# TrackballWatch: Trackball and Rotary Knob as a Non-Occluding Input Method for Smartwatches in Map Navigation Scenarios

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Fig. 1. We created three prototype variants with different placements of a trackball and a rotary knob to get three degrees of freedom input without occlusion for smartwatch interaction. In a map navigation scenario, we compared these variants with direct touch input.

A common problem of touch-based smartwatch interaction is the occlusion of the display. Although some models provide solutions like the Apple "digital crown" or the Samsung rotatable bezel, these are limited to only one degree of freedom (DOF). Performing complex tasks like navigating on a map is still problematic as the additional input option helps to zoom, but touching the screen to pan the map is still required. In this work, we propose using a trackball as an additional input device that adds two DOFs to prevent the occlusion of the screen. We created several prototypes to find a suitable placement and evaluated them in a typical map navigation scenario. Our results show that the participants were significantly faster (15.7 %) with one of the trackball setups compared to touch input. The results also show that the idle times are significantly higher with touch input than with all trackball prototypes, presumably because users have to reorient themselves after panning with finger occlusion.

CCS Concepts: • **Human-centered computing** → **Interaction techniques**; *Mobile devices*; Haptic devices; Touch screens.

Additional Key Words and Phrases: Smartwatch, Trackball, Navigation, Input Technique, Input Device

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## 1 INTRODUCTION

Mobile devices such as smartphones or smartwatches are a companion in our daily lives [7]. They allow us to quickly retrieve information, receive instant messages, and plan routes for our next trip. But the more complex the application or task, the more difficult it becomes to properly display and interact with it on the small screens. While the size of smartphones continues to increase [10, 38], the size of smartwatches is limited by the wrist on which it is worn. Even simple tasks, like selecting an item from a list or finding a location on a map, can be a problem on those small displays. From a design perspective, it is difficult to display all the relevant information on the small screen, and direct touch makes it difficult to interact and simultaneously observe the screen. The inability of seeing the display while operating the device with our fingers is a substantial drawback.

Some commercially available smartwatches address the occlusion problem by adding input options like the rotatable bezel of the Samsung watches [30] or the "digital crown" of the Apple Watch [13]. The bezel is physically rotatable on the Samsung Galaxy Watch 3. On the Samsung Galaxy Watch 4 it is a touch sensitive ring around the watch face. For the digital crown, Apple Watches recognize the rotation of the crown of the watch. Both add one non-occluding degree of freedom (DOF) to the device, which is helpful for tasks like scrolling in a list. However, when it comes to more complex interactions like navigating on a map, the user has to resort to the touchscreen.

In this paper, we present the addition of a trackball and a rotary knob as an input extension to a smartwatch that provides three degrees of freedom (DOF). We explored different placements of the input devices and mappings of the new DOFs and evaluated them in a user study that compares them to standard touch input in a typical scenario. Our results show that the participants were significantly faster (15.7 %) with one of the trackball setups compared to touch input. The results also show that the idle times are significantly higher with touch input than with all trackball prototypes, presumably because users have to reorient themselves after panning with finger occlusion.

## 2 RELATED WORK

To improve the user experience and minimize the problem of occluding the screen with the finger while using [6, 35], several approaches and additional input methods for smartwatches have been explored.

Software solutions to improve input performance on small screens were explored by Singh et al. [36]. They compared different approaches and propose a design space for creating new input techniques. Hartmann et al. [12] presented an input technique for smartwatches based on binary search for list search tasks. They showed that participants were faster with their approach than with a linear search.

A comparison of additional input methods from commercially available smartwatches was done by Kerber et al. [14]. They compared common touch input with the rotatable bezel and the digital crown. The participants of their study performed a search task from a list with a randomized order of items. They found that touch input is significantly faster than input with the rotatable bezel. However, the participants preferred the digital crown design.

Ahlström et al. [2] propose TiltCrown, an isometric joystick as an alternative to the touchscreen. They compared their design to a rotary knob, similar to the digital crown. The task was to select items from a linear and circular arrangement of items. Their design did not show a significant increase in performance, although the participants were slightly faster with the rotary knob.

To address the problem of occluding the screen while interacting with the touchscreen, HybridTouch [40] explores the back of the device as an input space in. A touchscreen on the back of a PDA allowed the user to zoom and scroll content on the front touchscreen. The participants reached faster task completion times with the HybridTouch prototype than with only using the touchscreen on the front. Baudisch and Chu [6] created a custom prototype to analyze back-of-device interaction for very small displays. In two studies they analyzed the design space and the accuracy of back-of-device interaction for different display sizes. Their results show that back-of-device interaction works well even for very small displays and is independent of the size of the display. However, for smartwatches the back of the device is inaccessible as an input space, because the back of the smartwatch is usually placed directly on the wrist.

Saviot et al. [31] created a custom wristband prototype to extend the input and output possibilities of a smartwatch. To this end, they placed a display on the ventral side of the wrist in addition to the normal smartwatch display on the dorsal side of the wrist. Furthermore, LED buttons were added along the wristband for notifications. The results show that small elements (< 3 mm) of the interface can be reliably selected with the screen on the ventral side of the wrist.

A combination of mid-air gestures over the device and tapping on the case of the device was explored by Arefin Shimon et al. [4] to identify suitable gestures. Other approaches to prevent occlusion include mid-air interaction around the device [17, 37, 46], tilting [11, 18, 26], on-skin interaction [24, 39], bezel interaction [23, 43, 45], non-speech audio [8, 28], pressure-based input [9, 32], and magnetic fields using a pen [1, 33, 44] or a magnet on a finger [5, 22, 27]. Xiao et al. [42] explored panning, rotating, tilting, and clicking the watch face as an input method for smartwatches. The use of a trackball as an input method for smartwatches to enter Korean text was also investigated by Lee et al. [19].

Perrault et al. [25] moved the input area from the touchscreen to the wristband in an eyes-free interaction task and a scrolling task. The results show that the wristband is a suitable input area for non-occluding input on smartwatches. Adding pressure sensors to the wristband, Ahn et al. [3] analyzed multi-touch gestures on the wristband and suggest to use their prototype in telephone book, number entry, and map interaction scenarios.

For navigating maps with a smartwatch Kerber et al. [16] analyzed peephole interaction, in which the smartwatch display is a metaphorical peephole over a virtual map. Moving the smartwatch as a peephole over the map instead of moving the map with the smartwatch turned out to be significantly slower. In another work, Kerber et al. [15] compared direct touch, the rotatable bezel, and the digital crown in list scrolling and map navigation scenarios. For the map navigation scenarios, the task was to find a marked parking lot on a map. With the bezel and digital crown which each provides one DOF, only one axis can be manipulated at a time. To switch the axis from x to y (or vice versa), it was necessary to press the digital crown button. The disadvantage of manipulating only one axis at a time resulted in a significant time increase for navigating on a 2D map compared to touch input. In the second study, a map navigation scenario with zoom support was conducted. The input methods were touch with pinch-to-zoom, touch with the bezel, and touch with a digital crown. A Friedman test showed no significant difference in the SUS scores. Comparing the NASA-TLX scores of the input modalities, a Friedman test showed that the perceived frustration and perceived effort are significantly higher using touch than using the digital crown or the rotatable bezel while the perceived performance is significantly lower.

An alternative to increasing the degrees of freedom of the input device is to reduce the degrees of freedom of the map navigation task. This is the strategy that StripeMaps [41] takes: The two dimensional map is transformed into a series of one-dimensional stripes. This works well in certain scenarios, like turn-by-turn indoor navigation, but is less suitable for more complex environments. After all, the navigation task is generally (at least) a 2D problem.

## 3 PROTOTYPE

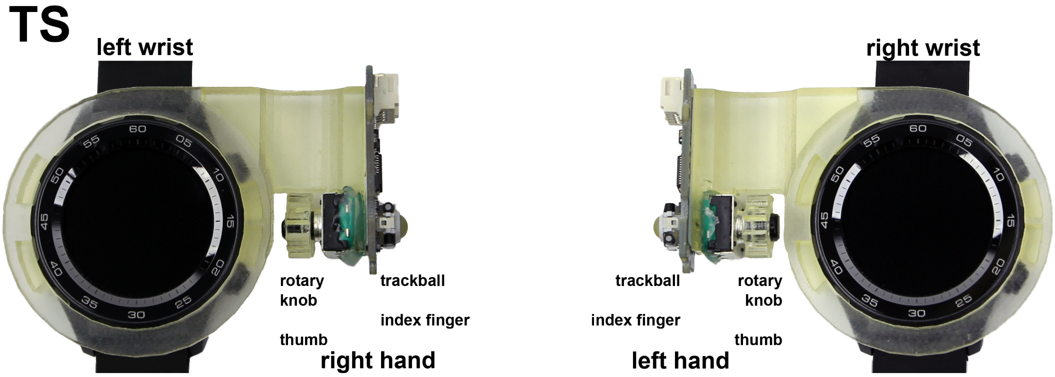

Fig. 2. For the placement of the **t**rackball and rotary knob on the **s**ide of the watch (**TS**), we created two clips. One for wearing the prototype on the left wrist (left image) and one clip for wearing the prototype on the right wrist (right image). Hence, it is possible to interact with the trackball and rotary knob without occluding the screen.

To avoid the occlusion of the screen while also offering three degrees of freedom input, our main idea was to include the trackball in the crown of a watch. To simplify the prototyping step, we decided to use the combination of a rotary knob to simulate the crown and a miniature trackball to extend the input by three DOFs. With the rotary knob the user is able to zoom the map, as with the digital crown of the Apple Watch. We decided to use a common mapping: rotating the knob clockwise zooms in and rotating it counterclockwise zooms out [30]. Panning the map in two directions is possible by moving the trackball.

We created three prototypes with a trackball and a rotary knob each. We decided to use two 3D printed clips for the placement on the **s**ides of the watch (**TS**) to support left- and right-handed users. There is one clip for which the trackball and rotary knob are placed on the right side of the watch. This placement is suitable for wearing the watch on the left wrist (see Figure 2). A second clip has a mirrored setup to ensure that the screen is not occluded by the left hand when the watch is worn on the right wrist (see Figure 2).

We started by extending the crown of a smartwatch with a trackball, and created two additional prototypes to analyze whether a placement of the trackball and rotary knob on the wristbands (above or below the watch face) would be superior placements. In particular, we placed the **t**rackball **a**bove (**TA**) the watch face and the rotary knob below the watch face (see Figure 3). To minimize the time to switch the prototypes, we decided to rotate the screen by 180° for a placement of the **t**rackball **b**elow (**TB**) the watch face and the rotary knob above the watch face (see Figure 3). Thus, the participants only had to turn the smartwatch and it was not necessary to change the wristband.

The trackball and the rotary knob are connected to an ESP32 microcontroller that communicates directly with the smartwatch via Bluetooth for navigating in our map scenario. To control the study environment that is shown on the smartwatch, we used a smartphone companion application.

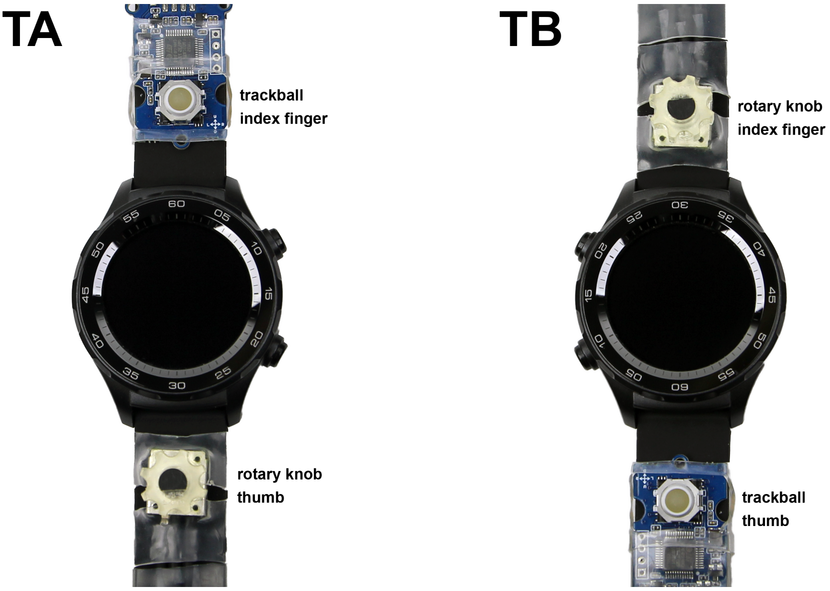

Fig. 3. We also analyzed whether a placement of the trackball and rotary knob on the wristband is suitable in our scenario. Therefore, we created a prototype with the **t**rackball **a**bove the watch face and the rotary knob below the watch face (**TA**; left image). With a 180° rotation of the watch and the watch content, a placement of the **t**rackball **b**elow and the rotary knob above the watch face (**TB**; right image) was realized.

## 4 STUDY

We conducted a user study to compare our prototypes and touch input in a typical map navigation scenario. We used mapbox[1] to show a city map. It provides the feature to create custom points of interest, which we used in our study. Further, we removed all indicators on the map identifying the city to prevent a participant from taking advantage of prior knowledge.

As shown in Figure 4 (left), the participants had to perform a search task on the map in which they had to find the point of interest with the best rating. The rating was centered at the point of interest as a small image, showing one to five yellow stars. The map contained six points of interest with random ratings, which we placed on the map at specific positions. We positioned the best rated point of interest at fixed distances between 100-2000 m from the city center which was our starting point for each trial. This range was divided into 10 equidistant steps to analyze different distances. The other points of interest had a randomized placement on the map at a distance between 90-2200 m. All points of interest were placed at random angles from the city center. As the rating icons were visible at all zoom levels and did not scale with them, we only allowed a selection above a specific zoom level to prevent the rating icons to occlude each other. Zoom level 15 was used as a threshold, as this is the threshold at which Mapbox shows buildings. A zoom level of 15 corresponds to 2.389 meters per pixel[2]. With a screen resolution of 390×390 pixels, an area with a diameter of 931.71 m can be depicted on the screen at zoom level 15. To indicate to the participants when a selection is possible and to simplify the selection, we added a small grey circle on the screen, as shown in Figure 4 (right).

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[1] https://www.mapbox.com/

[2] https://docs.mapbox.com/help/glossary/zoom-level/

Fig. 4. The study app showed a map with six points of interest. Each of them is a one to five star rating (left image). The task was to select the best rated point of interest. A selection was possible at a zoom level of 15 (or above) indicated by a grey circle (right image) to prevent that the randomly placed points of interest occlude each other.

For each input method, the participants had to perform a 90-second training phase before the actual search tasks started. The participants performed 10 search tasks for each of the input methods. If the participants took longer than 90 seconds for a task, we aborted the task and went on with the next task. Furthermore, the participants were allowed to take a break for as long as they liked between any two input methods.

## 4.1 Study Design

The study has a within-subjects design with the input method as the independent variable. The four input methods we analyzed are: **t**rackball **a**bove the watch face (**TA**) and the rotary knob below the watch face, **t**rackball **b**elow the watch face (**TB**) and the rotary knob above the watch face, **t**rackball and rotary knob on the **s**ide of the watch face (**TS**) and touch input. The order in which the participants used them was counterbalanced with balanced Latin square to minimize the impact of learning effects. We also randomized the order of distances to the best rated point of interest with Fisher-Yates shuffling. To compare the input methods, we recorded the completion time and error rate for each task and method as dependent variables. We used a Samsung Galaxy S6 to control the study app while the participant wore a Huawei Watch 2 with the prototypes on their left or right wrist, according to their choice.

For touch input three different modes of zooming were possible. We have not restricted the common touch input methods and thus provided pinch-to-zoom, double tap to zoom, and double tap followed by a swipe up or down gesture to zoom in or out. These input methods are usually available to interact with a map in Mapbox[21] and Google Maps[20]. However, we did not point out the zoom options to the participants as we wanted to prevent bias. The participants were thus able to perform the trials for all methods based on their prior knowledge and the knowledge they have acquired during the training phase.

## 4.2 Participants

For our study, we recruited 17 participants (9 female, 8 male, age 19-57, M = 24.2, SD = 8.7). 13 participants were right handed (10 wearing the watch on the left, 3 on the right wrist), one participant was left handed (wearing the watch on the left wrist) and three participants were ambidextrous (all wearing the watch on the right wrist). Six participants had experience with smartwatches (4 were iOS, 2 were Android users). The participants used their smartwatches for fitness tracking (6 participants), reading notifications (5 participants), getting weather information (3 participants), taking phone calls (1 participant), and navigation (1 participant) as well as controlling their music (1 participant) and smart home devices (1 participant). The 12 participants who did not own a smartwatch said that wearing a watch is uncomfortable for them (5 participants) and that a smartphone offers the same or a better functionality (4 participants).

We asked the participants about their experience with navigation software. One participant used navigation software everyday, 8 participants several times per week, 7 several times per month, and one participant several times per year. For navigation the participants used their smartphone (17 participants), computer (13 participants), tablet (8 participants), car (7 participants), or smartwatch (1 participant). Two participants used paper maps. Besides obtaining general navigation information (14 participants) and orientation cues (12 participants), the reasons to use maps were finding locations like hotels or craftsperson (10 participants), new places (6 participants), and getting information about travel time (1 participant). All of the participants found that up-to-date map data is important. The design of the map was important to 12 participants, the completeness was important to 11 participants, and 9 participants said that the performance of the navigation software was important.

### 4.3 Results

At first, we analyzed whether the placement of the TS prototype on the left or right wrist creates significantly different results regarding the task completion times. For the TS prototypes, the trackball and rotary knob is placed on the right side of the watch while wearing it on the left wrist (mean task completion time: M = 26.31 sec, SD = 9.7 sec) and on the left side while wearing it on the right wrist (M = 27.01 sec, SD = 8.6 sec). As the data is not normally distributed ($p < 0.001$), we conducted a Mann-Whitney-U test, which showed no significant difference between the both TS prototypes (U = 2773.5, p = 0.44). We will thus not distinguish between a placement on the left or right wrist in the following.

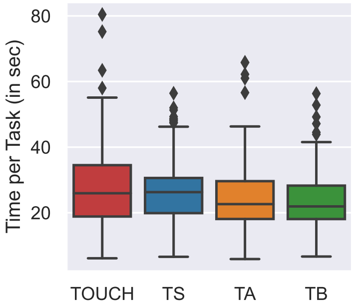

Fig. 5. The task completion times of our search task show that our participants found the best rated point of interest significantly faster with a placement of the **t**rackball **b**elow the watch face and a placement of the rotary knob above the watch face (**TB**) compared to **touch** input and a placement of the **t**rackball and rotary knob on the **s**ide of the watch (**TS**). A placement of the **t**rackball **a**bove the watch face and the rotary knob below the watch face (**TA**) was the second best input method regarding the task completion times.

A comparison of the task completion times (see Figure 5) shows that the participants were the slowest with touch input (M = 27.58 sec, SD = 12.56 sec), followed by TS (M = 26.52 sec, SD = 9.38 sec), and TA (M = 24.55 sec, SD = 10.5 sec). TB was the fastest placement in the given scenario (M = 23.25 sec, SD = 8.38 sec). For none of the methods, the participants expired the time or made errors finding the best rated point of interest. As the data is not normally distributed ($p < 0.001$), we conducted a Friedman test, which shows a significant difference between the input setups ($\chi^2(3) = 17.73$, $p < 0.001$). A pairwise post-hoc Conover test with Bonferroni correction shows significant differences for the task completion times of the TB setup in comparison with touch ($p < 0.001$) and TS ($p < 0.001$). TB was 12.3 % faster than TS and 15.7 % faster than touch. This shows that a placement of the trackball below and the rotary knob above the watch face leads to a faster input for finding locations on a map.

For a more detailed analysis of these results, and as shown in Figure 6 (left), we extracted and aggregated three components of the task completion time for comparison: idle time, movement time, and zoom time. We conducted a Friedman test for each of these components. The idle time was calculated by subtracting the zoom time and movement time from the task completion time and thus i.a. includes the time to reposition the hand as well as the time to orientate on the map.

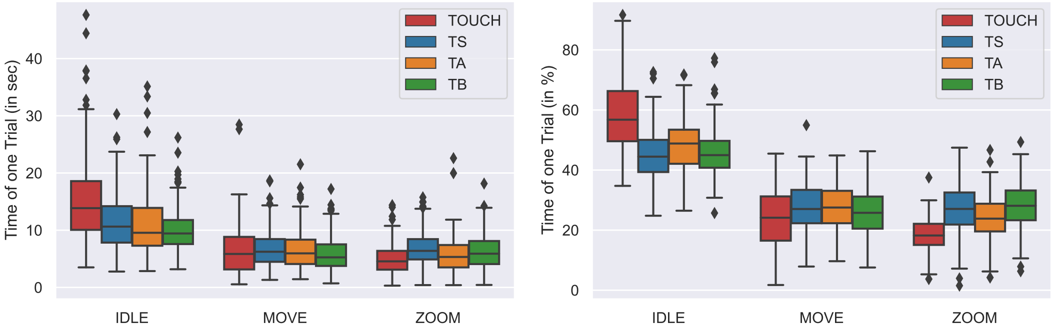

Fig. 6. We analyzed the three components of the task completion time: idle time, movement time, and zoom time. The absolute times (left image) show that the participants spend significantly more time idling with touch input than with all trackball prototypes. Further, the time spend relative to the task completion times (right image) shows that the participants spend more time idling. However, the participants spend less time zooming with touch input compared to all trackball prototypes.

For the idle times, the Friedman test shows a significant difference ($\chi^2(3) = 66.06$, $p < 0.001$). A pairwise post-hoc Conover test with Bonferroni correction shows significant differences for touch input with all other modalities ($p < 0.001$). The idle time of the touch input (M = 15.11 sec, SD = 7.49 sec) was significantly higher than the idle times for TS (M = 11.56 sec, SD = 5.13 sec), TA (M = 11.07 sec, SD = 5.23 sec) and TB (M = 9.98 sec, SD = 3.78 sec). For the movement times, the Friedman test shows a significant difference ($\chi^2(3) = 7.84$, $p < 0.05$). A pairwise post-hoc Conover test with Bonferroni correction shows a significant difference between TB and TS ($p < 0.05$). The participants spent significantly less time to move to the target with TB than with TS. Furthermore, for the zoom times, the Friedman test shows a significant difference ($\chi^2(3) = 47.63$, $p < 0.001$). A pairwise post-hoc Conover test with Bonferroni correction reveals significant differences between touch input and TS ($p < 0.001$) and between touch input and TB ($p < 0.001$). There is also a significant difference between TA and TS ($p < 0.001$). This indicates that the participants spent significantly less time for zooming actions during touch input compared to TS and TB. The participants also spent significantly less time for zooming actions with the TA placement compared to TS. We also analyzed the percentage share of the three components of the overall task completion time. Figure 6 (right) shows that 58.0 % (mean) of the task completion time of the touch condition was without any input by the participants. For TS, TA and TB, the participants spent 45.5 %, 48.2 %, and 46.1 % of the time idling. The participants spend 23.8 % of the task completion time moving the map for touch input, 27.5 % for TS, 27.9 % for TA, and 26.0 % for TB. The percentage share of the zoom times show that the participants spend 18.4 % of the time zooming for touch input, 27.1 % for TS, 24.0 % for TA and 28.0 % for TB.

After the study, we asked the participants about their opinion on the input methods. As shown in Figure 7, the participants were satisfied with the trackball and the rotary knob as input devices. They found the trackball input intuitive for all placements. Zooming via the rotary knob as well as getting an overview of the map with the trackball prototypes were easy according to the participants. Furthermore, the participants also judged touch input as intuitive. However, the subjective results show that zooming via touch input was found difficult. Moreover, there were mixed opinions about getting an overview of the map while using touch.

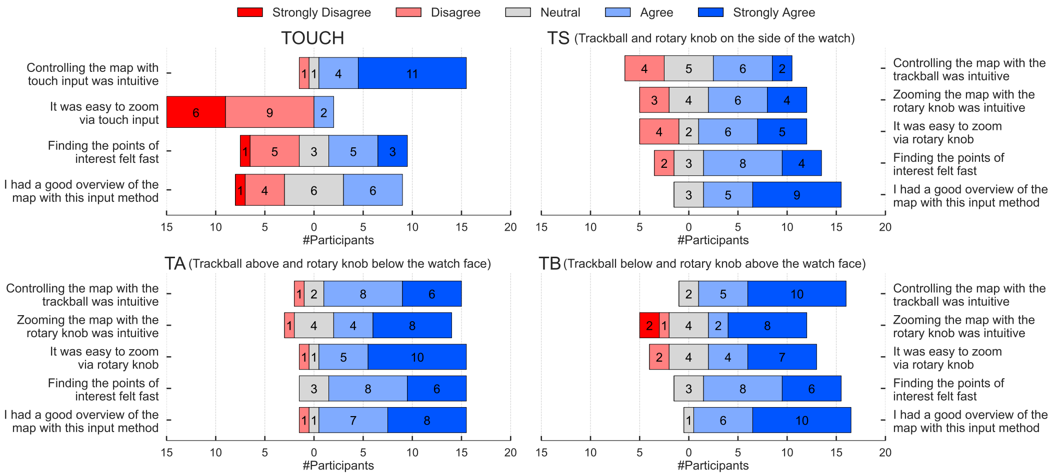

Fig. 7. After the study, we asked our participants for their opinion regarding the input methods. The participants judged all of the input methods as intuitive. Zooming via touch input was judged as more difficult, than using the rotary knob to zoom. Our participants felt that it was faster to locate the best point of interest with the trackball prototypes than with touch input. Getting an overview of the map and the points of interest was also rated better for the trackball prototypes compared to touch input.

We asked our participants about their experience with zooming methods for touch input on mobile devices and compared their self-reported experience to their usage patterns. All of our participants were familiar with the pinch-to-zoom method and 15 (of 17) participants used it in the study. 11 participants used pinch-to-zoom exclusively without using any other zoom option. Double tap to zoom was known by 10 participants, but only 6 participants used it (one of them exclusively). Only 3 participants knew that it was possible to zoom in or out via double tap with a directly following swipe up or down gesture. Interestingly, only one of our participants actually used this gesture.

Finally, we asked the participants to rank the input methods by preference, as shown in Table 1. We asked them to only rank the input methods they could imagine using in the given scenario. Two participants had no preference at all. We used the Schulze method [29, 34] to calculate the rankings. The ranking shows that our participants prefer TB, followed by TA, TS and touch. Interestingly, the ranking order corresponds to the task completion times.

| Input method | Individual Ranking | | | | | | | | | | | | | | | Schulze |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TB** | 3 | 4 | 1 | 3 | | 2 | 1 | 1 | 1 | | 1 | 4 | | 1 | 1 | 1 |
| **TA** | 2 | 2 | | 1 | | 1 | 3 | 2 | 2 | 1 | | 1 | | | 2 | 2 |
| **TS** | 1 | 3 | | 4 | 1 | 3 | 2 | 3 | | | | 3 | 1 | | 3 | 3 |
| **Touch** | 4 | 1 | | 2 | | 4 | 4 | 4 | | | | 2 | | 2 | 4 | 4 |

Table 1. The participants ranked the input methods by preference. They only had to rank those methods that they could imagine using in the given scenario. The column on the right shows the rank calculated with the Schulze method [29, 34]. Two of the participants did not rank any of the methods.

## 5 DISCUSSION AND LIMITATIONS

The results of the study show that the participants were significantly faster with TB than with TS or touch input. However, the analysis of the movement, zoom, and idle times shows that touch input yields shorter zoom times while the idle times are highest with touch input in comparison. The shorter zoom times could be caused by several factors, like fixed zoom times for double tapping for touch input or the change rate of the zoom levels for the trackball prototypes when using the rotary knob. The longer idle times for touch input, which took 58 % of the task completion time, suggest that occluding the screen disturbs the interaction as the user needs additional time to look at the map. This may indicates the need for a reorientation on the map for the user after occluding and panning the screen. We think that the map navigation task we have chosen is a representative pan and zoom task that shows typical problems, like occlusion, that also occur in other tasks with three DOFs.

The zoom and movement times also show that the interaction performed by the thumb for the trackball wristband prototypes (TA and TB) took less time than the interaction performed by the index finger. This indicates that for a placement on the wristband, the thumb is better suited than the index finger to operate the device.

We did not describe all of the details of the input methods to the participants as part of the instructions, because we wanted to observe their unbiased behavior as it can be expected from typical users of such devices. Thus, the participants had to rely on their prior knowledge and the knowledge they had acquired during the training phases. 15 of our 17 participants used pinch-to-zoom and stated that it is difficult to zoom with touch input on the tiny screen. During the study, we observed that the struggled to perform pinch-to-zoom gestures on the small screen of the Huawei Watch 2 (32 mm in diameter). Besides that 6 participants also used double tap to zoom in, only one participant used the double tap swipe gesture to zoom for touch input. The knowledge of this latter method could possibly lead to shorter task completion times as the participants would be able to zoom more accurately with only one finger instead of using two fingers when performing pinch-to-zoom. This could reduce occlusion.

One limitation of our prototype is the relatively large size of the prototype, as the TS prototype does not correspond to the size of a trackball integrated in a watch crown. Therefore, it was possible to use TS with index finger and thumb simultaneously. This may not be possible with a fully integrated prototype. However, with the TS prototype our participants were slower than with a placement of the trackball and rotary knob on the wristband. A placement of the 3D printed clips on the watch instead of placing it under the watch, is another limitation. We selected this placement to block the physical buttons on the side of the watch, as these are not used in the study and could lead to unintended inputs.

## 6 CONCLUSION

We presented the usage of a trackball and a rotary knob as a smartwatch input device with three degrees of freedom that does not occlude the display during use. To analyze potential placements we created three prototype variants and compared them to conventional touch input. A typical map navigation task, in which the participants had to find the best rated location on the map, served as the use case. The results of the user study with 17 participants show that a placement of the trackball on the wristband below the watch face and a placement of the rotary knob above the watch face (TB) lead to significantly shorter task completion times ($p < 0.001$) compared to touch input or to a placement of the trackball and rotary knob on the side of the watch (TS). TB was 15.7 % faster than touch input and 12.3 % faster than TS. Moreover, TB was the preferred input method in the map navigation task and touch input was rated worst. The order of the subjective ratings (best to worst) corresponded to the task completion times (shortest to longest).

Overall, the results show that input means beyond touch input have the potential to improve interaction with smartwatches with respect to task completion time and subjective preference. In particular, the use of a trackball and rotary knob as a smartwatch input device is beneficial in a map navigation scenario with a two-dimensional map with zoom support and is therefore better suited than the display-occluding touch input.

## REFERENCES

[1] Tetsuya Abe, Buntarou Shizuki, and Jiro Tanaka. 2016. Input Techniques to the Surface around a Smartphone Using a Magnet Attached on a Stylus. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 2395–2402. https://doi.org/10.1145/2851581.2892376

[2] David Ahlström, Khalad Hasan, Edward Lank, and Robert Liang. 2018. TiltCrown: Extending Input on a Smartwatch with a Tiltable Digital Crown. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia* (Cairo, Egypt) *(MUM 2018)*. Association for Computing Machinery, New York, NY, USA, 359–366. https://doi.org/10.1145/3282894.3289726

[3] Youngseok Ahn, Sungjae Hwang, HyunGook Yoon, Junghyeon Gim, and Jung-hee Ryu. 2015. BandSense: Pressure-Sensitive Multi-Touch Interaction on a Wristband. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI EA '15)*. Association for Computing Machinery, New York, NY, USA, 251–254. https://doi.org/10.1145/2702613.2725441

[4] Shaikh Shawon Arefin Shimon, Courtney Lutton, Zichun Xu, Sarah Morrison-Smith, Christina Boucher, and Jaime Ruiz. 2016. *Exploring Non-Touchscreen Gestures for Smartwatches*. Association for Computing Machinery, New York, NY, USA, 3822–3833. https://doi.org/10.1145/2858036.2858385

[5] Daniel Ashbrook, Patrick Baudisch, and Sean White. 2011. Nenya: Subtle and Eyes-Free Mobile Input with a Magnetically-Tracked Finger Ring. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 2043–2046. https://doi.org/10.1145/1978942.1979238

[6] Patrick Baudisch and Gerry Chu. 2009. *Back-of-Device Interaction Allows Creating Very Small Touch Devices*. Association for Computing Machinery, New York, NY, USA, 1923–1932. https://doi.org/10.1145/1518701.1518995

[7] Matthias Böhmer, Brent Hecht, Johannes Schöning, Antonio Krüger, and Gernot Bauer. 2011. Falling Asleep with Angry Birds, Facebook and Kindle: A Large Scale Study on Mobile Application Usage. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (Stockholm, Sweden) *(MobileHCI '11)*. Association for Computing Machinery, New York, NY, USA, 47–56. https://doi.org/10.1145/2037373.2037383

[8] Wei-Hung Chen. 2015. Blowatch: Blowable and Hands-Free Interaction for Smartwatches. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI EA '15)*. Association for Computing Machinery, New York, NY, USA, 103–108. https://doi.org/10.1145/2702613.2726961

[9] Rajkumar Darbar, Prasanta Kr Sen, and Debasis Samanta. 2016. PressTact: Side Pressure-Based Input for Smartwatch Interaction. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 2431–2438. https://doi.org/10.1145/2851581.2892436

[10] DSCC. 2018. Revenue share for AMOLED smartphone panels worldwide from 2017 to 2022, by screen size. https://www.statista.com/statistics/987480/worldwide-amoled-display-panel-revenue-share-by-screen-size/ , In *Statista*,

Accessed: January 10, 2022.

[11] Anhong Guo and Tim Paek. 2016. Exploring Tilt for No-Touch, Wrist-Only Interactions on Smartwatches. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Florence, Italy) *(MobileHCI '16)*. Association for Computing Machinery, New York, NY, USA, 17–28. https://doi.org/10.1145/2935334.2935345

[12] Johannes Hartmann, Maximilian Schirmer, and Florian Echtler. 2019. BinarySwipes: Fast List Search on Small Touchscreens. In *Proceedings of Mensch Und Computer 2019* (Hamburg, Germany) *(MuC'19)*. Association for Computing Machinery, New York, NY, USA, 333–340. https://doi.org/10.1145/3340764.3340774

[13] Apple Inc. 2021. How to use your Apple Watch. Learn how to use the Digital Crown, side button, and gestures. https://support.apple.com/en-us/HT205552 Accessed: January 10, 2022.

[14] Frederic Kerber, Tobias Kiefer, and Markus Löchtefeld. 2016. Investigating Interaction Techniques for State-of-the-Art Smartwatches. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 2540–2547. https://doi.org/10.1145/2851581.2892302

[15] Frederic Kerber, Tobias Kiefer, Markus Löchtefeld, and Antonio Krüger. 2017. Investigating Current Techniques for Opposite-Hand Smartwatch Interaction. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Vienna, Austria) *(MobileHCI '17)*. Association for Computing Machinery, New York, NY, USA, Article 24, 12 pages. https://doi.org/10.1145/3098279.3098542

[16] Frederic Kerber, Antonio Krüger, and Markus Löchtefeld. 2014. Investigating the Effectiveness of Peephole Interaction for Smartwatches in a Map Navigation Task. In *Proceedings of the 16th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Toronto, ON, Canada) *(MobileHCI '14)*. Association for Computing Machinery, New York, NY, USA, 291–294. https://doi.org/10.1145/2628363.2628393

[17] Hamed Ketabdar, Mehran Roshandel, and Kamer Ali Yüksel. 2010. Towards Using Embedded Magnetic Field Sensor for around Mobile Device 3D Interaction. In *Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services* (Lisbon, Portugal) *(MobileHCI '10)*. Association for Computing Machinery, New York, NY, USA, 153–156. https://doi.org/10.1145/1851600.1851626

[18] Hiroki Kurosawa, Daisuke Sakamoto, and Tetsuo Ono. 2018. MyoTilt: A Target Selection Method for Smartwatches Using the Tilting Operation and Electromyography. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Barcelona, Spain) *(MobileHCI '18)*. Association for Computing Machinery, New York, NY, USA, Article 43, 11 pages. https://doi.org/10.1145/3229434.3229457

[19] Ji-eun Lee, Jung-eun Ahn, Kyeongsoo Park, Go-eun Choi, and Il-Young Moon. 2015. Design and Implementation of Trackball Based UI for Efficient Text Entry on Smartwatch. *Journal of Advanced Navigation Technology* 19, 5 (2015), 452–457.

[20] Google LLC. 2022. Controls and Gestures. Zoom gestures. https://developers.google.com/maps/documentation/android-sdk/controls#zoom_gestures Accessed: January 31, 2022.

[21] Mapbox. 2022. User interaction. Default map gestures. https://docs.mapbox.com/android/maps/guides/user-interaction/#default-map-gestures Accessed: January 31, 2022.

[22] Jess McIntosh, Paul Strohmeier, Jarrod Knibbe, Sebastian Boring, and Kasper Hornbæk. 2019. *Magnetips: Combining Fingertip Tracking and Haptic Feedback for Around-Device Interaction.* Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300638

[23] Ali Neshati, Bradley Rey, Ahmed Shariff Mohommed Faleel, Sandra Bardot, Celine Latulipe, and Pourang Irani. 2021. BezelGlide: Interacting with Graphs on Smartwatches with Minimal Screen Occlusion. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 501, 13 pages. https://doi.org/10.1145/3411764.3445201

[24] Masa Ogata and Michita Imai. 2015. SkinWatch: Skin Gesture Interaction for Smart Watch. In *Proceedings of the 6th Augmented Human International Conference* (Singapore, Singapore) *(AH '15)*. Association for Computing Machinery, New York, NY, USA, 21–24. https://doi.org/10.1145/2735711.2735830

[25] Simon T. Perrault, Eric Lecolinet, James Eagan, and Yves Guiard. 2013. Watchit: Simple Gestures and Eyes-Free Interaction for Wristwatches and Bracelets. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 1451–1460. https://doi.org/10.1145/2470654.2466192

[26] Jun Rekimoto. 1996. Tilting operations for small screen interfaces. In *Proceedings of the 9th annual ACM symposium on User interface software and technology*. 167–168.

[27] Gabriel Reyes, Jason Wu, Nikita Juneja, Maxim Goldshtein, W. Keith Edwards, Gregory D. Abowd, and Thad Starner. 2018. SynchroWatch: One-Handed Synchronous Smartwatch Gestures Using Correlation and Magnetic Sensing. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 4, Article 158 (Jan. 2018), 26 pages. https://doi.org/10.1145/3161162

[28] Gabriel Reyes, Dingtian Zhang, Sarthak Ghosh, Pratik Shah, Jason Wu, Aman Parnami, Bailey Bercik, Thad Starner, Gregory D. Abowd, and W. Keith Edwards. 2016. Whoosh: Non-Voice Acoustics for Low-Cost, Hands-Free, and Rapid Input on Smartwatches. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers* (Heidelberg, Germany) *(ISWC '16)*. Association for Computing Machinery, New York, NY, USA, 120–127. https://doi.org/10.1145/2971763.2971765

[29] Julia Sageder, Ariane Demleitner, Oliver Irlbacher, and Raphael Wimmer. 2019. Applying Voting Methods in User Research. In *Proceedings of Mensch Und Computer 2019* (Hamburg, Germany) *(MuC'19)*. Association for Computing Machinery, New York, NY, USA, 571–575. https://doi.org/10.1145/3340764.3344461

[30] SAMSUNG. 2019. Bezel Interactions. https://developer.samsung.com/one-ui-watch-tizen/interaction/bezel.html Accessed: January 10, 2022.

[31] Léa Saviot, Frederik Brudy, and Steven Houben. 2017. WRISTBAND.IO: Expanding Input and Output Spaces of a Smartwatch. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 2025–2033. https://doi.org/10.1145/3027063.3053132

[32] Stefan Schneegass and Alexandra Voit. 2016. GestureSleeve: Using Touch Sensitive Fabrics for Gestural Input on the Forearm for Controlling Smartwatches. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers* (Heidelberg, Germany) *(ISWC '16)*. Association for Computing Machinery, New York, NY, USA, 108–115. https://doi.org/10.1145/2971763.2971797

[33] Maximilian Schrapel, Florian Herzog, Steffen Ryll, and Michael Rohs. 2020. Watch My Painting: The Back of the Hand as a Drawing Space for Smartwatches. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3334480.3383040

[34] Markus Schulze. 2018. The Schulze Method of Voting. *CoRR* abs/1804.02973 (2018). arXiv:1804.02973 http://arxiv.org/abs/1804.02973

[35] Katie A. Siek, Yvonne Rogers, and Kay H. Connelly. 2005. Fat Finger Worries: How Older and Younger Users Physically Interact with PDAs. In *Human-Computer Interaction - INTERACT 2005*, Maria Francesca Costabile and Fabio Paternò (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 267–280.

[36] Gaganpreet Singh, William Delamare, and Pourang Irani. 2018. D-SWIME: A Design Space for Smartwatch Interaction Techniques Supporting Mobility and Encumbrance. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3174208

[37] Srinath Sridhar, Anders Markussen, Antti Oulasvirta, Christian Theobalt, and Sebastian Boring. 2017. *WatchSense: On- and Above-Skin Input Sensing through a Wearable Depth Sensor.* Association for Computing Machinery, New York, NY, USA, 3891–3902. https://doi.org/10.1145/3025453.3026005

[38] Morgan Stanley. 2017. Share of smartphone shipments worldwide from 2012 to 2017, by screen size. https://www.statista.com/statistics/786865/smartphone-shipment-share-by-screen-size-worldwide/ , In *Statista*, Accessed: January 10, 2022.

[39] Jürgen Steimle, Joanna Bergstrom-Lehtovirta, Martin Weigel, Aditya Shekhar Nittala, Sebastian Boring, Alex Olwal, and Kasper Hornbæk. 2017. On-Skin Interaction Using Body Landmarks. *Computer* 50, 10 (2017), 19–27. https://doi.org/10.1109/MC.2017.3641636

[40] Masanori Sugimoto and Keiichi Hiroki. 2006. HybridTouch: An Intuitive Manipulation Technique for PDAs Using Their Front and Rear Surfaces. In *Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services* (Helsinki, Finland) *(MobileHCI '06)*. Association for Computing Machinery, New York, NY, USA, 137–140. https://doi.org/10.1145/1152215.1152243

[41] Dirk Wenig, Johannes Schöning, Brent Hecht, and Rainer Malaka. 2015. StripeMaps: Improving Map-Based Pedestrian Navigation for Smartwatches. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Copenhagen, Denmark) *(MobileHCI '15)*. Association for Computing Machinery, New York, NY, USA, 52–62. https://doi.org/10.1145/2785830.2785862

[42] Robert Xiao, Gierad Laput, and Chris Harrison. 2014. Expanding the Input Expressivity of Smartwatches with Mechanical Pan, Twist, Tilt and Click. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 193–196. https://doi.org/10.1145/2556288.2557017

[43] Xin Yi, Chun Yu, Weijie Xu, Xiaojun Bi, and Yuanchun Shi. 2017. COMPASS: Rotational Keyboard on Non-Touch Smartwatches. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 705–715. https://doi.org/10.1145/3025453.3025454

[44] Sang Ho Yoon, Ke Huo, and Karthik Ramani. 2016. TMotion: Embedded 3D Mobile Input Using Magnetic Sensing Technique. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (Eindhoven, Netherlands) *(TEI '16)*. Association for Computing Machinery, New York, NY, USA, 21–29. https://doi.org/10.1145/2839462.2839463

[45] Cheng Zhang, Junrui Yang, Caleb Southern, Thad E. Starner, and Gregory D. Abowd. 2016. WatchOut: Extending Interactions on a Smartwatch with Inertial Sensing. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers* (Heidelberg, Germany) *(ISWC '16)*. Association for Computing Machinery, New York, NY, USA, 136–143. https://doi.org/10.1145/2971763.2971775

[46] Junhan Zhou, Yang Zhang, Gierad Laput, and Chris Harrison. 2016. AuraSense: Enabling Expressive Around-Smartwatch Interactions with Electric Field Sensing. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (Tokyo, Japan) *(UIST '16)*. Association for Computing Machinery, New York, NY, USA, 81–86. https://doi.org/10.1145/2984511.2984568

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