Investigating the Effectiveness of Peephole Interaction for Smartwatches in a Map Navigation Task

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ABSTRACT
With the increasing availability of smartwatches the question of suited input modalities arises. While direct touch input comes at the cost of the fat-finger problem, we propose to use a dynamic peephole to explore larger content such as websites or maps. In this paper, we present the results of a user study comparing the performance of static and dynamic peephole interactions for a map navigation task on a smartwatch display. As a first method, we investigated the static peephole methaphor where the displayed map is moved on the device via direct touch interaction. In contrast, for the second method – the dynamic peephole – the device is moved and the map is static with respect to an external frame of reference. We compared both methods in terms of task performance and perceived user experience. The results show that the dynamic peephole interaction performs significantly more slowly in terms of task completion time.

Author Keywords
map navigation; smartwatch; mobile devices; dynamic peephole interaction; touch interaction

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces – input devices and strategies, interaction styles

INTRODUCTION
Smartwatches – small computing devices allowing for in- and output at the users wrist – have already been around since the 1980s with devices such as the Seiko D409 and the Seiko Epson RC-20. The technical limitations back then prevented them from making any impact in the mass market. With current devices such as the Samsung Galaxy Gear or the Sony SmartWatch 2, not only has the computing performance increased drastically, the available interaction techniques have also become much more versatile. In contrast to their predecessors from the 1980s, the devices are equipped with touch input and various sensors (e.g. GPS, accelerometer or camera), and they are extensible through the already well-known mobile app concept. Thus, the devices can be used in varied ways and can supersede specialized versions, e.g. sport watches. Nonetheless, most of the devices are only usable in combination with a smartphone. Besides the lack of meaningful dedicated applications for such devices, the input in particular is still cumbersome. While most of the current devices are equipped with a touch screen, the rather small display size, usually only about 1.5” to 2.5”, makes it hard to use due to the fat-finger problem [1].

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Figure 1. A dynamic peephole map application - The user moves his arm to browse the map (created by blending two photos and the original map)

However, some of the typical use cases of smartphones can be of relevance for smartwatches as well. The exploration of large-scale content such as websites or maps is one of the most common tasks on today's smartphones, for which reason this paper investigates map navigation. This task would come in handy when a user is in a foreign area, with his hands occupied by e.g. luggage. Sophisticated interaction techniques for these tasks might let smartwatches overcome the perception of being only a notification auxiliary.

On current smartphones, this task is typically handled using a static peephole [2]. This means that the map that is presented on the display is only a zoomed-in section of a complete map. Thus, the display provides access to a larger virtual workspace behind through a limited viewport. To be able to explore the complete workspace, it can be moved, e.g. by scrolling or panning, whereas the viewport stays fixed. An

Figure 2. A user exploring a map using the direct touch static peephole interaction technique.

analysis of this interaction method by Guiard et al. [3] shows that the navigation time increases when the view size is reduced. Since smartwatches have a limited form-factor to keep them wearable on the user's wrist, this will decrease task performance on such devices.

To ease this problem, Fitzmaurice et al. [2] introduced the concept of the so-called dynamic peephole. In this technique, the viewport is physically moved above the virtual workspace that is static with respect to an external frame of reference (see Figure 1). With the help of a spatially-aware display, it is detected which part of the virtual workspace should be shown. The sensors embedded in current devices, such as gyroscopes and accelerometers, would allow such devices to track their relative position and thereby allow them to become spatially-aware.

In this paper, we investigate two methods for map navigation for a wrist-worn smartwatch. The first one is the standard static peephole interaction based on direct touch (see Figure 2). The second one is a dynamic peephole interaction technique where the user controls the position of the peephole with his arm movements. We present the results of a user study comparing the performance of these two interaction techniques. Both methods are compared with respect to task performance and perceived user experience. The results show that dynamic peephole interaction performs significantly worse in a map navigation task. Nonetheless, in terms of user preference, the participants favored the dynamic peephole interaction over the static one.

RELATED WORK

Initial work on dynamic peephole interaction has been conducted by Fitzmaurice et al. [2]. They presented the Chameleon prototype, a virtual cubic spreadsheet accessible by a spatially aware handheld device. An extension of this approach is provided by Yee [12] who investigated menu selection, note taking and map navigation on four prototypes of peephole display hardware. A comparison of the static and dynamic peephole metaphor by Mehra et al. [9] shows the superiority of the dynamic approach for a line length discrimination task: Both discrimination thresholds and required time for discrimination are lower, if line length exceeds the peephole area. Additionally, it has been shown that the majority of participants preferred the dynamic approach. Similar results could be gained by Hürst and Bilyalov in their comparison study of dynamic and static peephole navigation of virtual reality panoramas on handheld devices [5]. In recent years, investigations of map navigation with mobile phones have also been conducted. Rohs and Essl examined in [10] sensing methods for an abstract map navigation task. In [11], Rohs et al. present a study comparing the dynamic peephole method, joystick navigation and the magic lens paradigm. Among those, joystick navigation was found to be inferior in terms of search time and degree of search space exploration.

In [8], Kaufmann and Ahlström investigated collaborative map usage by comparing classical touchscreen interaction and dynamic peephole interaction with a mobile projector. Although their results showed equal map navigation performance, they could show that spatial memory performance was better using the peephole interaction with the projector phone. In contrast to the aforementioned work, we investigate a device with a distinctly smaller display. Furthermore, the typical movement patterns are expected to be different when using a smartwatch, as it is directly attached to the user's arm.

Another suitable interaction technique for smartwatches would be touch input on the back of the device, as was proposed by Baudisch and Chu [1]. Unfortunately, their investigation focused only on small displays that allowed for touch input directly on the back. This is not possible on smartwatches since they are wrist-worn. The forearm between the watch and a possible touch area might lead to interferences between the perceived touches by the user and the sensed touches, and would therefore need further investigation.

EXPERIMENT

To evaluate the effectiveness of dynamic peephole interaction with a smartwatch, we conducted a user study to compare a dynamic peephole against a static one using the touch screen of a smartwatch. Similar to [10], we provided a virtual city map on which parking lot symbols are displayed, providing information on the hourly parking rates. The task for the participants was to find and select the cheapest parking option. For solving the task, an exhaustive map search was required while at the same time, location and cost of the currently-cheapest parking space had to be remembered. Finally, navigation back to the memorized target place was necessary. Thus, the experiment combines a navigation task on a small display with spatial memory components.

Apparatus

We used a smartwatch by simvalley (AW-414.Go) with a screen diagonal of 1.5" and a screen resolution of 240 pixels $\times$ 240 pixels running Android 4.2.2. The 1 GHz dual-core processor enables an implementation without any observable delay. The implementation of the dynamic peephole interface was done using an optical tracking system from NaturalPoint (OptiTrack V120:Trio) attached to an additional computer handling the position computation. To be able to track the watch, we equipped it with a thin 3D-printed frame carrying IR-reflective material (see Figure 1). For the static peephole navigation task the same device was used, but without being tracked by the OptiTrack system. In all settings, the target spot had to be selected by double-tapping on the display.

Participants and Experimental Design

We recruited 12 participants (6 female), aged 21-32 (M=27.2, SD=3.1). All participants are daily smartphone users, but had no prior experience with smartwatches. We split the experiment into two conditions: 6 participants (3 female) started in the static peephole condition, whereas the rest first completed the dynamic peephole condition. In both conditions, the participant first pushes a virtual start button on the smartwatch and then explores the presented map, beginning in its center, to find the cheapest parking spot. The underlying map was presented in a size of 1725 pixels × 1725 pixels. For the dynamic condition, this area was mapped to a physical movement space of 20.1 cm × 20.1 cm. This mapping represents an exact mapping of device to pixel movement. If the device is moved by 2mm the pixels on the screen are moved accordingly. The covered movement space of 20.1 cm × 20.1 cm was determined in a pre-study in which we tested comfortable arm movements for three participants with different arm lenghts. The covered area was easily accessible for all of them. In both conditions, zooming was not possible.

After finishing the first condition, participants were required to take a 5 minute break before they started with the second condition. After completing each condition, all participants were requested to fill out a short post-session questionnaire consisting of a NASA TLX[4], an ISO 9241-9 [6] questionnaire as well as personal preference questions. Overall, the whole procedure took around 45 minutes.

Tasks

The scenario for both map navigation methods was the same. Users had to find the cheapest among a varying number of parking lots on a map. Three different numbers of parking lot symbols were shown on the map: 4, 8 and 16. The presented city map was unknown to all participants. Each parking lot was marked with a white P symbol on blue background. The rates were randomly assigned to the P symbols and displayed next to each of them (compare Figure 2). We made sure that no more than one target was ever displayed at the same time. A single trial consisted of exploring the map using the given method and finally selecting the target. Selecting was done by double-tapping the P symbol. After each selection, the subject was informed about success or failure of the trial and the next trial could be started. However, it was assured that no parking spots were presented in the initial view directly after pressing the start button. Five trials were conducted for each condition and P symbol count. Overall, this sums up to 360 trials (12 users × 2 conditions × 3 P symbol counts × 5 trials). We counterbalanced the two conditions as well as the P symbol counts to eliminate possible learning effects.

Measures

- *Task completion time*: Time between starting the task and selecting a target (including trials with wrongly selected targets).
- *Error rate*: Percentage of selected parking spots that were note cheapest over all performed trials.
- *Map coverage*: The amount of the map that was explored (pixels displayed at least once) using the different techniques (including trials with wrongly selected targets).
- *Personal preference*: NASA TLX and ISO 9241-9 questionnaire assessing subjective information on a 7-point scale.

Hypotheses

Based on our review of prior work, we expected the dynamic peephole interaction to be significantly faster compared to using a static peephole with direct touch (*H1*). We did not expect any difference in error rate (*H2*) or covered map area (*H3*) between the two interaction techniques.

Results

We used a two-way ANOVA test with the different interaction technique and number of targets as factors for task completion time, map coverage and number of errors. We used the univariate ANOVA test for the NASA TLX and ISO 9241-9 results analysis with the subject as a random factor.

Task completion time: There was no significant effect of target number, but we found a significant difference for interaction techniques ($F_{1,358} = 7.28, p < 0.01$). The dynamic peephole interaction was significantly slower (M=65.56 sec, SD=28.63 sec) compared to the static one using direct touch (M=58.46 sec, SD=22.45 sec).

Error rate: Target number as well as interaction technique had no significant effect on error rate (M_{Touch}=8.9%, M_{Peephole}=8.3%).

Map coverage: There was no significant effect of target number on the covered map area. Nonetheless, interaction technique again had a significant effect ($F_{1,358} = 11.69, p < 0.01$). With the dynamic peephole technique, the participants explored a significantly larger area of the map (M=87.7%, SD=11.7%) compared to the static peephole implementation using direct touch interaction (M=82.2%, SD=18.4%).

Personal preference: We found no significant differences for the NASA TLX questions. However, for the following parts of the ISO 9241-9 (see Figure 3) questionnaire, we found significant differences (p < 0.05): Users rated the dynamic peephole technique as causing less strain for their fingers (M=1.08, SD=0.28) compared to the static peephole (M=2.92, SD=1.71). On the other hand, the operation using the dynamic peephole was rated as being less accurate and not as smooth as the static one. Nevertheless, when asked whether they would rather use the dynamic peephole or the static one with direct touch interaction, eight of the twelve participants chose the dynamic peephole.

DISCUSSION

In contrast to the related work, the dynamic peephole interaction performed significantly worse in terms of task completion time. With an on-average 12% slower task completion time, we have to reject *H1*. The main reason for this might be the limited degrees of freedom of possible arm movements, compared to a hand-held device that was used in the related

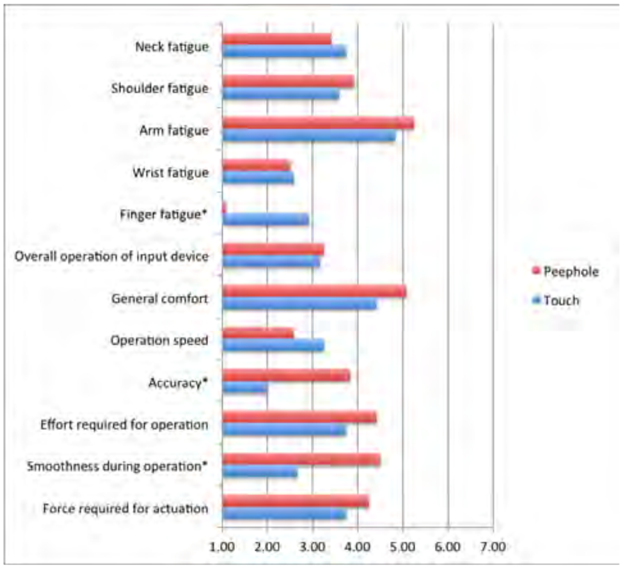

Figure 3. Results of the ISO 9241-9 questionnaire (lower values represent a better rating). For values marked with a *, a significant difference was found ($p < 0.05$).

works. Another reason could be that the users on average explored a significantly larger part of the map (rejects *H3* as well). But the increase in coverage map area could be explained with the overshooting behavior that is generally observed when using dynamic peephole interaction [7].

As we could not find any significant differences or a correlation in error rate between the two techniques, *H2* can neither be confirmed nor rejected. Even though the dynamic peephole performed objectively worse compared to the static one using direct touch, it was the favorite technique in subjective preference selected by eight out of twelve participants.

Overall, it is questionable whether the dynamic peephole technique is a reasonable interaction technique for wrist-worn smartwatches. The 12% higher task completion time compared to direct touch interaction would argue against using it. Nonetheless, the advantage of exploring large-scale content with one hand might compensate for the slower speed. This is also reflected in the user preferences.

CONCLUSION AND FUTURE WORK

In this paper, we presented the results of our user study investigating the usefulness of a dynamic peephole interaction for wrist-worn smartwatches that can be controlled by arm movements. Our results show that compared to the static peephole using direct touch interaction, the dynamic peephole performs significantly worse in terms of task completion time. In terms of user preference, the dynamic peephole was favored by eight out of twelve participants. Keeping in mind the advantage of one-handed interaction, we would argue for further investigation of this interaction technique.

As future work, we want to analyze whether the slower task completion time is an effect of the restricted arm movements or the result of overshooting. One possibility would be to investigate different mappings for the dynamic peephole, i.e. non-linear mappings of arm and pixel movement. Another approach could be to map the radial movements of the arm to the y-direction of the dynamic peephole.

Furthermore, we want to develop a system that is based only on the internal sensors, i.e. accelerometer, magnetometer and gyroscope, instead of relying on an external tracking system.

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