D region-based user interface (comparable to a selection menu) to their ear arc and touch the highlighted area (cf. Figure 3). Technically, the areas were mapped to the corresponding electrodes on the EarPut prototype. The beginning of the ear helix is mapped to the first electrode and the ear lobe to the last electrode.

The experiment was subdivided into two parts: a learning phase and the actual experimental phase. During the learning phase, the on-screen interface provided visual feedback for the touched area. Thus, the participants could familiarize themselves with the functionality of the prototype. During the experimental phase, the on-screen interface only showed the highlighted area and did not provide any visual feedback with respect to the participant's performance. The system advanced to the next target after each touch, regardless of whether the participant had successfully touched the area.

We chose a within-subject design with 27 participants (25m, 4f, avg. 27 years). The independent variable was the amount of areas, considering region-based interfaces with 2 to 6 different equally-sized areas. The dependent variable was the success rate of a user touching the highlighted region on her ear arc. During the experiment, the participants were seated. After each task, we asked the participants to touch the table, to prevent relative positioning of the touches. Each single user session lasted about 15 minutes.

Results

For each region-based interface, the participants had to touch each individual area 3 times (e.g. the interface with 2 regions resulted in 2x3 touch tasks, 3 per area). The order of the target areas was fully counterbalanced. Overall, each participant had to complete 60[1] touch tasks leading to 60 x 27 = 1620 data points in total for the experimental phase. We did not collect any data during the learning phase.

[1] 60 = 3 repetitions x (2 + 3 + 4 + 5 + 6 areas)

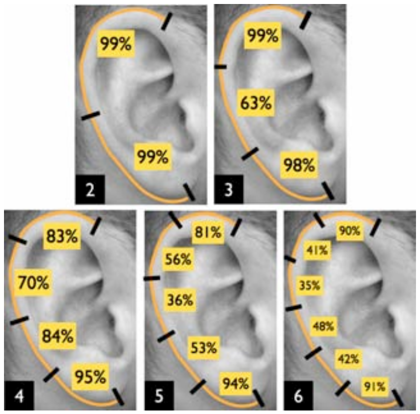

Figure 4: The average touch effectiveness for each individual area per region-based user interface.

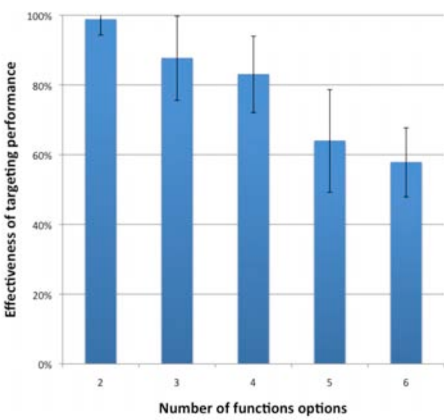

Figure 5: The average effectiveness of targeting areas per region-based user interface.

The average touch effectiveness of the individual touch areas for each region-based user interface is visualized in Figure 4. In the case of 2 areas, the participants touched both areas equally well. In the other conditions, the upper and lower parts of the ear arc were touched more effectively than the parts in the middle. Across all conditions, the average effectiveness for touching the ear lobe was above 90% and at least 81% for the upper part of the ear helix.

Figure 5 shows the average effectiveness of targeting areas per region-based user interface. The effectiveness decreased monotonically over all conditions. The average effectiveness is above 80% for region-based interfaces with up to 4 areas and decreases to 64% for 5 and 58% for 6 areas, respectively. ANOVA tests with Bonferroni post-hoc tests revealed that all differences but the one between 3 and 4 areas are statistically significant ($p<0.001$).

The decrease in effectiveness is in line with qualitative findings from the semi-structured interviews. The participants stated that it was hard to precisely distinguish between more than 4 areas. Moreover, despite region-based interfaces, the participants envisioned EarPut to be useful for more advanced interactions, such as gestures, multi-touch or grasping.

Discussion

The results from the experiment show that users can touch certain areas of their ear arc precisely and effectively, such as the ear lobe (>90%). For an odd total amount of areas, the middle part of the ear arc is more difficult to touch precisely. Thus, both upper and lower parts of the ear arc afford more fine-grained interaction than the middle part (see Fig. 4.3, 4.5). Consequently, interface elements should not be distributed equidistantly alongside the ear arc, but instead elements placed at the middle part of the arc should be larger than those at the ends.

This finding is also interesting for continuous interactions, such as sliding along the ear arc. To give a simple example: the results suggest that gestures starting at the outer parts of the arc (either lobe or upper helix) toward the middle tend to be less error-prone than gestures starting in the middle.

Furthermore, our results provide evidence that users can distinguish up to 4 salient regions on their ear arc effectively (>83%). We envision this to be leveraged as region-based shortcuts, as well as for multi-touch interactions on multiple areas for future EarPut interfaces.

In the interviews, the participants repeatedly suggested to use EarPut for a variety of other atomic interaction primitives, besides single touch. We transcribed the interviews, selected salient mentions of primitives and analyzed them using an open coding approach. This enabled us to get a first, systematic understanding of the interaction design space of EarPut, which we present in the following, along with envisioned applications.

Design Space and Future Applications

The analysis of the qualitative results yielded three major categories for EarPut interaction: (1) touch interaction, (2) grasp interaction, and (3) mid-air gestures. We first present atomic interaction primitives within these categories and show how we envision their application in two salient use cases.

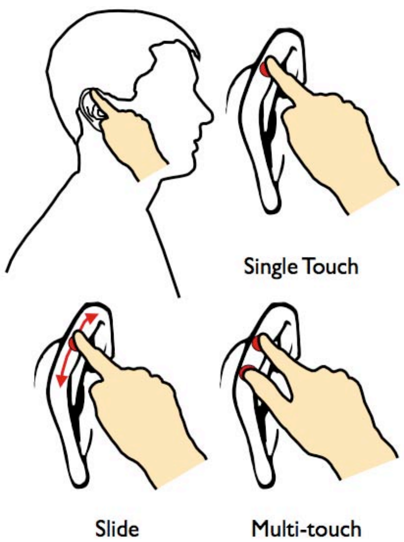

Figure 6. Touch Interaction

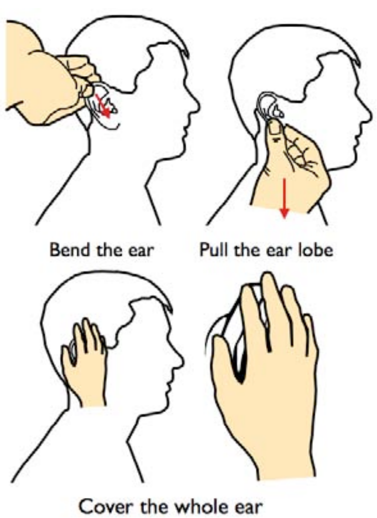

Figure 7. Grasp Interaction

Interaction Primitives

- *Touch Interaction* (see Fig. 6)**:** The whole ear arc can be used for *single touch* and *multi-touch* input, enabling the user to perform discrete and continuous gestures similar to those found in traditional touch surfaces, e.g., a one-finger *sliding* gesture or a two-finger *pinch*.

- *Grasp Interaction* (see Fig. 7): Grasp interactions comprise *bending* or *pulling* the earlobe or the upper helix, as well as *covering* the whole ear. The deformation of the ear is sensed and can be used as both continuous and discrete input.

- *Mid-Air Gestures* (see Fig. 8): Mid-air gestures close to the ear can be sensed and used as continuous or discrete input, similar to [9]. *Hovering* with the hand above the ear can be sensed for distance-based interactions. Then *swiping* the hand near the ear allows for directional interactions.

Exemplary Application Scenarios

The interaction primitives can be combined to compound interactions, which we exemplify in the following application use cases: one for outdoor and one for indoor use.

Outdoor: Music Player

Listening to music on the go is rather common. Oftentimes users have earphones with an integrated remote, enabling them to control their phone without visual attention. However, such interfaces are rather clumsy to use: The user has to find the remote and identify the right key based on her sense of touch. EarPut can provide more direct and thus more efficient interaction based on the users sense of proprioception, which enables her to perform actions on her ear with high precision and speed.

A possible mapping could be to have two *single touch* areas, one at the top the other at the bottom of the ear, to navigate within the playlist, a single finger *sliding* gesture to control the volume, and a *covering* gesture to start and pause playback, respectively.

Indoor: Home Automation

EarPut can be used to control home automation, enabling the user to control e.g. lighting, shading, audio-visual devices or domestic robots. One interaction category can then be used to select target devices. As an example: different bending gestures can be mapped to different classes of devices. Bending the upper helix selects lighting appliances, whereas bending the lower helix selects audio-visual devices. A different interaction category, e.g. touch, can then be used for controlling the appliances.

Summary and Future Work

We presented EarPut, a novel interface concept, which instruments the ear as an interactive surface for touch-based interactions and its prototypical hardware implementation. The central idea behind EarPut is to go beyond prior work by unobtrusively augmenting a variety of accessories that are worn behind the ear, such as headsets or glasses. In a controlled experiment with 27 participants, we assessed both precision and effectiveness of single touch interactions with EarPut. The results provide empirical evidence that people are able to distinguish between up to 4 salient areas on their ear arc. They further show that the upper and lower parts of the ear arc afford more precise interaction, than the middle part. Based on qualitative findings from post-

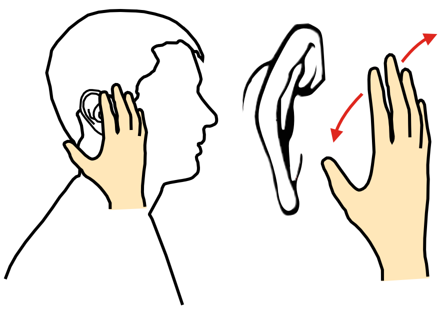

Figure 8. Mid-air Gestures

experiment interviews, we systemically set up a first interaction design space for ear-based interaction and showcased how interaction primitives can be combined in two exemplary application scenarios for more advanced interactions, such as touch-based, grasp-based and mid-air gestures.

As a next step, we want to further decrease the dimensions of the utilized hardware (e.g. with smaller modules and a two-sided printed circuit board design), to set up a truly mobile prototype with wireless connection. We will further investigate how to optimize region-based user interfaces for the ear arc, particularly considering non-equidistant spacing of interface elements. Last, we will explore concurrent interactions with two hands, when using EarPut on both ears.

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