Enhancing Spatial Input on the Body with a Smart-Ring

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Abstract

Smart, interactive fabrics are enabling a new generation of wearables that can sense touch input with high fidelity. However, while sensing systems are improving, we argue that human challenges remain: touch input on clothes will be hard due to a lack distinctive physical cues to guide users and the fact that many wearable scenarios involve eyes-free input. We propose to address these issues by combining touch selections on the body with complementary input on a ring wearable. We validate this idea with an empirical study that contrasts targeting performance with input on the body against that with a combination of input on ring and body. The results show that times remain static, while error rates and workload are significantly improved.

Keyword

Wearable; smart-ring; eyes-free.

1. Introduction

We can now create smart clothing with interactive textiles capable of acting as rich and expressive touch input spaces. Enabling technologies for this kind of on-body input are diverse and include sound [4], conductive fabrics [5, 8, 9], capacitive sensors [6, 10, 11] piezoelectric material [2], and flexible touchpads [13]. While these techniques can enable eyes-free one-handed input to almost any location on the body, in practice users are comfortable making input on only a very few socially acceptable hotspots [3, 14], such as the front and back pants pockets [3, 5, 13], the shirt pockets [10, 11] or the sleeves [9]. However, there are fundamental challenges with this type of input. Specifically, users have poor visual access to many of the viable body sites, making touch selections with no visual or haptic feedback a challenging task [6].

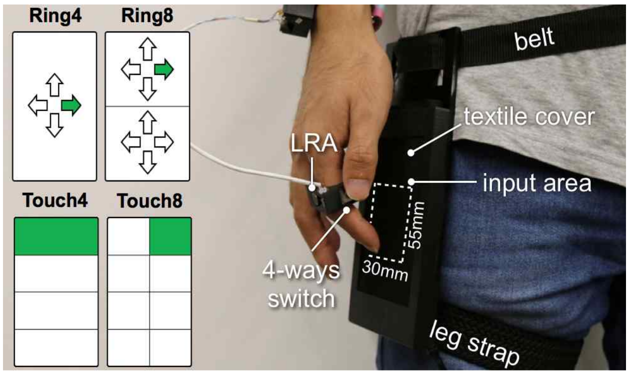

Figure 1. Ring hardware prototype and experimental setup.

In this paper, we propose Ring+Touch, a technique for achieving more effective eyes-free touch input on the body. The core idea is to combine on-body touch with a simultaneous complementary input on a wearable smart-ring. Basically, by splitting a single on-body targeting selection into two simpler but non-conflicting actions, we argue that users will be able to make selections more accurately, more quickly and while experiencing lower workload. To assess the validity of these claims, this paper presents a target selection study that compares traditional single-touch input on the body to the Ring+Touch combination of pair of inputs on a ring and body.

2. Related Work

Smart-rings and other finger augmentations are a longstanding topic of interest in HCI [12], and can support touch input on the body. Within this space, capacitive input technology is currently attracting considerable research interest as the sensors it requires are simple, small and flexible enough to be embedded directly in fabrics [9]. Holleis et al. [6], for example, evaluated touch input on capacitive garments, stressing the importance of avoiding unintentional input and of providing visual and haptic. PinStripe [8] addresses this problem by physically constraining interaction to a limited number of pinch-able and foldable areas. GesturePad [10], PocketTouch [11] and FabriTouch

[5], on the other hand, create touch surfaces on limited areas, such as the inside of a pocket, to support diverse input styles. Skinput [4] uses an array of bio-acoustic sensors to detect the sound of touch to the skin as they propagate through the body.

3. Ring+Touch Prototype and Interaction

Ring+Touch (Figure 1) is a smart-ring prototype, consisting of a wrist mounted driver board and a smart ring worn on a finger. The ring features a 4-way (up, left, down, right) toggle button (ITS-1500S) mounted on its side, in easy reach of the thumb. It can also provide high fidelity vibration feedback using a ø8mm Linear Resonant Actuator (LRA) from Precision Microdrives (C08-001). The ring prototype is an incomplete circle (a "C") to more easily accommodate different finger sizes. It was 3D printed using flexible PolyLactic Acid (PLA) filament. The ring is connected to the driver board strapped to the wrist, containing an Arduino Nano and a custom PCB with an amplifier for driving the LRA actuator (FZT849). The board is housed inside a 53 x 24 x 21(height) mm box, and interfaced through USB to a computer.

The ring is intended to be used as a complementary selection to on-body input. For example, tapping the same location on the thigh in conjunction with inputting a different direction on the ring would signify four different inputs. If there were two targets on the thigh, this would result in a maximum of eight possible inputs. In this way, we seek to increase the range of inputs that can be achieved through on-body touches in the space-constrained set of viable and socially acceptable body-areas.

4. Evaluation

In this study, we opted to study a simple targeting task with a single finger operating on a constrained input area. We believe this is sufficient to provide valuable baseline data (speed, accuracy and workload) about making a combination of selections on a ring and the body, rather than an equivalent selection made using solely on-body touches.

4.1 Participants and Material

We recruited 12 volunteers aged 20-35 (M: 25.8, SD: 4.9, 4 females), a mix of students and researchers from our university. Five were familiar with wearable devices, but none with smart-ring technology. One participant commonly wore a ring.

For the experiment, we built two Ring+Touch prototypes in US 8 and 11 sizes. These sizes were empirically determined from a survey of 48 local participants. To simulate on body touch input using high-resolution capacitive cloth, we simply used the touchscreen of a smart-phone (ASUS Zenfone) wrapped in a piece of black cloth. The phone was placed inside a 3D printed case and strapped to participants' thighs (Figure 1). This solution provides high performance touch input on an appropriately positioned fabric surface.

4.2 Procedure

The study followed a 2x2 repeated measures design. Conditions were interface-type (direct-touch vs. Ring+Touch) and number-of-targets (4 vs. 8). As displayed in Figure 1, users were required to perform an eyes-free target selection with their dominant hand on a 55 x 30 mm capacitive touch surface on the front part of the thigh. This location was selected as it is comfortable to reach with the fingers, socially acceptable, and sized comparably to that studied in previous work [5, 13, 14]. As shown in Figure 1, the direct-touch condition with four targets (Touch4) consisted of the touch area subdivided in four rows (each with a height of 13.8mm) for a total of four possible selections. In the Touch8 condition, each of the same four rows was divided into two columns (15mm wide) for a total of eight possible selections. In the Ring+Touch condition with four targets (Ring4), the space was not divided and users could enter a selection by first clicking one of the four directions on the ring (up, left, down, right) and then the targeting area. Finally, in the Ring8 condition, the on-body touch area was split in two rows (55x15mm) to achieve eight possible selections (two locations on the body by four directions on the ring).

The study followed a repeated measures scheme. Interface-type was fully balanced, while number-of-targets was arranged using a Latin square order. Each condition involved 13 blocks containing one occurrence of each possible target. The first three blocks were treated as practice and discarded. Participants were required to complete all trials successfully; errors were repeated, in randomized order. As such, we retained data from 40 and 80 trials per participant in the 4-target and the 8-target conditions (a total of 240).

During the study, participants were introduced to the hardware and task, then completed demographics and started the study. Each trial consisted of the following steps. First, the participant pressed the spacebar of a keyboard placed on a table in front of them with their dominant hand wearing the ring. This action initiated a trial and reset the time counters. The system then graphically displayed a target location on a monitor and, for the ring conditions, an arrow pointing in one of the four cardinal directions. The user's task was to make the input specified by these instructions with their dominant hand. We note the same hand is purposely used for keyboard and on-body selections as we wanted to simulate the task of reaching towards an on-body touch target. During the selection task, participants received vibrotactile feedback (a 200ms vibration) when touching the selectable input area. After dwelling in a target location for one second, a selection was recorded and the user notified by an additional vibration feedback. In the ring conditions a 100ms vibration pulse provided feedback that input on the four-way switch had been registered.

After the completion of all the trials for each condition, participants filled in a NASA TLX questionnaire to assess their cognitive workload. The experiment concluded with a short informal questionnaire. The study took approximatively 45 minutes and participants were compensated for their time with ~10 USD in local currency. From the study, we analyzed a total of 2880 correct input trials (12 participants x 240 trials) on the metrics of input time and errors.

5. Results

Figure 3 presents the task time, error, and cognitive load results. These were analyzed with two-way repeated measures ANOVAs on the variables of interface-type and number-of-targets. As both independent variables are binary no post-hoc tests or sphericity corrections are required. In terms of the task time, neither the interaction ($F(1, 11) = 0.011$, $p=0.919$, $\eta_p^2=0.001$) nor the interface-type main effect ($F(1, 11) = 1.418$, $p=0.259$, $\eta_p^2=0.114$) attained significance. Number-of-targets led to a significant effect with a moderate effect size ($F(1, 11) = 11.813$, $p<0.01$, $\eta_p^2=0.518$). The error data tell a more dramatic story with a significant interaction ($F(1, 11) = 27.157$, $p<0.001$, $\eta_p^2=0.712$) and main effects of both interface-type ($F(1, 11) = 160.643$, $p<0.001$, $\eta_p^2=0.936$) and number of targets ($F(1, 11) = 37.846$, $p<0.001$, $\eta_p^2=0.775$). Workload shows similar variations. The trend in the data across the individual measures is aptly exemplified in the overall workload score, so we restrict our analysis to this compound measure. Although the interaction did not attain significance ($F(1, 11) = 1.011$, $p=0.336$, $\eta_p^2=0.084$), both main effects showed significant differences with moderate to substantial effect sizes: interface-type ($F(1, 11) = 50.688$, $p=0.001$, $\eta_p^2=0.822$) and number-of-targets ($F(1, 11)= 36.127$, $p<0.001$, $\eta_p^2=0.767$).

The story these results tell is a simple one. As the

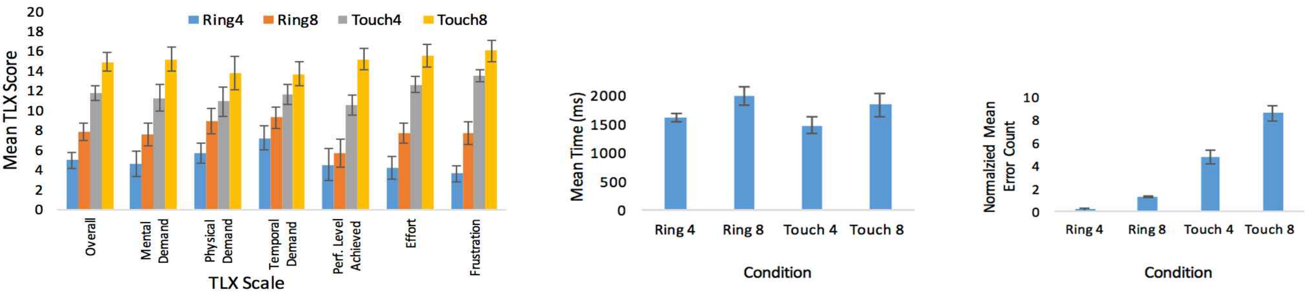

Figure 2. Cognitive workload results (left), input time (center) and errors (right).

number of targets went up, the selection task became more difficult across all measures. This is unsurprising. However, interface-type severely impacted the magnitude of this issue. While participants were able to execute successful selections equally rapidly with both devices, their error rates and resultant subjective experience deteriorated substantially in the direct-touch condition. We also note that the two selections on the ring and body were truly complementary in the sense that performing these paired operations did not take longer than performing a single on-body selection. We explain this by suggesting that participants made a ring selection with their thumb whilst moving their hand to the body and without impeding the speed or accuracy of this ballistic motion. Taken together, these results provide a strong endorsement for using an input ring to create more expressive on-body touch spaces.

6. Limitations and Conclusions

This work presented an interaction technique for on-body touch input that uses complementary input on a wearable ring to create a more expressive input space. An empirical study documents performance benefits in the form of substantially reduced error rates and workload with higher target cardinalities. Future work on this topic will focus on viable input methods on a smart-ring interface to achieve extra input bandwidth, such as miniature touch surfaces.

Acknowledgement

This research was supported by the MSIP, Korea, under the G-ITRC support program (IITP-2017-2015-0-00742).

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