# Investigating Interaction Techniques for State-of-the-Art Smartwatches

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## Abstract
We present initial results from a comparative study targeting three different input techniques for smartwatches. We developed a prototype capable of two different mechanical input techniques, namely digital crown and rotatable bezel, as well as touch input. In a user study with 14 participants, we analyzed task completion time, error rate and perceived usability in a one-dimensional list selection task. Our results show that touch and digital crown are perceived as significantly more usable. Also, the digital crown technique is ranked significantly higher than the rotatable bezel in terms of user preference. Regarding task completion time, the rotatable bezel is significantly inferior to touch. In terms of error rate, no significant difference is observable. Overall, 9 of 14 participants preferred interaction with the digital crown.

## Author Keywords
Input techniques; opposite-side interaction; smartwatches

## ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces

## Introduction
The popularity of wearables, i.e. small computing devices such as smart glasses or watches that are directly attached to a user's body, is on the increase. Ashbrook et al. [3]

showed that access to a wrist-mounted device is significantly faster than, e.g., accessing a smartphone carried in the user's pocket. According to Profita et al. [20], the wrist and the forearm are the most socially acceptable areas to position wearable devices to interact with. Based on these findings, a smartwatch seems to be a suitable device for quick interactions on the go. Future smartwatch designs and applications should be, among other things, informed by usage patterns of current digital watches [14], but cultural concepts and fashion will also play a role [15, 25].

While increasing miniaturization can be seen as an enabler for wearables, it is not advantageous in all respects. Consequently, recent research investigated alternative input possibilities such as utilizing the wristband [1, 8, 19], adding additional sensors [18, 26] or using gestural input [22]. Additionally, manufacturers of commercial devices introduced their own approaches, such as the digital crown of Apple's Apple Watch or the rotatable bezel of the Samsung Gear S2. These components, as well as the interactions with them, are inspired by classic watches. In contrast to the somewhat ambitious research attempts, they do not require complex and possibly power- and space-consuming hardware components. But, little is known about whether these can improve interaction with smartwatches. We contribute to this question by comparing touch input with rotatable bezel and digital crown with respect to perceived usability, task completion time and error rate.

## Related Work

Various input techniques for wearables have been examined in the past. Raghunath and Narayanaswami investigated touch input on wrist-worn devices more than a decade ago [21] and the guidelines they developed can be found nowadays in wearable operating systems such as Android Wear. Eyes-free input for smartwatches using bi-directional strokes and tactile landmarks has been investigated by Blaskó et al. [6, 7], whereas Ashbrook et al. focused on touch interaction on a round wristwatch without using tactile landmarks [4] to predict error rates based on target size.

To deal with problems of screen occlusion, back-of-device interaction [5] or utilizing the smartwatch's wristband (e.g. [1, 8, 19]) are suitable techniques, but input utilizing the skin nearby (e.g. [13, 17]) may also provide suitable solutions. Oakley and Lee presented a smartwatch prototype that allows for touch sensing on the edge of the device [16].

Instead of relying on touch input, techniques for around device interaction have also been investigated. Kim et al. utilized infrared proximity sensors to detect gestures in the surroundings [12], whereas other researchers made use of magnetically driven input techniques (e.g. [2, 9, 11]).

Techniques for same-side interactions [10], i.e. using only the arm that is wearing the device, also provide solutions for problems of occlusion as well as the fat-finger problem [24]. The GestureWrist system by Rekimoto [22] embeds capacitive and acceleration sensors in a normal wristband to detect hand gestures and forearm movements; other approaches utilize surface electromyography (e.g. [10, 23]).

Xiao et al. developed a multi-degree-of-freedom mechanical interface for smart-watches allowing for continuous 2D panning and twist as well as binary tilt and click [26]. Pasquero et al. developed a smartwatch prototype with a rotatable bezel that allows for mechanical input with five discrete positions around the clock face [18].

In summary, many possible interaction techniques have been investigated so far. However, only a very few are available in current off-the-shelf smartwatches. First of all, nearly all available devices offer touch input. Samsung de-

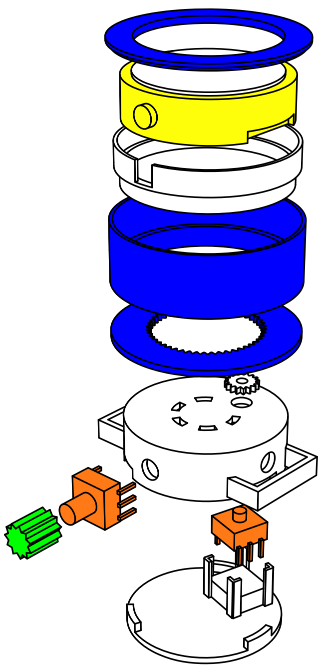

**Figure 1:** Exploded view of the self-built smartwatch housing with the Moto360 (yellow) and the mechanical components: crown (green), rotatable bezel (blue) and the corresponding rotary encoders (orange).

cided to add a rotatable bezel in their newest model Gear S2[1] which is very similar to the prototype developed by Pasquero et al. [18]. The Apple Watch utilized the "digital crown" as mechanical input control[2]. Other input possibilities may not be suitable yet, as they require additional sensors resulting in an increased power and space demand.

Notwithstanding the above, it is an interesting question whether an additional a mechanical input control, instead of using touch only, is a reasonable approach for wrist-worn devices with small screen sizes. To the best of our knowledge, no such investigation has been done before. We fill this gap by investigating the three most commonly used input possibilities for smartwatches as of today.

## Smartwatch Prototype

To ensure comparability between the different input techniques, we decided to build a single device that offers all three input modalities, instead of comparing results from different devices such as an Apple Watch and a Samsung Gear S2, for example. To preserve the sophistication of current smartwatches with regards to display and touch capability, we opted for extending an existing device with the additional mechanical input controls.

Hence, we constructed a 3D-printable housing (see Figure 1) for a Moto 360 smartwatch in which the required additional components could be integrated. We modeled the housing parts in Rhino[3] and printed it using an Ultimaker 2[4]. The resulting housing has a diameter of 52 mm and a height of 39 mm. The remarkably larger height compared to typical smartwatches nowadays (usually around 10–12 mm) is necessary to include the rotary encoders for both rotatable bezel and digital crown. However, this does not affect the prototype with respect to the properties we want to examine. Regarding the diameter, which is, for example, relevant to the required motion when turning the bezel, we made sure to keep it comparable to existing watches, e.g. the LG G Watch R with a diameter of 54 mm.

To digitize the analog motion of the rotatable bezel and the digital crown, we used rotary encoders with 24 steps per full rotation (BOURNS PEC11R). For the one below the display, which is responsible for the rotatable bezel, we shortened the pin as much as possible to reduce the device's height. Both encoders were connected to a Raspberry Pi B+ via 90 cm long wires to ensure that the participants could freely move their arm. The Raspberry Pi was externally powered and provided a wireless network to connect the smartwatch as well as the computer we used to control the user study. Figure 2 shows a picture of the setup.

To ensure comparability of the three input methods, we empirically matched the physical to digital movement ratio, keeping those of both the Apple Watch and the Samsung Gear S2 as reference. This resulted in a ratio of 1:1 for the digital crown and 1:3 for the rotatable bezel. To mimic the default touch scrolling behavior, we made use of the smooth scroll functionality provided by Android's list view.

## User Study

To compare perceived usability, task completion time and error count of the three input methods under investigation, we conducted a user study. We provided a selection task in an unsorted list, which required scrolling in one dimension to be able to select the requested entry. Following the design principles for Android Wear, three items were shown simultaneously on the screen, the middle one being highlighted as the active entry.

[1] www.samsung.com/gears2/, last accessed 16/02/2016
[2] www.apple.com/watch/, last accessed 16/02/2016
[3] www.rhino3d.com, last accessed 16/02/2016
[4] www.ultimaker.com, last accessed 16/02/2016

**Figure 3:** Smartwatch view of the user study task. The user interacts with the rotatable bezel.

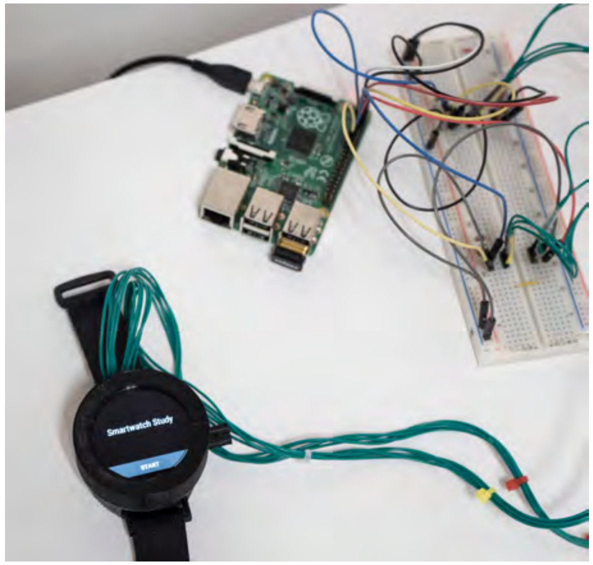


**Figure 2:** Smartwatch prototype consisting of our custom-built, 3D-printed housing including the mechanical components, a Moto 360 and a Raspberry Pi B+.

**Figure 4:** Smartwatch view of a completed training task for the digital crown condition.

We recruited 14 participants (7 females) with an average age of 23.6 years. All participants are daily smartphone users, but do not use a smartwatch in their daily life. We balanced the three conditions using a Latin square to exclude carryover effects. In all three conditions, the participants were presented an unordered list consisting of 50 shopping items such as bread, milk and eggs.

Prior to the actual study, all interaction methods were presented to the participants and they could test them on their own. As a pre-study with 12 participants suggested that there is no clear preference for scrolling direction, i.e. whether rotating the bezel or the digital crown clockwise should move the selection up or down, we first requested the participants to define their desired scrolling direction. To ensure that the participants were familiar with the interaction methods before starting the actual study, we included a training phase: A rectangle was placed virtually outside the currently visible display space and a large arrow showed the direction the participant had to scroll to in order to reach the rectangle. When the rectangle was reached, i.e. it was visible in the middle of the screen, it turned green (see Figure 4). To ensure that participants did not simply pass over the target, it had to be in the center area for 1.5 seconds. Four repetitions in a row, each completed in less than six seconds, were required to finish the training phase.

The scenario for all three input types was the same: Participants were given the opportunity to redo the training process for the specific interaction type, but were also able to skip this step. Afterwards, the actual task started. First, we presented one of the 50 shopping items in a message dialog on the smartwatch. After confirming with a touch of an "OK"-button, the unsorted list was shown (see Figure 3). The participants then had to scroll to the desired list entry and select it by pressing the digital crown (in the rotatable bezel and digital crown condition) or touching it (in the third condition). During the trial, participants could ask the experimenter which item to select, in case they forgot. After selecting an entry (regardless of whether it was the correct one or not), the next item was presented in the message dialog again. This procedure was repeated ten times. After each trial, the list was randomized and presented in a different order. In two subsequent trials, we alternated between short scrolling distance (with the target 7 to 10 items away from the start position of the participant) and large scrolling distance (20 to 24 items). After completing all ten trials, participants were requested to fill out a questionnaire consisting of the NASA TLX as well as the SUS. After a short break, the same procedure was repeated for the next condition. Finally, participants were asked to give their personal preference by rating the interaction techniques from most preferred (3) to least preferred (1).

*Measures*

- *Task completion time*: Time between starting the scrolling movement and selecting a target (including trials with wrongly selected targets).
- *Error rate*: Percentage of selected list entries that were not the requested one.
- *Personal preference/perceived usability*: NASA TLX and SUS questionnaire assessing subjective information as well as personal ranking.

*Hypotheses*

We expect touch to be significantly faster (*H1*) as people are most accustomed to it, but we do not expect any difference in error rate (*H2*) between the techniques. For a typical – vertical – list task, we expect rotatable bezel to be inferior to the other techniques in terms of usability (*H3*).

*Results*

Due to violation of normality, we used Friedman tests with the different interaction techniques, digital crown (DC), rotatable bezel (RB), and touch (T) as factor for task completion time, error rate and personal preference/perceived usability. For post-hoc analysis, we used Wilcoxon signed-rank tests with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$.

*Task completion time*

There was a statistically significant difference in task completion time, $\chi^2(2) = 8.143, p < 0.05$. Median times for DC, RB and T were $12,921$ ms ($9,245$ ms to $14,735$ ms), $13,793$ ms ($9,226$ ms to $21,842$ ms) and $11,224$ ms ($7,546$ ms to $14,713$ ms), respectively. There were no significant differences in DC vs. T input trials ($Z = -2.040, p = 0.041$) and in RB vs. DC trials ($Z = -1.350, p = 0.177$). However, there were statistically significant differences for RB vs. T trials ($Z = -2.668, p < 0.01$). In summary, T is significantly faster than RB for the considered task.

*Error rate*

There were no statistically significant differences in the number of errors depending on the input technique, $\chi^2(2) = 1.727, p = 0.422$. Mean error rates for DC, RB and T were $0.29$ ($0$ to $1$), $0.07$ ($0$ to $1$) and $0.29$ ($0$ to $2$), respectively.

*Personal preference/perceived usability*

We found no significant differences for all but one of the NASA TLX questions. Only question 2 (physical demand) revealed a significant difference, $\chi^2(2) = 9.515, p < 0.01$. Median scores on a scale from very low (1) to very high (7) for DC, RB and T were $1$ ($1$ to $3$), $2$ ($1$ to $5$) and $1.5$ ($1$ to $3$), respectively. There were no significant differences between the DC and T ($Z = -1, p = 0.317$) nor the RB and T trials ($Z = -1.097, p = 0.046$), but there were in the DC vs. RB trials ($Z = -2.588, p < 0.05$). In summary, DC is rated significantly less physically demanding than RB.

Regarding the score of the System Usability Scale, there was a statistically significant difference, $\chi^2(2) = 9.102, p < 0.05$. Median SUS scores for DC, RB and T were $92.5$ ($80$ to $100$), $80$ ($37.5$ to $100$) and $92.5$ ($77.5$ to $100$), respectively. There were no significant differences for the DC and T input trials ($Z = -0.277, p = 0.782$), but statistically significant differences were observed for the DC vs. RB trials ($Z = -2.816, p < 0.01$) and the RB vs. T trials ($Z = -2.435, p < 0.05$). In summary, T and DC were perceived as significantly more usable than RB for a one-dimensional selection task in an unsorted list.

There was a statistically significant difference in popularity (ranked from most preferred technique (3) to least preferred (1)), $\chi^2(2) = 10.429, p < 0.01$. Median popularity ranks for DC, RB and T were $3$ ($2$ to $3$), $1$ ($1$ to $3$) and $2$ ($1$ to $3$), respectively. There were no significant differences between the popularity of DC and T ($Z = -2.003, p = 0.045$) and RB and T ($Z = -1.334, p = 0.182$). However, DC was ranked as significantly more popular than RB ($Z = -3.090, p < 0.01$). Overall, 9 out of 14 participants ranked DC first for the list selection task.

*Discussion*

Although we found a significant difference in the task completion time between rotatable bezel and touch interaction, we cannot fully confirm *H1* as we did not observe a significant difference in the task completion times of digital crown and touch interaction.

In accordance with our expectations, we did not observe any significant difference in error rate (confirms *H2*); the error rates are low in general, which could be related to the very simple task.

For a one-dimensional list selection task, participants rated rotatable bezel as significantly less usable than digital crown or touch interaction. As the movement of the rotatable bezel is not vertically oriented in the first place, it is not surprising that it is perceived as less usable for a vertically oriented task, complying with *H3*.

Overall, we see that the mechanical input techniques of rotatable bezel and digital crown are perceived as usable alternatives to touch input with an average SUS score of 80 and 92.5, respectively. However, in terms of task completion time and perceived usability, touch as well as digital crown seem better suited than rotatable bezel for a vertically oriented list task.

## Conclusion & Future Work

In this paper, we presented first results of a user study comparing three interaction techniques for state-of-the-art smartwatches. We thereby focused on a one-dimensional list selection task with an unordered list. To be able to effectively compare the different techniques, we designed and built a smartwatch housing enabling mechanical input via rotatable bezel and digital crown based on two rotary encoders, and a Motorola Moto 360 as output device as well as for touch input. The results of our user study with 14 participants show that all interaction techniques are basically suitable, but in terms of user preference, the digital crown is preferred by nine of the participants, whereas the rotatable bezel is inferior compared to the other techniques (e.g. in terms of usability).

While we already presented first insights regarding the question of whether the integration of a mechanical input control in addition to touch input is meaningful, we see several aspects to investigate further. One the one hand, we will extend our comparison from a one-dimensional task to a two-dimensional one such as navigation on a map. As this includes horizontal movements as well, we will put a special focus on the rotatable bezel in this condition. Furthermore, we will investigate combinations of the different interaction techniques, e.g. using one input technique per dimension. Combinations of touch and a mechanical input techniques are also worthwhile to study, as insights, e.g. in terms of design guidelines, could directly be used by current app developers, since the corresponding hardware is already available for consumers.

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