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Evaluation of edge-based interaction on a square smartwatch

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ABSTRACT

Researchers are proposing many approaches to overcome the usability problem of a smartwatch owing to its small touchscreen. One of the promising approaches is to use touch-sensing edges to expand the control space of a smartwatch. We considered possible interaction techniques using touch-sensing edges in combination with the smartwatch touchscreen: single-edge, multi-edge, and edge × screen (edge and touchscreen in combination). We call these techniques square watch interaction (SWI) techniques in this paper because they exploit the form factor of a square smartwatch. To explore the design space and evaluate the usability of the SWI techniques, we implemented a square smartwatch prototype with touch-sensitive edges, and conducted a series of user experiments. The experiment results showed that the SWI techniques enable precise 1D pointing and occlusion-free 2D pointing. The experiments also produced empirical data that reflect human manual skills for the edge × screen techniques. The produced empirical data will provide a practical guideline for the application of the edge × screen techniques.

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1. Introduction

The computing power of a smartwatch and its network environment are already good enough to make it a computing platform for diverse mobile applications. A more difficult challenge seems to be developing new user interfaces and new interaction techniques to overcome usability problems due to its small touchscreen. For example, the occlusion problem of a touchscreen interface is now more pronounced than before because its touchscreen size is comparable to the finger size. In addition, its small touchscreen may make useful multi-finger gestures, such as pinch-to-zoom, impractical.

To overcome the small screen problem of a smartwatch, researchers have proposed many new user interface ideas. A common approach is to extend the control space beyond the touchscreen. The control space can be extended to the edges of a watch (Oakley and Lee, 2014), to the space above a watch (Harrison and Hudson, 2009), or even to the skin area around a watch (Laput et al., 2014). Among the various ways to extend the control space of a smartwatch, we are particularly interested in extending the control space to the edges of a watch, specifically the four side faces of a square watch, because of the following advantages: (1) Watch edges are physically contiguous with the touchscreen. Mapping from the edges to the GUI controls is almost direct. (2) Watch edges provide a physical guide for a stable finger movement. Moving a finger along an edge enables a precise operation. (3) The control space combining the touchscreen and the edges is small. Manipulating the touchscreen and the edges simultaneously with one hand is easy.

The implication of the first two advantages seems clear: the edges will make precise 1D physical controls and do not occlude the screen. The third advantage is, in fact, more appealing to us and prompted us to imagine many possible operations with the simultaneous use of the touchscreen and the edges, which we call edge × screen techniques in the following sections. For instance, touching an icon with a thumb on an edge may invoke a secondary function for the icon. In addition, sliding on the edge with another finger on a volume icon may change the music volume.

We conducted a brainstorming session to collect possible scenarios using a touchscreen and edges for a smartwatch with a square form factor. While compiling the scenarios, which we call square watch interaction (SWI), we thought of the following questions. Will the edges really make a precise and occlusion-free physical control? Will the two finger operations covering the edges and the screen be really convenient? Among the various combinations of the edges and the screen areas, which one will be more usable?

The goal of the current study was to answer the above questions. Toward this goal, we constructed a smartwatch prototype with touch-sensing edges, and, using the prototype, we implemented five main SWI operations that we selected from the SWI scenarios. Finally, we designed and conducted a series of user experiments to answer the above questions. The results of the experiments support the advantage

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of precise and occlusion-free edge-based operations in comparison with touchscreen-based operations. In addition, the results provide empirical data that can be used as a basis for the design of various SWI operations, which we believe is the main contribution of the current study.

2. Related work

In this section, we review the diverse approaches to overcome the limitations of the small touchscreen of a smartwatch.

Researchers have proposed the use of space around a smartwatch, including the mid-air space and the skin surface, as an extended input channel for a smartwatch. Kim et al. (2007) proposed the Gesture Watch, a contact-less hand-gesture recognition system using infrared proximity sensors. Harrison and Hudson (2009) achieved a more precise gesture interaction by using magnetic sensors and a magnet attached to a fingertip. Laput et al. (2014) utilized the skin around a smartwatch as an input space by projecting small, touch-sensitive icons onto the skin. Sensing techniques using electric fields (Zhang et al., 2016c) and acoustic waves (Zhang et al., 2016a) were developed to capture touch inputs on the skin near a smartwatch. More recently, Sridhar et al. (2017) utilized a wearable depth sensor to capture multi-finger gestures on and above the skin on the back of a hand. Han et al. (2015) proposed an interaction strategy for a hover-tracking smartwatch that allows a user to continue a touch-screen operation into the mid-air space.

Researchers also proposed the use of other parts of a smartwatch as an input space, including the bezel of the screen (Zhang et al., 2016b), the body of a smartwatch (Ogata and Imai, 2015; Seyed et al., 2016; Xiao et al., 2014; Yeo et al., 2016), and the band area (Ahn et al., 2015; Funk et al., 2014; Lyons et al., 2012; Perrault et al., 2013) of a smartwatch. Among the different parts of a smartwatch, the screen edge is the most popularly explored interaction area except for the touchscreen. Early researchers focused on the possibility that an edge provides tactile guidance for a precise and stable linear movement. Blasko and Feiner (2004) proposed the use of tactile landmarks to enhance and enrich stroke interactions on the edge of a smartwatch. Blaskó and Feiner (2006) also showed that tactile landmarks are helpful in eyes-free stroke interaction with a cursorless numeric entry system. Ashbrook et al. (2008) investigated the effectiveness of round watch interaction techniques wherein the watch bezel is used as a movement guidance. Kerber et al. (2016) investigated the usability of the digital crown of Apple Watch and the rotatable bezel of Samsung Gear S2.

More recently, researchers have explored possible interaction techniques utilizing the touch-sensitive side edge of a watch. Oakley and Lee (2014) explored interaction techniques using the side edge of a round smartwatch. They proposed occlusion-free target selection and gesture input using a grasping pattern around the smartwatch. A patent by Yoo and Kim (2015) describes a comprehensive set of interaction techniques using the edges of a square smartwatch. The patent includes interaction techniques using one edge or two edges in combination for 1D pointing, 2D pointing, and other screen manipulation operations. Kubo et al. (2016) utilized the combination of sequential inputs on the touchscreen and bezel of a rectangular smartwatch as input gestures. They showed that the four sides of the screen bezel could be used as distinct input spaces.

We could gain from these previous works many valuable insights for utilizing the edges of a square watch. First, movements along the edge may be more precise and stable because of tactile guidance. This also means that we may utilize a touch on the edge for a more precise input. Second, the four edges of a rectangular smartwatch may be used as distinct input spaces. Third, the touchscreen and the edges are close, and, therefore, we may manipulate easily the touchscreen and the edges in combination using a single hand. These insights suggest the potential of the input space using the edges of a square watch. We noted, however, that this input space has not been fully explored, and, in particular, we needed empirical data for designing the edge-based input space. Therefore, our main focus in the current study is to produce empirical data to highlight the strong and weak points of edge-based interaction and provide a basis for the optimal design of various edge-based interaction techniques for a square smartwatch.

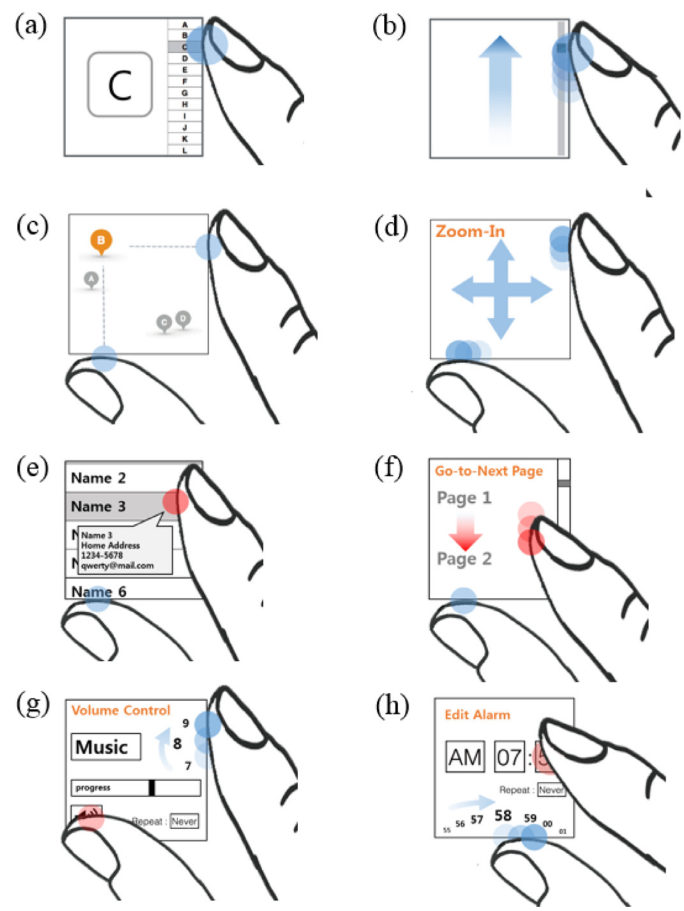

Fig. 1. Single-edge (a and b), multi-edge (c and d), and edge × screen (e – h) interaction examples: (a) 1D pointing, (b) 1D scrolling, (c) 2D pointing, (d) zooming in and out, (e) alternative function, (f) alternative scrolling, (g) changing the music volume, and (h) changing a number.

3. Square watch interaction

Below, we summarize SWI scenarios arranged in three categories: (1) using a single edge, (2) using multiple edges at the same time, and (3) using the touchscreen and an edge in combination.

3.1. Single edge interaction

An edge can be mapped to a 1D control such as a list control and a scroll bar. As shown in Fig. 1a, list items on the smartwatch screen may be small and direct pointing may be difficult owing to occlusion by the finger. In this case, an edge that is parallel to the list control may be used to select an item. The resulting interaction is occlusion-free and nearly direct, similar to the old technique of using an offset cursor (Potter et al., 1988). In Fig. 1b, the right edge, mapped to a vertical scroll bar, is used to scroll the page. Similarly, the bottom edge may be mapped to a horizontal scroll bar. The mapping between the edges and the scroll bars in these cases is intuitive and the scroll operations are occlusion free.

3.2. Multiple edge interaction

Selecting a small target in the smartwatch screen is difficult owing to occlusion by a finger. Fig. 1c shows a technique using a horizontal edge and a vertical edge in combination to define a point on the screen.

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