Preliminary Study of Screen Extension for Smartphone Using External Display

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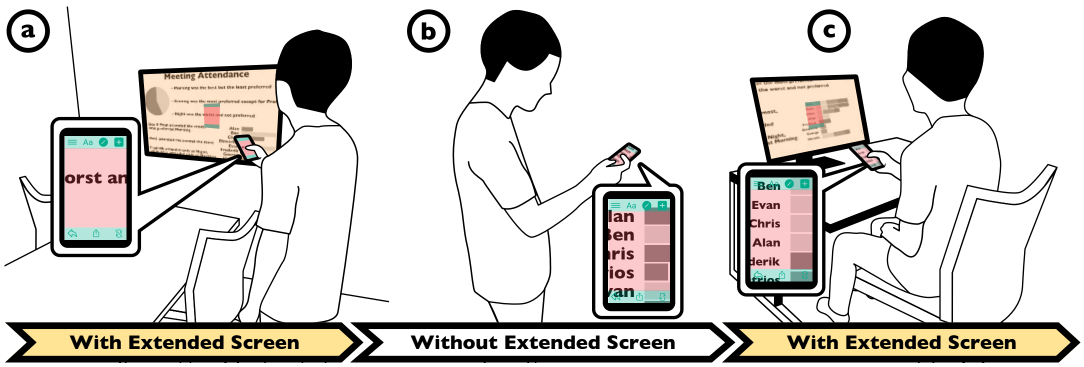

Figure 1: A scenario of *Screen Extension*. *Screen Extension* allows the user to facilitate a discussion in a meeting room by showing the content of the smartphone on a large external display (a). Next, he can check the content to find the points to be modified while waiting for an elevator (b). Now, he can modify these by showing the content on a display on his desk (c).

ABSTRACT

There are some techniques to show the smartphone's content on an external display in large. However, since smartphones are designed for mobility, a seamless interaction is necessary to make the best use of external display by a smartphone. We are currently exploring the feasibility of another technique, which we call *Screen Extension*. Our technique seamlessly adds display spaces to a smartphone using an external display, allowing users to use displays available in many places. To test search performance with *Screen Extension*, we conducted a pilot study; which suggested that *Screen Extension* helps users to search content faster.

CCS CONCEPTS

• **Human-centered computing** → **Graphical user interfaces**.

KEYWORDS

off-screen, seamless interaction, cross-device interaction

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1 INTRODUCTION

While some studies (e.g., [4]) have shown that smartphones with a large display area enhances user efficiency, other studies (e.g., [1, 3]) have demonstrated that enlarging a smartphone can make users challenging to use by one-hand-thumb. Instead of enlarging the built-in screen in a smartphone, some techniques, especially mirroring and casting, show the content of a smartphone on an external display in large. The mirroring technique shows the content of a smartphone on an external display in exactly the same way that it is seen on the built-in screen, while the casting technique shows particular content over the full-screen of an external display. However, smartphones are designed for mobility; therefore, seamless interaction is necessary to make the best use of external displays with a smartphone.

We are currently exploring the feasibility of another technique, which we call *Screen Extension*. Our technique seamlessly adds display spaces to a smartphone using an external display, allowing users to use displays available in many places such as meeting rooms and desktops on demand (Figure 1). While an external display is connected to the smartphone, *Screen Extension* provides additional display spaces while maintaining the representation of the content and GUI on the smartphone as they are.

One of the points of interest in our research is how *Screen Extension* affects user efficiency. In particular, since our technique offers users additional display spaces, it is expected that *Screen Extension* will improve users' search performance. In this study, we conducted a pilot study to test search performance, including pointing performance, with *Screen Extension*.

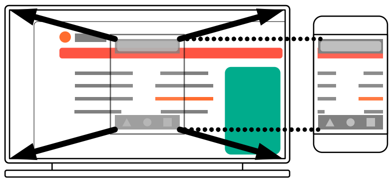

Figure 2: *Screen Extension.* While an external display is connected to the smartphone, *Screen Extension* adds display spaces without modifying content on the smartphone.

2 RELATED WORK

Similar to ours, a number of other studies have used an external display in addition to the built-in screen in a mobile device. Seifert et al. [5] proposed MobIES, which distributes application interfaces both on a smartphone and on an external display. In contrast to MobIES, which provides independent user interfaces between the smartphone and the external display, our technique provides the same content and GUI as the built-in screen in the smartphone on an external display, regardless of whether they are connected. Grubert et al. [2] proposed to show additional content around a mobile device's built-in screen using an HMD. Our technique utilizes displays available in many places while their technique uses an HMD.

3 SCREEN EXTENSION

Our technique provides additional display spaces to a smartphone using an external display by mirroring the smartphone's screen at the center of the external display on the same scale and by filling the rest with the off-screen content of the smartphone (Figure 2). We named our technique *Screen Extension* and the additional display space *Extended Screen* after the research by Grubert et al. [2].

Screen Extension provides additional display spaces while maintaining the representation of the content and GUI on the smartphone as they are. That is, all content and the GUI is mirrored on the *Extended Screen*; moreover, *Screen Extension* offers users additional display spaces, unlike mirroring. With this design, *Screen Extension* can offer users seamless interaction with content between situations with and without an external display. Moreover, due to the additional display spaces, it is expected that *Screen Extension* will improve users' search performance.

4 PILOT STUDY

To test the search performance with *Screen Extension*, the first author (22 year old, right-handed, male) performed tapping tasks under a Screen-Extended condition (SE) and Smartphone-Only condition (SO), with (WH) and without (NH) directional hints. Under SE, he could see both the smartphone's screen and the *Extended Screen* on the external display, while he could only see the former under SO. For each trial, he tapped two circular targets continuously. At the beginning of each trial, the first target was placed at the center of the display and the next was placed within surroundings. If he failed the tap for the first target, he tried the same trial again. As a directional hint, a line segment between the targets was shown. In one session, he performed 108 trials with combinations of three target widths (7.0, 14.1, and 21.1 mm on each screen), three target distances (112.6, 119.7, and 126 mm), and 12 directions from the first target to the next (from 0° to 330° in 30° increments). Five sessions were conducted for each combination of conditions (SE/SO) and hint visibilities (WH/NH) with, at most, a five-minute break between them; therefore we collected the data of 2160 trials. We used an iPhone 7 as the smartphone and a 49-inch 4K monitor as the external display. The connection between them was established via AirPlay by Apple TV 4K.

Table 1: Successfully selected time/accuracy in the pilot study.

	SE	SO
WH	0.81 s / 95.2%	0.84 s / 94.6%
NH	1.11 s / 96.1%	1.58 s / 95.7%

As a result, a faster selection time was achieved under SE while a similar target selection accuracy was achieved under each condition (Table 1). Welch's t-tests showed that there are significant differences in selection time between SE and SO both with the hint ($t_{1065.4} = -2.89$, $p < .01$) and without the hint ($t_{638.5} = -10.4$, $p < .01$). Also, there were significant differences in selection time between the cases with and without hints both under SE ($t_{917.3} = -19.3$, $p < .01$) and SO ($t_{590.1} = -16.6$, $p < .01$).

Summarizing the above, these results suggest that *Screen Extension* helps users search content. However, these results were collected within the pilot study in which only the first author participated. Therefore, a user study is required to validate these findings.

5 CONCLUSION

We proposed a technique called *Screen Extension* that adds display spaces to a smartphone using an external display, allowing users to use displays available in many places such as meeting rooms and desktops on demand. Since our technique offers users additional information, it is expected that *Screen Extension* will improve users' search performance. To test search performance with *Screen Extension*, we performed a pilot study. The pilot study suggested that *Screen Extension* helps users to search content faster.

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