ExtensionClip: Touch Point Transfer Device Linking Both Sides of a Smartphone for Mobile VR Environments

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Abstract

We show ExtensionClip, a system that offers back-of-device touch interaction for a cardboard head-mounted display; it links the back of the smartphone to its touchscreen to greatly enhance the touch input area and usability. ExtensionClip sandwiches the smartphone between two magnets; the front magnet, which tracks the position of the back magnet, triggers touch events on the smartphone's touchscreen by capacitive coupling. ExtensionClip detects the user's touch of the back magnet from a change in the size of the touch area on the smartphone's touchscreen; thus ExtensionClip offers pointing functionality like a mouse. We fabricate an ExtensionClip prototype and conduct user studies. In the first study, we determine the threshold needed to detect the user's touch on the back magnet. Next, we measure the precision and the selection speed possible with ExtensionClip.

Author Keywords

Pointing; conductive; back-of-device interaction.

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces - Input devices and strategies

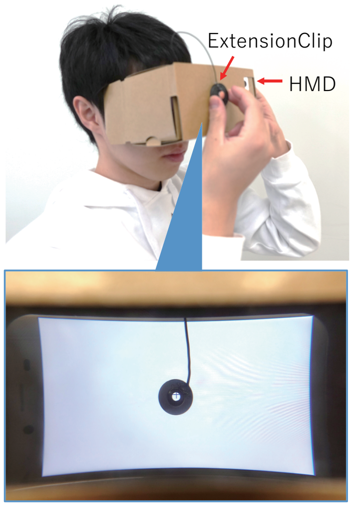

Figure 1: ExtensionClip.

Introduction

Mobile virtual reality (VR) systems based on a cardboard frame and a smartphone as the head-mounted display (HMD) such as Google Cardboard are expected to achieve rapid penetration of the consumer market. However, such systems hide the touchscreen of the smartphone and prevent the user from touching the screen. Current mobile VR user interfaces (UIs) are designed assuming that Head-Rotation is the main UI. This greatly limits the UI design space and UI performance. With Head-Rotation, a crosshair cursor is centered in the middle of the view, and the user can only select targets on the center of the screen. Therefore, it is difficult to realize applications that place targets on the edges of the screen (e.g., menu boxes placed along the edges or in the corners of the display).

To address this problem, we present ExtensionClip (Figure 1), a touch point transfer device for flexible target selection in mobile VR systems. ExtensionClip is a technique that allows the front touchscreen to detect user's operation on the back of the smartphone making the back an active area.

ExtensionClip is simple and inexpensive to fabricate, and allows direct interaction with all virtual contents in the user's field-of-view. ExtensionClip sandwiches the smartphone with two magnets; the front magnet is forced to follow the user movements of the back magnet by the strong magnetic field linking them. A light and thin electrical wire joins the magnets to provide capacitive coupling, thus generating continuous touch events on the display. The touch area size increases when the user touches the back magnet, and use this characteristic for user touch detection. To prevent the target from being hidden by the front magnet, we give it the form of a donut shaped magnet; the user can see the target through the hole.

In the first study, we determined the threshold needed to detect user's touch on the back magnet. Next, we measured the precision and the selection speed possible with ExtensionClip.

Related Work

Our work is related to the research fields of back-of-device interaction, HMD pointing, and touch point transfer.

Back-of-Device Interaction

In order to extend the input area, Baudisch et al. [1] proposed back-of-device interaction; it leverages the back of the mobile device as an input surface. Several studies [14, 3, 17] apply this interaction to mobile VR interfaces. Matsushima et al. [14] proposed a technique for recognizing physical objects placed on the back of the smartphone. FaceTouch [3] uses an additional touch panel as an input area. Back-Mirror [17] is a camera-based touch input technique for smartphones that uses mirror reflection. It can track the index finger position on the back surface of the smartphone.

ExtensionClip turns the back of the smartphone into an active area and tactile feedback of pointer location is realized by the physical presence of the back magnet.

Pointing Techniques for Mobile VR

User touch input in mobile VR environments can be achieved by placing a touchpad on the external side of the HMD. Several techniques [3, 12] that offer multi-touch capabilities are based this method. However, such arrangements are costly and heavy. Compared with using an additional touchpad on the external side of the HMD, ExtensionClip is much simpler and more efficient.

Several proposals use the built-in camera to implement pointing functionality. Hakoda et al. [5] proposed a real-time eye tracking technique that uses the built-in front face camera to capture the user's eye. Using this technique, the user can select targets based on gaze position. CamTrack-Point [18] is a pointing technique that captures index finger gestures by the rear camera of the mobile device. ExtensionClip uses only the front side touchscreen of the smartphone, so it is much faster and uses far less power than camera-based back-of-device interaction techniques.

FistPointer [7] and PACMAN UI [8] are pointing techniques for mobile VR environments; they detect hand gestures by the rear camera of the smartphone. Unfortunately, making hand gestures in front of the HMD requires a lot of free space to prevent hand-object collisions. ExtensionClip minimizes the space needed for interaction.

Other pointing techniques for HMD have been proposed. Lyons [13] uses a compass sensor and a magnet placed on the side of the HMD for 2D pointing. Kato and Miyashita [10] transfer touch points on the side of the HMD to the smartphone via conductive patterns. Unlike these proposals, ExtensionClip can detect clicks and offers simple 1:1 direct mapping between front and back sides of the smartphone.

Touch Point Transfer
Touch panels are now being widely used. To extend the input area of existing touch panels, several touch point transfer techniques have been proposed. ExtensionSticker [11] is a conductive-ink printed striped pattern sticker that allows touch inputs to be transferred from an external source by simply attaching a sticker to the touch panel. This technique allows the use of 3D printed objects [9, 15]. ExtensionClip uses the concept of touch point transfer to mirror the smartphone's original touchscreen onto the back of the phone; the result is an enhanced UI for mobile VR.

To extend the touch interaction with touch transfer device, the characteristics of touchpad can be used. Ohmic-Touch [6] is a interaction technique using conductive object on a touchpad. In this technique, the touch area size of conductive object changes when a user touches the conductive object. We use this characteristic for click detection.

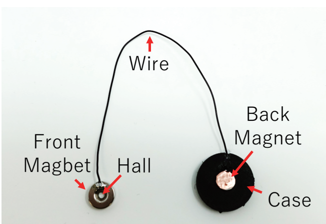

Figure 2: The prototype of ExtensionClip.

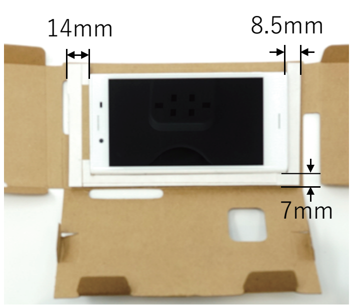

Figure 3: Positioning the smartphone.

ExtensionClip
ExtensionClip allows the user to select targets freely in the field of view provided by the mobile VR application.

ExtensionClip slaves a magnet on the smartphone screen to the user-shifted magnet on the back of the smartphone. The strength of magnetic coupling is sufficient to prevent the magnets from falling off the phone and ensure that the front magnet accurately follows the back magnet.

As the two magnets are linked electrically, the touchscreen will record continuous touch events due to the capacitive coupling created by the front magnet. When the user touches the conductor on the back magnet, the touch area size is changed which yields reliable click detection. ExtensionClip does not consume any power as all components are passive.

Figure 2 shows the prototype. The front-side magnet is a donut type magnet (OD 14 mm, ID 3 mm, Thickness 3 mm, Magnetic force 343 mT, conductive). The hole in the magnet allows the user to see the current touch position. The back magnet is a disk type magnet (D 10 mm, Thickness 5 mm, Magnetic force 410 mT, conductive). The wire linking them is 190 mm long, over the twice smartphone's width, to prevent the wire from hindering magnet movement. The wire is soldered to the magnets, the back magnet is mounted in a 3D printed case to enable easy control, and a small piece of copper foil tape is set on the back magnet's surface for stable detection of user touch.

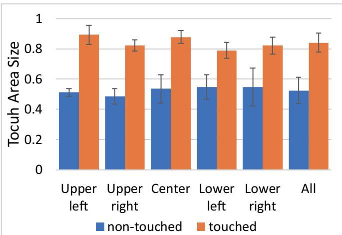

Figure 4: Touch area size at each position when user touched / did not touch the back magnet.

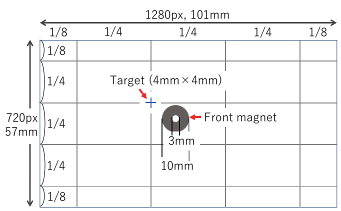

Figure 5: Application design for target selection.

X position [px] \ Y position [px]	160	480	800	1120
630	2.52	3.11	2.96	4.82
450	3.10	2.53	2.36	3.62
270	2.78	2.24	2.79	3.99
90	3.16	2.47	4.03	4.35

Figure 6: Target selection time of each target (unit: seconds).

Evaluation

We conducted two user studies; first, we evaluated the change in touch area size when the user touched the back magnet; second, we evaluated target selection speed and accuracy by using ExtensionClip in a mobile VR environment. All evaluations used an Android smartphone (Xperia X Compact, dimensions: 129 mm × 65 mm × 9.5 mm, display size: 4.6 in, resolution of the screen: 1280 pixels × 720 pixels, OS: Android 7.1.1). This smartphone was mounted in a monocular lens type VR goggle, HACOSCO Tatami 1 [4]. We used a monocular lens device to reduce the problems possible with binocular vision (e.g., VR sickness, adjustment of parallax). We improved the HACOSCO set in order to center the smartphone relative to the user's face as shown in Figure 3.

Volunteer

We recruited six volunteers (all males, laboratory members) aged between 22 and 25 years (mean: 23.2). All participants used a smartphone everyday (mean period of time: 75.8 months); all participants were right-handed. One participant had prior experience of using an HMD (period of time: 1 month); None of the participants had ever used any mobile VR application. Three participants had corrected vision; one wore glasses and two wore contact lenses.

Evaluation of Touch Area Size Change

We investigated the degree to which touch area size changed when the user touched the back magnet.

Procedure and Task

Each participant was asked to sit on a chair, hold the HMD with the left hand, and to operate ExtensionClip with the right hand. The participants were instructed to select the target as quickly and accurately as possible. The participant puts the ExtensionClip above the targets displayed red circles as a trial. The targets appeared at the center and the four corners (placed 1/8th of the screen size from the corner of the screen). We conducted 5 trials in both touched/not touched condition for each target yielding 150 trials (= 5 trials × 5 places × 6 participants) in total. Since in six trials the touch area size didn't change due to not updating the touch events when the participant touched the back magnet, we analyzed 144 trials. The Android OS allows touch area size to be measured only when touch events (touch start, move, end) are generated. This experiment took approximately 10 minutes per participant, including initial briefing.

We show the result of the first experiment in Figure 4; the error bars show standard deviation. We determined that the threshold value for click detection was 0.776, which is the lower end of the variance value of "All" in Figure 4. If the difference between the threshold value and the inherent touch area size is large, incorrect click detection can be minimized; especially when the user moves ExtensionClip.

Evaluation of Selection Speed and Accuracy

To evaluate the target selection speed and accuracy, we designed a target selecting application as shown in Figure 5. The target is a blue cross and the application shows one of 16 targets, see Figure 5. We defined the target width as 40 px (3.16 mm), which is slightly bigger than the front magnet ID size.

Procedure and Task

We gave the same initial instructions to the participants as in the previous experiment. Each participant was instructed to select the target as quickly and accurately as possible. The participant started the experiment by selecting the cross in the screen center. The next target was displayed after the participant succeeded in selecting the current target. To eliminate the order effect, the targets were presented in random order without duplication. The par-

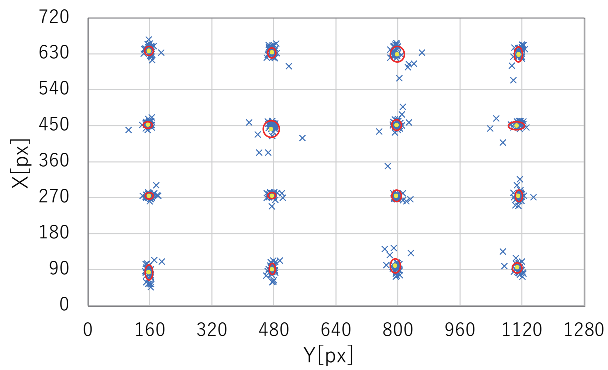

Figure 7: Touch positions for each target (blue cross: touch point, yellow circle: average of touch points, red circle: standard definition of touch points).

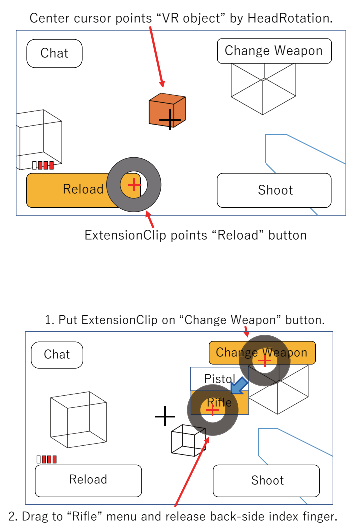

Figure 8: Target selection application.

ticipant selected 16 targets as one cycle and performed 5 cycles continuously. Therefore, 480 targets were selected (= 16 targets × 5 cycles × 6 participants) in total. Since the front magnet fell off seven times, we analyzed the remaining 473 target selections. This experiment took approximately 15 minutes per participant, including initial briefing.

Results and Discussion

Figure 6 shows the average target selection time for each position. The average time of all target selections was 3.18 seconds. Figure 6 shows that targets placed on the right side had longer selection times. Figure 7 shows the accuracy of target selection. In Figure 7, the blue crosses show the selection positions; the yellow circles show the average position of each target; the red circles show standard deviation. The largest red circle radius (standard deviation) is 19.26, this shows that the current version of ExtensionClip allows the user to select 40 px (3.16 mm) square UI buttons.

Discussion

ExtensionClip is a simple touch interaction technique for mobile VR environments, and does not consume any power. In the user study, several participants said that the electrical wire used to link the magnets obstructed magnet movement. By using PUCs [16], which uses only a conductive connection to trigger touch points on touch screen, and a back of device tap detection technique [2] to realize click detection, we can eliminate the electrical wire for linking both magnets; it becomes more simple.

By combining ExtensionClip and Head-Rotation, the VR world view can be navigated and objects are freely selected as shown in Figure 8. Figure 8 shows a first person shooting application with both UIs active: ExtensionClip and Head-Rotation. In this application, the user can aim at VR objects by centering them in the crosshair which is moved by Head-Rotation, while menu items and actions can be selected by ExtensionClip. ExtensionClip allows pull down menus to be accessed without losing the VR world view.

The prototype uses a donut type magnet to eliminate the occlusion problem. We can expect a similar effect with a Polka dot pattern of magnets mounted in transparent resin.

We tested multi-touch using two ExtensionClips on the same touch screen and we confirmed that it is possible. However, the smartphone captures the touch area size of just the last magnet to move; multi-touch gestures (e.g., pinch in/out) would be difficult. Furthermore, the magnets can alter each other's position.

The smartphone always receives a strong magnetic field while using ExtensionClip, but no damage was noticed during the experiments. While the compass sensor was strongly impacted, we think this effect can be eliminated by using the magnet position.

When selection is not needed, ExtensionClip can be parked on the bezel of the smartphone.

Conclusion

We introduced ExtensionClip, a simple but effective target selection UI that leverages the touchscreen of the smartphone for mobile VR applications. ExtensionClip is easy to implement and is inexpensive. ExtensionClip allows for direct interaction with virtual contents inside the VR world view by sliding a magnet on the back of the smartphone to the desired point. We conducted a user study and evaluated selection speed and accuracy. The results showed that the user can select a target within 3.18 seconds on average, and minimum UI button size is 40 px (3.16 mm). We plan to test ExtensionClip on binocular-type HMDs and HMDs that use other materials such as plastic, cloth, and rubber.

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