POV Display and Interaction Methods extending Smartphone

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ABSTRACT

Persistence of Vision (POV) display uses a technique that presents an after-image that occurs when rhythmic blinking LEDs are moved swiftly. It is a cost-effective and simple method used to turn a large surface into a display. In addition, a characteristic visual expression, such as one floating in the air, can be produced. This technique is widely used because of its advantages, however, it has the limitation of poor interactivity. In this study, a system in which a smartphone can be used as a POV display by mounting a rotation mechanism and installing original applications is suggested. Furthermore, examples of the application and the possibility of interaction methods using this system are presented, including the concept, implementation, experimental results, and implications.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI).

KEYWORDS

POV Display, Smartphone, Interaction, Afterimage display

ACM Reference Format:
Yura Tamai, Maho Oki, and Koji Tsukada. 2021. POV Display and Interaction Methods extending Smartphone. In *Augmented Humans Conference 2021 (AHs'21), February 22–24, 2021, Rovaniemi, Finland.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3458709.3458992

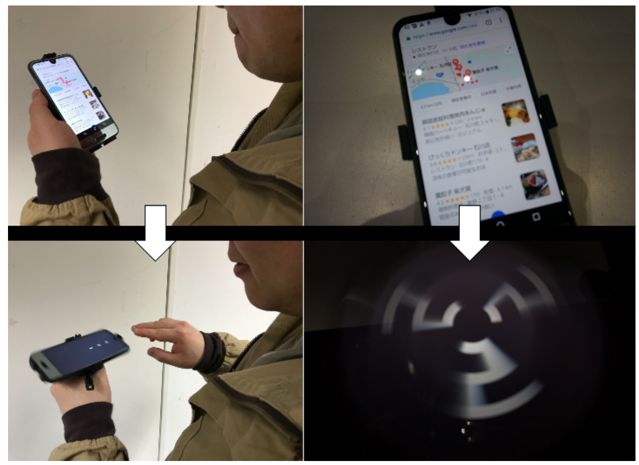

Figure 1: System overview. By integrating a rotating unit into a smartphone, a new type of interaction that combines the normal state (top) and the afterimage display state (bottom) during rotation is created.

1 INTRODUCTION

Persistence of Vision (POV) display uses a technique that presents an after-image that occurs when rhythmic blinking LEDs are moved swiftly. By using it, a large surface can be turned into a display by a cost-effective and simple means. In addition, a characteristic visual expression such as floating in the air can be produced. It is widely used because of these advantages; however, it has the limitation of poor interactivity. In this study, to overcome these limitations, a smartphone display was considered for a POV display (Figure 1). The smartphone is mounted in a case with a rotating unit, and the user can rotate it while using it. A POV display is constructed by detecting the rotation speed using an angular velocity sensor and blinking a part of the screen in accordance with the speed. In addition, we aim to develop new interaction methods and applications that combine everyday smartphone use and afterimage display states when the smartphone is rotated.

2 RELATED WORKS

Previous studies regarding POV displays and new interaction methods that extend smartphones are introduced below.

2.1 Systems using POV display

Most of the studies regarding afterimage displays are aimed at constructing lightweight and wide afterimage displays by rotating the LED arrays at a high speed to present information to individual users and their surroundings.

Kunita et al. [1] have developed a large POV display that consists of several layers of large LED panels arranged in a circle around the user and rotates it around the user, demonstrating its application to the presentation of 3D images and remote communication. The PhantomParasol [2] is a device with multiple LED arrays inside the umbrella. By rotating the umbrella, the entire surface of the umbrella is made into a POV display. When the parasol is open, it can present general information; when it is rotated, it can present detailed information. AwareCycle [3] uses the wheel of a bicycle as an afterimage display to present the physical information of an athlete, measured by devices such as a heart rate monitor, to make the competition more exciting. Panorama Ball Vision [4] is the first spherical display achieved by rotating an arc-shaped LED array,

AHs'21, February 22–24, 2021, Rovaniemi, Finland

ACM ISBN 978-1-4503-8428-5/21/02…$15.00
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and when used in conjunction with an omnidirectional imaging system, it can project a unique image, as if the surrounding scenery was pasted onto a sphere. The iSphere [5] is a floating spherical display with multiple LED arrays mounted on the periphery of the drone, which can be rotated to display images in all directions.

In addition, studies have attempted to create an afterimage by projecting a well-timed light onto an actual moving object without using an LED array. The Morphovision [6] is a new visual system in which a real object is continuously irradiated with a slit-shaped beam of light, which makes the actual object appear to be distorted by an afterimage effect. The Phyxel [7] is an afterimage display that can add material texture to an image. This is achieved by rotating a disk made of multiple materials and projecting a pattern of light from a projector that can be controlled at a high speed.

2.2 Interaction methods extending smartphone

Several studies proposed new interaction methods by extending built-in sensors and display of smartphones with external devices.

The ExtensionSticker [8] is a method that can extend the touch interface by attaching a sticker to a touch panel display. A line of conductive ink is printed on the sticker, and when the user touches the line extending outside of the display, the touch input is detected from the display surface at the end of the line.

Several new input systems using magnetic sensors and magnets embedded in smartphones have been proposed. Ketabdar et al. [9] proposed a method of operating a smartphone by using pen or ring-shaped magnets with gestures. The MagNail [10] is a system in which magnets are attached to the fingernails to recognize the movements of fingers with the magnetic sensor of a smart phone, allowing for various operations in conjunction with touch operations.

Several new input methods that extend the smartphone's built-in camera have also been proposed. Grubert et al. [11] proposed a method for extending the input space around a device using the reflection of a user's sunglasses and other objects by the smartphone's in-camera to estimate hand poses and gestures. Watanabe et al. [12] proposed a method for intuitive smartphone input using a camera to identify the deformation of a doll in a case where a small doll is attached to the camera of a smartphone. For example, a user can type a repulsive emoticon by denting the doll's cheek and reject a call by covering its ears.

2.3 Our approach

Thus, several methods and applications of afterimage displays and interaction methods that extend the use of smartphones have been proposed. In this study, an interactive afterimage display is constructed by extending a smartphone, which aims to achieve a new interaction method that combines static and rotating images.

3 PROPOSAL

A rotating afterimage display that is an extension of a common smartphone is proposed in this study (Figure 2). The approach is characterized by the following three points:

- Highly Interactive afterimage display
- Quality improvement with built-in sensors
- Combined stationary/rotational interaction

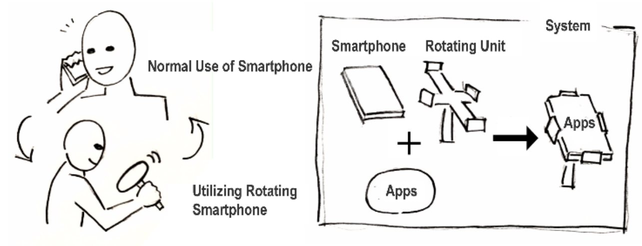

Figure 2: Concept of our system.

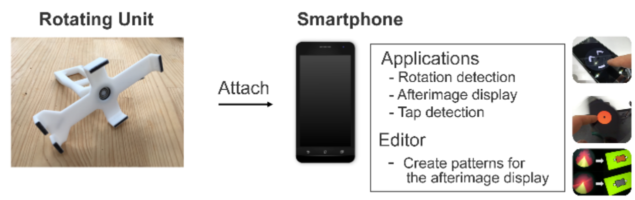

Figure 3: System configuration.

First, constructing a highly interactive afterimage display using a touch screen, microphone, and speaker of a smartphone is proposed. For example, it is possible to specify the contents of a display by a touch panel or voice input, or to interact with a rotating touch panel.

Second, improving the display quality of an afterimage is attempted using a sensor in the smartphone. Specifically, a gyroscope is used to detect the rotation speed to adjust the interval between the presentation of the afterimage, and a built-in magnetic sensor is used to adjust the starting position of the drawing by inserting a magnet into a part of the rotating unit.

Third, constructing a new interaction that combines the stationary/rotational interaction of a smartphone is proposed. A rotating mechanism is designed to enable the retraction of the handle, making it easy to link the use of the case as a normal smartphone with the use of an interactive afterimage display.

4 IMPLEMENTATION

This chapter presents a rotating unit and software implemented as the main components of the proposed system, which is followed by prototype applications. The system is operated by installing various applications for rotation detection and an afterimage display in the smartphone, as well as mounting the rotating unit on the smartphone (Figure 3).

4.1 Rotating unit

The rotating unit consists of a smartphone case with a built-in rotating mechanism and a grip to hold it by hand.

It was implemented using a high-performance Android smartphone (AQUOS R compact, SHARP) with a 120 Hz refresh rate. The size of the case was approximately one size larger than the size of the smartphone (135 x 69 cm), and the grip was 10 cm long and 5 cm wide. The total weight was approximately 30 g. Ball bearings (NTN 626ZZ) are used in the rotation mechanism because they have low

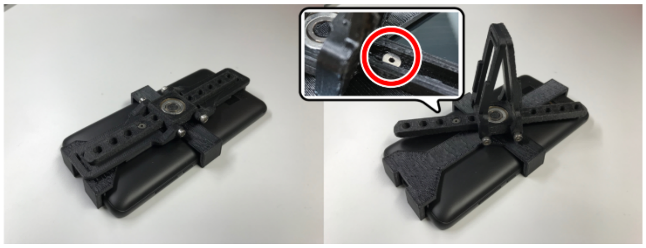

Figure 4: The appearance of the rotating unit, its deformation in use, and the position of the magnets.

friction and can be rotated with a small force, making it easy to sustain rotation. The ball bearing was placed in the center of the back of the smartphone for ease of rotation, and was degreased and oiled to make for smooth rotation. The handle is foldable and is usually stored in the case; it is bent out of the case only when it is necessary to rotate it.This allows for a smooth transition to the rotatable state while being easily carried around. In addition, a magnet for correcting the display position of the afterimage display was placed on the back of the case, which was 2 cm from the rotation axis. The housing was printed out of the ABS resin using a 3D printer.

4.2 Software

A POV display software that runs on the Android OS was developed. Figure 5 presents the method used to display the afterimage. The two-dimensional arrangement of the display pattern is switched and flickered at regular intervals, one row at a time, and the pattern is displayed as an afterimage. Although the display color can be adjusted, the background is set to black and the pattern is set to white in the standard setting because the visibility of the afterimage is generally enhanced with a high contrast ratio.

A gyroscope and a magnetic sensor are used to correct the display to improve the visibility of the afterimage display. The gyro sensor recognizes the stationary/rotational state, changes it to the afterimage display screen, and adjusts the blinking interval of the pattern by detecting the rotational speed. The magnetic sensor detects the timing of the passage of the magnet in the rotating unit, and thus corrects the starting position of the afterimage display.

In this study, a circular grid-type editor was prototyped to create patterns for the afterimage display (Figure 6). This editor allows users to draw graphics by tapping on any cell. The current editor is designed with a circular drawing resolution of 10 vertical and 36 horizontal columns for visibility and ease of touch operation when displaying afterimages. The drawing content is stored as a two-dimensional array in the internal storage and is referenced when displaying the afterimage. The drawn contents can be viewed as an afterimage on a simple viewer. Currently, the program must be rewritten, but the interaction can be set to touch the screen during rotation. The right side of Figure 7 presents an example of changing the color of the letters by touch.

4.3 Applications

Several applications were built to explore the combined stationary/rotational interaction of the smartphone. Some examples

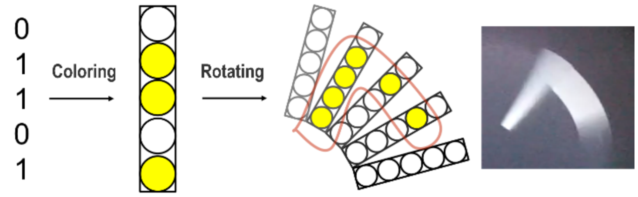

Figure 5: Method of displaying the afterimage. The two-dimensional array converted from the original image is referenced one column at a time, and a specific position on the screen is made to emit light. The luminous points that switch over one after another connect the lines, and an afterimage emerges.

Figure 6: The editor's screen (left) and the drawing process (right).

Figure 7: Afterimage display of what was drawn in the editor. Tapping on the right during rotation changes the color (right): "Yes" to green and "No" to red.

from each of the three categories including "entertainment," "practical," and "extended rotating unit" are presented.

4.3.1 *Entertainment apps.*

Considering examples for entertainment, apps were created for a "record player," "spinning meat cooking," and a "whack-a-mole." These apps take advantage of rotational/stationary states, screen touches during rotation, and changes in rotational speed.

Record player. An app that only plays music when a finger touches the rotating screen was created (Figure 8) analogous to how music was played back from a record only when the needle descends. If the smartphone is rotated by hand with a maximum force, it will continue to rotate for approximately 30 s. If the screen is lightly touched during rotation, the rotation time is reduced to

Figure 8: Record player app.

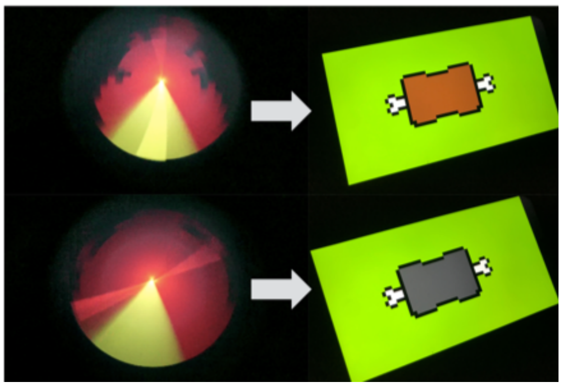

Figure 9: Spinning meat cooking app. The flames appear as an afterimage as it rotates, and depending on the timing of stopping the rotation, the result of success (above) or failure (below) is displayed.

approximately 10 s. Therefore, if a user wants the music to play for a longer period of time, the user needs to periodically turn the smartphone manually to maintain the rotation speed. In the current design, the screen is decorated with a red pattern that resembles a record, but it is also possible to display a text afterimage of a part of a song title, etc. when it is rotated. Additionally, it has a mode that synchronizes the music playback speed with the rotation speed.

Spinning meat cooking. This is a simple game that uses the rotation of the smartphone to cook meat (Figure 9). When the smartphone starts spinning, it begins to cook the meat, and the flames appear on the screen as an afterimage. The flame becomes stronger in proportion to the rotational speed. The user determines the appropriate time to stop the rotation, considering the intensity of the flame and the rotation time. If the user stops the rotation at just the right time, the meat will be sufficiently browned and the game successful. If the baking time is too short or long, undercooked or overcooked meat will result, and the game fails.

Whack-a-mole game. A whack-a-mole style game that utilizes afterimage display and screen touch was created (Figure 10). While the smartphone is spinning, a simple mark that looks like a mole appears randomly, and the user can score points by touching it. A successful touch can be judged by the color change and the sound

Figure 10: Whack-a-mole game. The target turns red when a user touched it.

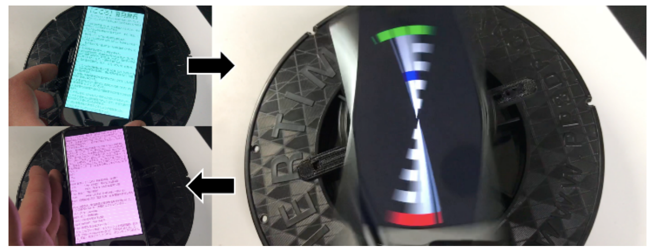

Figure 11: Example of using the scrolling app. It scrolls from the top of the list (green) to the bottom of the list (red) at a high speed by rotation. The blue color indicates the current position.

effect. When the rotation stops, the result is displayed on the screen, and the score can be checked. The rotation is reduced according to the tap force applied by the user; therefore, the user needs to apply an accurate touch without an excessive force to increase the score.

4.3.2 Practical apps. Here, the "scrolling app" and "decision-making app", which are the prototypes for exploring practical applications, have been presented.

Scrolling app. This app quickly scrolls through a large list using a rotating motion (Figure 11). Scrolling starts when the smartphone is rotated and stops when the rotation stops. The speed and direction of the scroll can be adjusted according to the speed and direction of the rotation. The scroll bar is displayed as an afterimage during the rotation so that the user can easily predict when to stop.

Decision-making app. A (somewhat random) decision may be required during the operation of a smartphone; for example, when one searches for a nearby restaurant but cannot decide because there are too many to choose from. As a tool to assist such decision-making, an app that uses rotational movements was developed (Figure 12). When the smartphone is rotated after entering multiple lists, the items are displayed successively as an afterimage. When the rotation is stopped, one of the items is selected and can be used for decision making. This app was considered because of its physical and visual appeal controls, such as a roulette or a rotating decision maker.

4.3.3 Extension of the rotating unit. Several various prototypes considering the rotating unit with different rotation axes and number of installed smart phones were created.

Change of rotation axis. In this prototype, the rotation axis of the rotary unit was changed from the center of the smartphone's back

Figure 12: Scenes of decision-making app usage. During the rotation, the number of the afterimage switches from one to the next.

Figure 13: Prototype of the omnidirectional display. View of the system on the desk from the front (left) and left side (right). (https://www.mazda.co.jp/cars/mazda2/design/)

to the center of the sides. It was thought that an omnidirectional display could be achieved by switching images successively during rotation, thus, creating the prototype application shown in Figure 13. While the smartphone was being rotated, eight images of the car were displayed in eight different directions including in the front, diagonally forward, sideways, etc. in an order. This allows the user to keep looking at the same directional view of the car by viewing it from a specific direction.

Expanding the display area by connecting smartphones. To expand the display area of the afterimage, a unit that connects two smartphones was created (Figure 14). In this rotating unit, the axis of rotation was the connection point of the two smartphones, thus it was difficult to touch the screen while rotating. The software needs to be improved to synchronize the timing of correction using Bluetooth, considering that the afterimage display of the two smartphones was misaligned.

5 PRELIMINARY EXPERIMENT

To analyze the performance of the sensors required for afterimage display correction, the measurable rotational speed of the gyroscope and the stability of the magnetic detection of the grip were investigated using a magnetic sensor.

Using the prototype device presented in Sections 4.1 and 4.2, the sensor data was collected using the following procedure. The device was rotated by hand in a clockwise direction with the display facing upwards and horizontal with respect to the ground. The

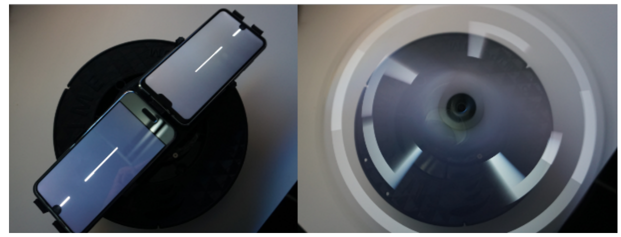

Figure 14: Expanding the display area by connecting smartphones.

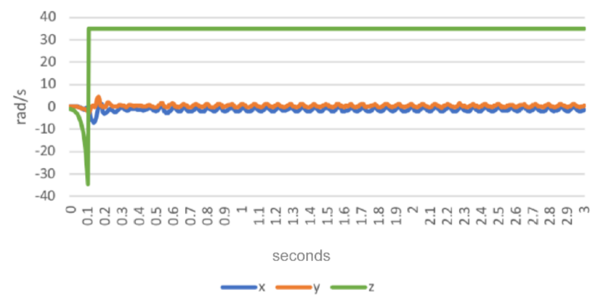

Figure 15: Gyroscope values: high speed, vertical axis: rad/s, horizontal axis: seconds.

following two speed conditions were considered: low speed (approximately one revolution per second) and high speed (approximately 8 revolutions per second, when turned manually with a maximum force). To compare the magnetic sensor values with and without a magnet, the sensor data for high-speed rotation was also collected without a magnet in the grip section. The minimum delay time, "SENSOR_DELAY_FASTEST", was used for the sensor detection settings.

5.1 Results

The results of the gyroscope are shown in Figure 15. The sensor value saturated at a speed of approximately 34 rad/s (approximately 5.5 revolutions per second) and was difficult to detect at higher speeds. The z-value of the gyro sensor (green color) decreased gradually from 0 to -34; the positive and negative values were then reversed to 34. When returning to the low-speed rotation, the sensor value increased from -34 to near 0 again; this behavior may be attributed to exceeding the sensor's measurement limit.

The magnetic sensor data are shown in Figures 16 and 17. Figure 16 presents a time-series graph of the detected value (μT) of a high-speed rotation without a magnet. The values of the X and Y axes vary in a period of approximately 0.2 seconds between -30 and 30 μT, suggesting that the geomagnetic field can be measured stably. Next, Figure 17 presents the results of a low-speed/high-speed rotation with a magnet attached. At low speeds, the X-axis and Z-axis changed significantly up to 1000 μT and 600 μT, respectively, in a period of approximately 1 s, indicating that the sensor could stably

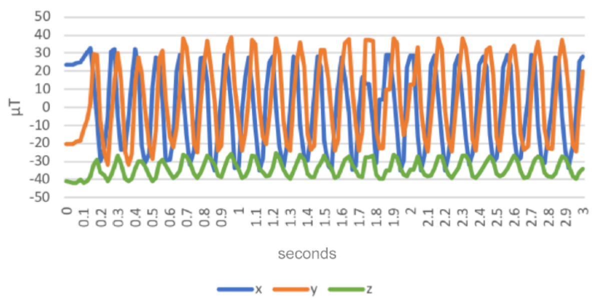

Figure 16: Magnetic sensor value: without magnet/high speed. Vertical axis: μT, horizontal axis: seconds.

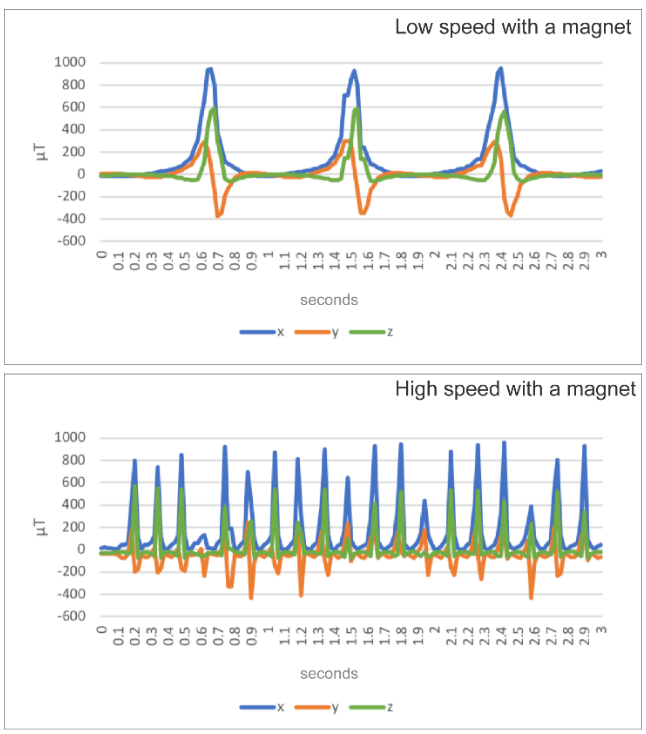

Figure 17: Magnetic sensor values: Low speed with a magnet (top) and high speed with a magnet (bottom). Vertical axis: μT, horizontal axis: seconds.

measure the timing of the addition of the sensor on the magnet. At high rotation speeds, there was a tendency for the X-axis and Z-axis to change up to approximately 800 μT and 600 μT, respectively, in a period of approximately 0.2 seconds, but there were some cases where data were lost (e.g., near 0.6 s) and where the amount of change was small (e.g., around 1.9 seconds and 2.6 s).

Currently, it is thought that the adjustment of the position of the afterimage display using a magnet works to some extent, but further adjustment and verification of the magnet strength/arrangement is required.

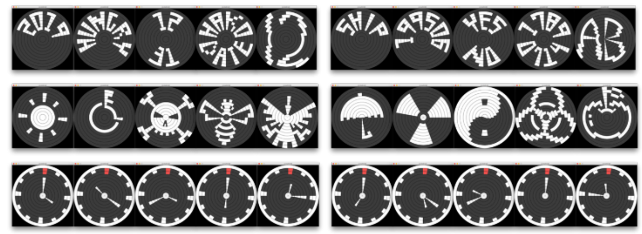

Figure 18: List of patterns. Left side indicates the first set; right side indicates the second set. From top to bottom: text, marks, and clocks.

6 EVALUATION

To validate the proposed approach, two user studies were conducted. There were eight subjects (All the eight were in their 20s and there was one female subject), and the study was conducted in a room under fluorescent lighting.

6.1 Study 1: Visibility of the afterimage display

The purpose of this study is to evaluate the visibility of afterimage displays, a method of presenting information during the rotation of the smartphone. Subjects were asked to hold the system in their hands and rotate it, and to look at the pattern of the afterimages displayed during the rotation. Subjects were asked to answer the patterns orally or in writing as soon as they understood the content of the patterns. Five patterns were prepared for each of the three categories: text, mark, and analog clock. Two sets were prepared, and each subject was presented with either set of patterns in the order of text, mark, and clock. The five patterns in the same category were shown randomly. A total of 30 patterns were presented to the subjects, consisting of two sets of five pieces in three categories, as shown in Figure 18. The time from when the subject rotated the system to the time of answer by the subject was measured; the correctness of the answers was verified.

The pattern of the text was limited to alphanumeric characters, considering the number of strokes. The marks were chosen for ease of reproduction considering the system's drawing resolution and cell shape. The analog clock patterns are used to measure if the user could read minute differences in time. This pattern is colored in red only in the 12 o'clock direction to avoid losing track of the direction, and there are five patterns with different degrees of difficulty.

6.1.1 Results. Figure 19 presents the results of the text pattern. Numbers 1, 2, 3, 6, and 8 presented sufficient results, with an average response time of approximately 5 s and a correct response rate of 100% in 4 out of 5 items. In particular, the response time of number 1 was approximately 1.6 s. Contrarily, the results for 4, 5, 7, 9, and 10 were relatively poor, with an average response time of approximately 18.7 s. Number 9, which has several characters, and number 10, which has a significant amount of text on the entire screen, resulted in considerable difficulty for viewing.

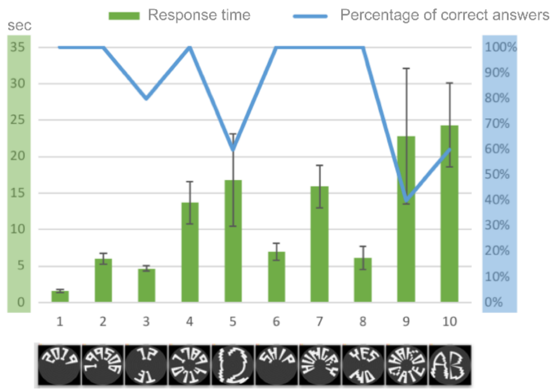

Figure 19: Average response time and the percentage of correct answers for the "text" pattern.

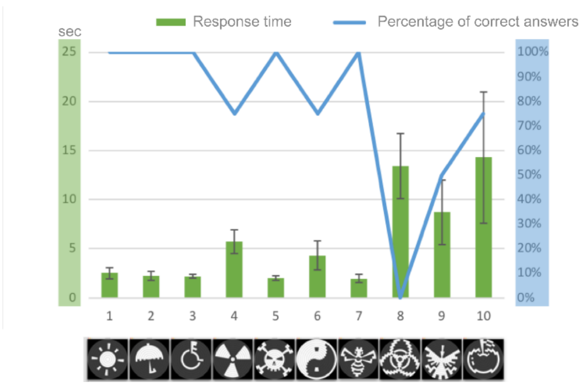

Figure 20: Average response time and the percentage of correct answers for the "mark" pattern.

The results of the mark are shown in Figure 20. The results for 1 to 7 were sufficient, with an average response time of approximately 2.8 s, and a 100% response rate for 6 out of 7 items. For simple marks, the percentage of correct answers was high almost immediately after the start of the game. Contrarily, the results for 8, 9, and 10 were relatively poor, with an average response time of approximately 11.3 s and a low percentage of correct answers. The reason why the percentage of correct answers for No. 8 was 0% may have been due to the fact that the biohazard symbol was not well-known, since the pattern drawn by the participants was similar in most of the items (Figure 21).

Finally, the results of the clock pattern are shown in Figure 22. The results for numbers 1, 2, 7, 8, and 10 were relatively good, with an average response time of approximately 3.7 s. In contrast, the results for numbers 3, 4, 5, 6, and 9 were relatively poor, with an average response time of approximately 8.0 s. However, the difference between the percentage of correct answers was insignificant, with the lowest being 80%. Although the pattern with the hands pointing away from the red mark is more complex, the high percentage of correct answers may be due to the fact that the clock face is a precondition.

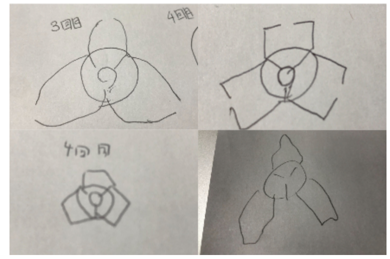

Figure 21: The eighth mark (biohazard symbol) drawn by the subjects.

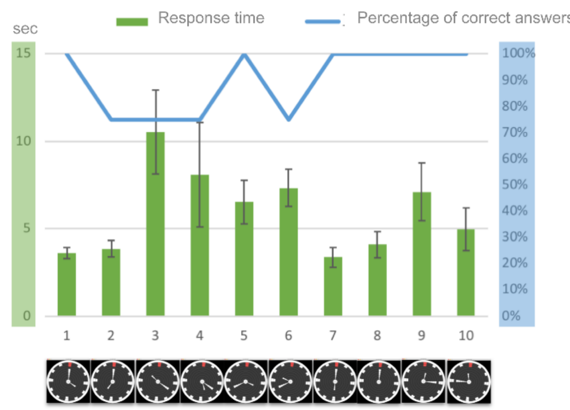

Figure 22: Average response time and the percentage of correct answers for the "clock" pattern.

In summary, simple text and marks were highly visible because of the high percentage of correct answers and short response times, but complex text and marks were not sufficiently visible. To improve the latter, it is necessary to increase the resolution and stabilize the movement of the afterimage position to improve visibility.

6.2 Study 2: Interaction with a rotating screen

To investigate interactivity, the success rate and subjective impressions of the whack-a-mole application presented in 4.3.1 were evaluated. The participants practiced the Whack-a-Mole app and played the game three times. Afterwards, they were asked to rate a questionnaire asking for "visibility," "operability", and "fun" on a five-point scale.

6.2.1 Results. The average values for the number of successful taps, total number of taps, and total rotation times are shown in Table 1. The average touch success rate was approximately 57% (with a standard deviation of 17%), indicating that the game scores varied for each subject. On a five-point scale of impressions (Figure 23), the average value for the questions regarding pattern visibility and fun to play exceeded 4. The average operability was just under 3, which was considered to be influenced by the difficulty of the app as a game. These results suggest that this system can be used as a game and can be applied to entertainment applications.

Table 1: The average values for the number of successful taps, total number of taps, and total rotation time.

	Average	SD
Number of successful taps (times)	5.5	3.38
Total number of taps (times)	9.08	4.6
Total rotation time (seconds)	12.19	6.62

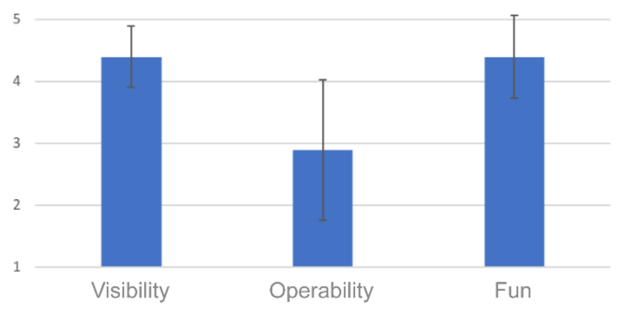

Figure 23: Average rating on a 5-point scale for the whack-a-mole app.

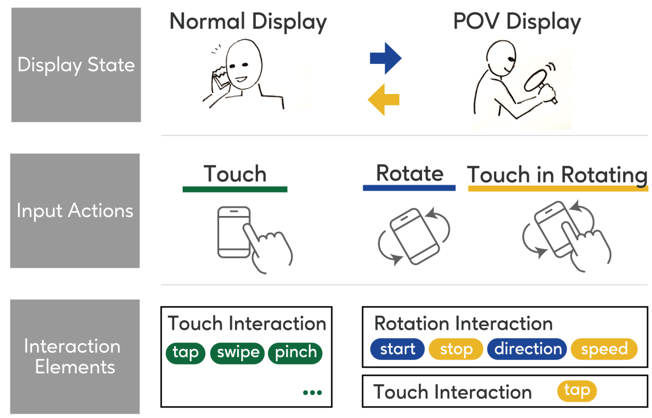

Figure 24: The user actions and interaction elements.

7 DISCUSSION

In this section, we discuss the limitations and possibilities of our method.

First, we discuss on the visibility. As mentioned in Study 1, complex text and marks are not sufficiently visible. To solve this limitation, we plan to improve the resolution by increasing the vertical pixels (e.g., 20 pixels). Moreover, we also try to stabilize the afterimage position more correctly by adjusting the position and strength of the magnet.

Next, we discuss on the interaction features of our method. We summarized the user actions and interaction elements in figure 24. Our method supports two actions (rotate and touch in rotating), three elements of "rotation interaction" (start/stop, direction, and speed) and an element of "touch interaction" (tap). Touch action also affects rotating elements (stop and speed). Since the start/stop interaction require larger physical movement than conventional touch input, it is not suited for sensitive/immediate control. We think the start/stop interaction is suitable for mode switching in applications and games because such physical movement may lead to exhilarating/joyful feeling. The rotation speed is decayed in time as well as by touching during the rotation. The former feature can be used to express the time limit. The later feature increases the difficulty of the touch, which may lead to increase fun of the gameplay. These features can coexist with conventional operation of the smartphone. A person can use the conventional application when the smartphone is stationary, and then use the afterimage display and its corresponding functions only when rotating. For example, an app can equip a common music player when stationary, as well as a unique record player (described in 4.3.1) when spinning. We will organize these interaction features more thoughtfully, and explore further applications suited for the features.

8 CONCLUSION

In this study, an interactive afterimage display is proposed using a smartphone. A prototype system and several applications have been implemented. The possibility of whether the state of a smartphone can be detected from sensor values was investigated; furthermore, a visibility and user evaluation of the prototype application was conducted. In the future, the visibility of an afterimage display will be improved, the interaction methods will be organized, and the applications will be expanded, to achieve a high-quality afterimage display; killer applications will also be explored.

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