

Back-of-device wheel for mobile one-handed interaction

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Abstract:

The use of smartphones has become a significant part of everyday life for many people and is still increasing, yet the challenges of one-handed horizontal smartphone use persist. The difficulties in reaching all corners of the screen and maintaining a stable grip during one-handed horizontal use has led to the exploration of alternative solutions. Therefore, we aim to introduce an innovative solution – a back-of-device tangible user interface in the form of a rotary wheel. The aim is to enhance user satisfaction and stability when holding a smartphone horizontally with one hand. The device, implemented using an Arduino Uno, features a rotary encoder and a Bluetooth module for wireless communication with a dedicated smartphone app. Initial test compare the efficiency of using the back-of-device wheel to skip video content with the conventional manual method: skipping by hand. In the following we provide details on the design, implementation, and initial testing of this novel approach to address the challenges of one-handed horizontal smartphone use.

Context:

The smartphone has become an essential part of everyday life. However, certain ergonomic challenges persist, particularly when users attempt to operate their smartphones with only one hand in a horizontal orientation.

The thumb's range of motion is often insufficient to reach all corners of the screen comfortably, leading to frustration and a less-than-optimal user experience. Additionally, the grip stability of the smartphone is limited when held horizontally with only one hand, resulting in a potential drop risk.

Current solutions and gestures designed for general smartphone use, as a one-hand-mode often fall short when applied to horizontal scenarios. Conventional gestures such as swiping, or tapping are less user-friendly and more likely to cause errors in this particular context. Users frequently find themselves struggling to execute precise commands or access specific areas of the screen efficiently.

Motivation:

The decision in favour of a tangible user interface results from the existing limitations of conventional touch-based interactions. Our specific tangible user interface introduces a back-of-device rotary wheel to meet the need for a customised and convenient method of interaction.

The tangible user interface presents a physical element that users can manipulate to interact with their devices. This approach offers a more direct and intuitive way of communication, based on the natural way humans interact with physical objects in the real world. By introducing a rotary wheel at the back of the smartphone, users gain a familiar and tangible method for navigating content without the need to compromise on comfort or stability. The tangible user interface offers the potential to redefine the way people interact with their smartphones in challenging situations and contribute to a more enjoyable and efficient user experience.

To measure the effectiveness of the tangible user interface on the back of the device empirically, we carried out a comprehensive test task focusing on one of the most common activities in one-handed

horizontal smartphone use - skipping videos. This task was selected due to its relevance to everyday smartphone interactions and its direct application in scenarios where users hold the device with one hand in a horizontal orientation. This idea leads us to our main question, which we wish to answer in our experiment: Can a back-of-device wheel increase overall user-satisfaction in one-handed video skipping?

State of the Art:

A notable contribution to the field of around-device video skipping is presented in the paper entitled "Exploring Around-Device Tangible Interactions for Mobile Devices with a Magnetic Ring" [1]. In this work, a magnetic ring is used as a tangible input device that allows users to rotate the ring to skip through video content on their smartphones. While this approach has similarities to our implemented wheel, the main difference lies in the positioning - the magnetic ring is not located on the back of the device.

Whereas an exploration of back-of-device interactions is presented in the paper "BackSwipe: Back-of-device Word-Gesture Interaction on Smartphones" [2]. This work introduces a technique where users perform swiping gestures on the back of the smartphone to initiate word-gesture interactions, like using an "invisible keyboard." While this method showcases the potential of back-of-device interactions, the swiping technique may not align with the specific needs addressed by our rotary wheel. The fat finger problem, often encountered in touch-based interactions, could hinder the precision and reliability of swiping gestures.

Our back-of-device tangible user interface distinguishes itself by combining the advantages of a tangible rotary wheel positioned at the back of the smartphone. As there are no directly comparable solutions, we decided to compare it with manual video skipping only by hand. By focusing on the direct comparison with the manual technique, we want to highlight the specific advantages and improvements that our solution brings to the task of one-handed video skipping.

Implementation:

At the core of our design was the usage of an Arduino Uno in combination with a KY-040 rotary encoder, which was chosen due to its central role in our project. The rotary encoder's ability to infinitely rotate by 360 degrees and to provide sensory feedback with each tick became the key feature of our tangible user interface. This characteristic, essential for precision, was central to the decision to design our prototype as a wheel rather than a slider. While a slider could have served the purpose of video skipping as well, its lack of precision, reinforced by the fat finger problem, and the lack of sensory feedback made the rotary wheel a more suitable choice.

To improve the ergonomic functionality of the rotary encoder, we 3D printed a specially designed knob for this purpose. The slim profile of the encoder required the attachment of a knob for easy operation with just a single finger. The attachable knob with a diameter of about 3 cm ensures easy turning. The dents on the underside of the knob improve grip. As the top of the knob has no dents, users can choose the side that suits their grip preference. We included an Arduino Bluetooth module HC-05 for seamless communication between the tangible interface and the smartphone. This module is used to transmit the rotary encoder data to the smartphone. Each registered tick of the rotary encoder triggers the transmission of a Bluetooth message that encodes the direction of rotation. Clockwise rotations are labelled "F", while counter-clockwise rotations are labelled "B".

On the smartphone side, we have developed an app with AndroidStudio. The app features a video player that displays a 5-minute-long video that shows a counter, which starts at 00:00:000 and counts up the time in milliseconds. This visual feedback complements the traditional time bar at the bottom of the video player and provides the user with an additional indication of time. The app receives Bluetooth signals sent by the Arduino and interprets the messages containing "F" and "B" to skip the video forwards and backwards respectively. The number of skipped seconds is dynamically determined based on the number of Bluetooth messages received within one second. This threshold value defines the number of seconds per skip and ranges from a minimum of 500 milliseconds to a maximum of 10 seconds per encoder tick. This allows for bigger skips the faster the wheel is turned.

For testing purposes, we included an Arduino push button. The first button press starts a timer that measures the elapsed milliseconds until the next button press. This approach allows us to accurately measure the time it takes participants to complete each video skipping task in the trials and provides valuable insights into the efficiency of the prototype. Although the rotary encoder also allows for a button press, the additional Arduino push button facilitated an equalized start/stop technique for both methods, which is necessary for a comparative analysis.

Experimental Protocol:

In this experimental study, eight participants were divided into two groups, each of which was assigned a specific starting technique for the experiment. Participants were given the task of performing time skipping exercises using the implemented back-of-device wheel, followed by the same tasks performed manually by hand, or vice versa, depending on their assigned group.

The aims of the trials included measuring the time each participant took to complete the skipping exercises, measuring usability, where participants were asked to fill in the System Usability Scale, and investigating the precision and potential risk of dropping the smartphone associated with an unstable grip. The latter was investigated by recording the participants' hand movements while performing the task.

To ensure a standardised test environment, an Android smartphone, in this case the OPPO Find X3 Lite, was used for all participants.

For the group that started with the wheel, the experiment began with a 5-minute try-out phase. Otherwise, the try-out-phase would take place after absolving the experiment by hand.

The participants familiarised themselves with the wheel, which was a new technology for them, while holding the smartphone horizontally with one hand. They were allowed to choose their preferred hand for holding the phone and could readjust the position of the wheel on the back of the phone for maximum comfort, taking into account different hand sizes. The tasks were instructed in the same way as the following actual test. The participants were given some randomly selected time stamps in the video to skip to, which gave them insight into the upcoming tasks (e.g. "skip to 1:32 min"). Milliseconds were not taken into account and participants only had to hit the correct second, which allowed for a fair level of difficulty and a small deviation. The short 5-minute trial time was sufficient to a clear understanding of how the wheel works, which boosted confidence in the subsequent test.

During the actual test phase, the participants continued to hold the smartphone horizontally with one hand. Different categories were defined for the size of the skips in the video: small skips (≤ 10 seconds), medium skips (≤ 30 seconds) and large skips (> 60 seconds), with five time stamps for each category. This categorisation was used to evaluate the behaviour of both methods, the wheel and by hand, to determine possible differences within the individual categories. The trials all began with

medium sized skips to avoid starting with one of the extremes, followed by short skips and ending with long skips. All participants were instructed to perform the same exact predetermined skips. After a complete round with all 15 time skips, participants performed a second round with all 15 time skips to obtain a more representative data set.

The experiment format remained consistent: the participants were told the next time point, started the timer by pressing the Arduino button with their spare hand that was not holding the smartphone, performed the video skip to the specified time point and stopped the timer by pressing the button again when the timestamp was reached. The measured time per trial was automatically written into an Excel file, serving as the repository for time data essential for subsequent result evaluations.

The final phase of the experiment consisted of a review. Immediately after completing the test phase with the wheel, the participants received a questionnaire with ten statements from the standardised usability score system, each with five possible answers (strongly agree - strongly disagree). In addition to that, at the end of the entire test phase with both methods, four questions on personal preferences (e.g. "Which technique do you prefer for short skips (≤ 10 seconds)?") with two answer options (by hand or by wheel) and two questions on strengths and difficulties with the wheel (e.g. "Where do you see the strengths of the wheel?") requiring textual responses, were asked. This post-trial protocol aimed to gain detailed insights into the users' subjective preferences and feedback, contributing to a detailed evaluation of the implemented tangible user interface.

Results:

When analyzing the test results, we focused on comparing the efficiency of the implemented wheel for time skipping tasks with manual skipping. Our approach was to average the skip times for each timestamp across all participants for both techniques. The resulting average skip times were then compared between the two methods, and graphical representations were created for the different categories of timestamps (≤ 30 sec, ≤ 10 sec, > 60 sec) to provide a clear visualization of the results.

The video recordings during the trials revealed instances of overskipping with the wheel, especially on medium and large sized skips. Users tended to overskip by turning the wheel too fast and therefore too far, which required backward corrections. This made it clear that the precision and responsiveness of the system is a challenge with sudden changes to slower turning speeds or changes of turning direction. Overskipping during manual skipping, on the other hand, occurred more frequently during short skips, which was due to the fat finger problem that prevented users from seeing the time bar of the video underneath their thumb, resulting in inaccurate selection of the correct second.

The risk of dropping the phone was also evaluated using video recordings. This showed that both techniques made it difficult to hold the smartphone. The participants who used the wheel found the prototype hard to hold. 1/4 of the users placed one edge of the smartphone on the table to increase stability. This suggests that the size of the prototype is an obstacle to comfortable gripping with the wheel attached. However, the wheel allowed the users to hold the smartphone naturally with holding on to the short side of the phone. Whereas this holding technique was not possible anymore with manual skipping by hand. That way users could not reach every corner of the screen anymore, resulting in readjusting their holding technique. They had to lay the phone into the palm of their hand to be able to reach the corners of the screen with their thumb from underneath the long side of the screen again. Therefore, one participant dropped the phone due to an unstable grip.

The results of the questionnaire were consistent with these findings and showed the wheel as the preferred technique for short skips (100% voted in favour of the wheel), a balanced preference for the

medium skips 50% voted in favour of the wheel) and an outweighing preference for manual skipping for long skips (only 25% voted in favour of the wheel).

The strengths of the wheel cited by the participants included its high precision for short skipping tasks, the sensory tick feedback, and the ergonomic feel.

Challenges included the longer time required for long skips, the difficulty in finding a proper position on the smartphone due to its size, and occasional inconsistencies in time changes most likely due to rotary encoder inconsistencies.

Overall, the wheel achieved a System Usability Scale (SUS) score of 74, indicating intermediate to good usability. This comprehensive evaluation offers valuable insights into the strengths, challenges, and user preferences associated with our implemented tangible user interface.

Conclusion:

To summarize, the research question focused on finding out whether a tangible user interface on the back of the device could improve the users' overall satisfaction when skipping videos with one hand. The results showed that the tangible user interface on the back of the device was not able to outperform users' overall preferences for manual skipping. Although the implemented wheel was efficient for short skips, its overall performance for long skips fell short of expectations, even when a feature to skip faster by turning quickly was incorporated. The transitions between fast and slow skipping as well as sudden changes in the direction of rotation proved to be less precise.

Despite these challenges, the wheel proved to be promising when it comes to increasing user satisfaction during precise tasks. The sensory feedback of the encoder effectively solved the fat finger problem during manual use and contributed to a more satisfying experience. This suggests that even if the wheel is not universally preferred for all skipping scenarios, it can be a notable improvement in certain use cases.

Looking to the future, there are opportunities to improve the wheel's performance for less precise tasks. Our proposed improvements include refining the faster skip function upon faster rotation to better respond to subtle changes in rotation behaviour, reducing inaccuracies in the encoder's encoding of rotation direction to reduce false skips, and reducing the size of the prototype to make it easier to place on the smartphone and improve grip.

Prospectively, the wheel has the potential to cover a wider range of functions in everyday smartphone use, such as zooming the camera and precise selection of text sections. Despite the current limitations, the results suggest that continued development and refinement could position the back-of-device tangible user interface as a valuable addition to smartphone interaction that will meet the diverse needs and preferences of users in the future.

References:

[1] Victor Cheung, Audrey Girouard. "Exploring Around-Device Tangible Interactions for Mobile Devices with a Magnetic Ring." Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, 2018, Pages 108-114. DOI : <https://dl.acm.org/doi/abs/10.1145/3173225.3173283>

[2] Wenzhe Cui et al. "BackSwipe: Back-of-device Word-Gesture Interaction on Smartphones." Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 2021, Pages 1-12.
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