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Providing Graphic Content for Visually Impaired People using Haptic Feedback on Smartphones

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Abstract. Due to limited visual ability, visually impaired people usually rely on tactile graphics to understand graphic content. However, such tactile graphics usually cannot be changed after creation, making it either inconvenient or impossible to deliver content that requires frequent updates. Therefore, this paper proposes to utilize the haptic feedback on smartphones to deliver refreshable virtual tactile graphic content to visually impaired people. A prototyped application providing haptic-enabled geometry shapes is developed and is experimented with blindfolded participants. The results imply that the participant can correctly recognize the experimented shapes and can further shorten the response time if a certain exploration strategy is used.

Keywords: accessible computing, visually impaired, haptic feedback

1. Introduction

Visual graphic content, such as pictures, graphs, maps, etc., is among the most efficient ways to deliver information. Through the visual sense, the information shown in graphic content can usually be conveyed easily by most people. However, such a kind of content is often inaccessible to visually impaired people due to the absence or impairment of their visual ability, which may lead to communication barriers. Unlike sighted people, visually impaired people must rely on other sensory systems, such as tactile or auditory, to perceive any type of information [1]. Therefore, several research have been conducted to interpret graphic content from the visual form to tactile and/or audio form to make them more accessible to visually impaired people [2-3].

Tactile graphic is a common way of representing graphic content to visually impaired people [4]. The content that requires attention (e.g., dots, edges, shapes, Braille blocks, etc.) is elevated on a flat physical piece of material (e.g., tactile paper, tactile board) so that it can be felt through the sense of touch [5]. Such a method is straightforward and easy to implement. However, the content on a tactile graphic is fixed at once and cannot be updated over time (non-refreshable) [6]. If the content needs to be modified, one must create it again on a new piece of material. Thus, for tasks that require frequently updated content (e.g., learning, navigation and walking support, reading data charts, etc.), using tactile graphics is not feasible.

Meanwhile, recent research has focused on creating smartphone applications for supporting visually impaired people with several types of daily activities [7]. In fact, the recent survey in [8] has revealed that 97% of 466 visually impaired participants used a smartphone and 71% of them were highly confident of their usage skills. Modern smartphone models integrate haptic feedback (i.e., vibration patterns and sound effects), which simulates the tactile feeling when the user interacts with the virtual elements on the phone. Such a feature has the potential to promote 'virtual' tactile graphics on smartphones that can be updated frequently.

In this manner, this paper proposes a haptic feedback approach to delivering graphic content to visually impaired people via smartphone. A prototype smartphone application was developed that can provide haptic-enabled basic geometry shapes. An experiment was conducted with blindfolded participants, consisting of a training phase for users to learn and experience the feedback mechanism of the application, and an exercise phase for evaluating their ability to recognize the shapes. The results showed that the participants have different strategies for discovering the shapes' edges, which affect their time to correctly recognize the shapes.

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2. Related Works

Zamprogno et al. [9] proposed to place physical tactile graphic papers precisely on corresponding graphic content shown on a tablet to provide additional audio descriptions. Such a method was also considered in [5]. Intuitively, as visually impaired people explored the tactile paper, they also touched the tablet and triggered the audio descriptions programmed at positions of interest. However, this method still required physical material, which was not suitable for frequently updated content. Also, the tactile paper must precisely align with the corresponding content on the tablet, which could not be adaptable to different screen sizes. Meanwhile, a refreshable tactile display consisting of grids of programmable elevated pins was utilized in [6] to deliver various types of animated graphic content. Although such a type of device was obviously capable of handling frequently updated graphics, it was costly and still has not been available to general customers.

On the other hand, a purely smartphone-based application was proposed in [10] that utilized haptic feedback as a way of information interpretation. It was proven that any simple on-the-shelf smartphone could provide understandable tactile information to visually impaired people via haptic feedback. Yet, this work only focused on navigational tasks. No existing research has proposed such a smartphone-based haptic feedback solution for interpreting graphic content for visually impaired people.

3. Methodology and Experiment Procedure

This section provides the principle of the feedback design, implementation of the prototyped application, participants' information, and the experiment procedure.

3.1. Feedback Design

Intuitively, when using physical tactile graphics, visually impaired people perceive graphic content by distinguishing the difference in tactile feeling between the elevated patterns (dots, lines, shapes, etc.) and the plain surface (pattern-free area) [5-6]. In order to simulate such tactile feelings, a constant vibration is applied when any pattern is being touched, while no feedback is given otherwise. In concrete, as long as the user is touching at least one pattern on the phone screen, the vibration remains playing.

Additionally, the user may move their finger directly from one pattern to another without passing by the pattern-free area (e.g., move from one edge to another at the shape vertex). In such a case, the vibration stays constant and it would be hard to realize the existence of multiple patterns. Therefore, when any pattern switches from the idle state (i.e., not being touched) to the touch state, a short (milliseconds-long) vibration and sound effect is triggered to inform the user of its existence.

3.2. Prototype Implementation

In this work, a prototype smartphone application that provided haptic-enabled geometry shapes was implemented based on the design principle in Section 3.1. In this case, the patterns were the edges of the shapes. The prototype was implemented using only the native Kotlin libraries for Android via Android Studio and was deployed on a Google Pixel 7a smartphone running Android 13 for experimental evaluation. Figure 1 provides a screenshot of the prototype showing a haptic-enabled rectangle.

3.3. Participants

12 blindfolded participants (e.g., Fig. 2) were recruited for this study, all of whom were university students. The information of the participants is summarized in Table 1. Before participation, all participants were informed of the purpose of the study, the data and information collected and published. All participants have confirmed that they fully understand the study and consented to data and information management.

3.4. Experiment Procedure

The experiment was conducted in 2 phases: training phase and exercise phase. During the training phase, the participant tried out 4 basic lines to familiarize with the feedback mechanism. The lines provided were straight horizontal lines, straight vertical lines, straight diagonal lines, and curve lines. The participant was informed of the type of line in advance of their trial and was given unlimited time to freely learn it.

Table 1: Participants' information ($n = 12$)

Information	Frequency	Percentages
Age		
20 or younger	5	41.7
Between 20 to 29	4	33.3
Over 30	3	25
Gender		
Male	8	66.7
Female	4	33.3
Education		
Undergraduate university student	6	50
Graduate university student	6	50

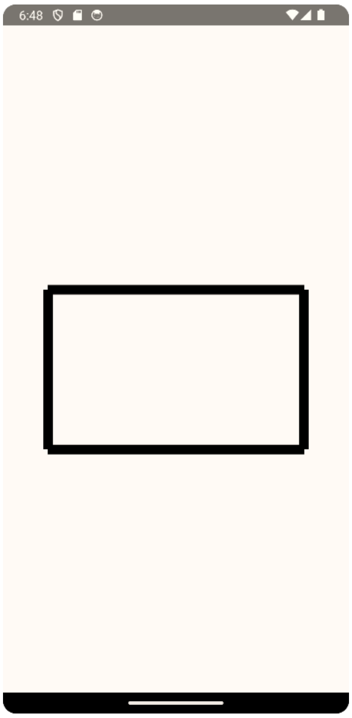


Fig. 1: Screenshot of the prototyped application used in the experiment

Fig. 2: A blindfolded participant was conducting the experiment with the prototype.

Once the training phase was completed, the participant continued to the exercise phase, where they had to correctly guess 3 types of basic geometry shapes. The shapes were given in a consistent order as follows: rectangle, triangle, and circle. The time elapsed until the participants correctly recognized each shape (response time) and the movements of their fingers were collected for evaluation.

4. Results and Discussion

Figure 3 shows the time elapsed until the participants correctly recognized all the experimented geometry shapes during the exercise phase. In general, the response time tended to decrease as the participants tried out from the first shape (i.e., rectangle) to the last one (i.e., circle). Specifically, the median time spent on recognizing the rectangle, triangle, and circle were 72.1s, 41.6s, and 31.7s, respectively. Such a tendency was probably because the participants gradually got more familiar with the application through every shape. This suggests that had the participants been given more time for training and more training tasks, they could have required less time to recognize the shapes.

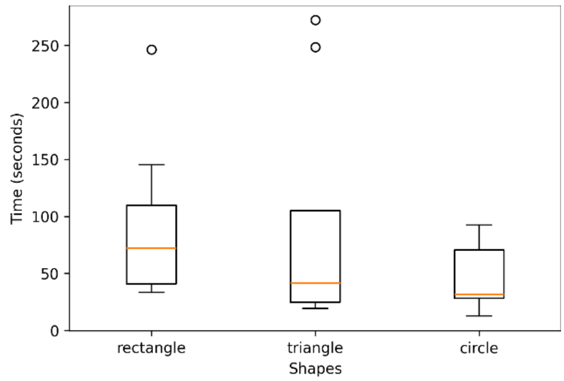
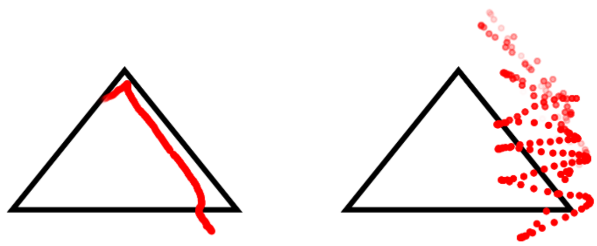


Fig. 3: Response time of each shape.



(a) Following (b) Scanning

Fig. 4: Exploration strategies used by the participants.

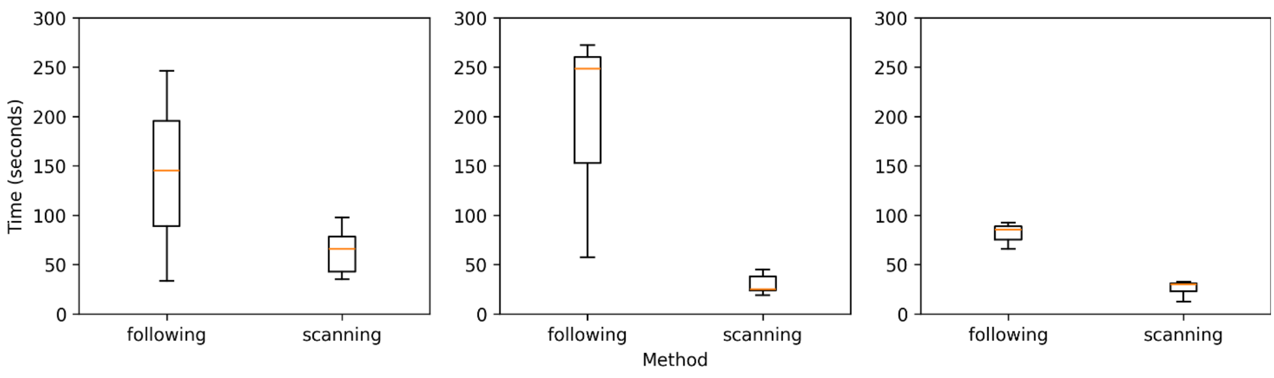


Fig. 5: Comparison of the response time when using the following and scanning strategies.

However, Fig. 3 also demonstrates that there were high variations in response time, especially for the rectangle and triangle where high outliers existed. Investigating the finger movements during the experiment, it was found that the participants utilized different exploration strategies, which are illustrated in Fig. 4. Those strategies were 'following' (Fig. 4a), in which the participants tried their best to precisely draw lines overlapping with the edges of the shapes, and 'scanning' (Fig. 4b), where they moved the fingers in a zigzag motion to localize the edges. Such a difference directly affected the response time, as shown in Fig. 5.

According to Fig. 5, for all shapes, the participants needed much more time to correctly recognize them when using the following strategy compared to the scanning strategy. Through observation during the experiment, when a participant lost trails of an edge (e.g., exceeding the edge's length), they tended to restart drawing lines from many different positions. Such a behavior not only was time-consuming but also caused confusion and distraction as the drawn lines often touched edges different from the previously following one.

Meanwhile, the scanning strategy could provide the participant with the number of edges and their relative locations, thus making it easier to guess the shapes. Overall, the scanning strategy helped the participants save 69.8% of the response time compared to the following strategy. Thus, the scanning strategy should be introduced to future participants during the training phase, so that they can use the application more efficiently.

5. Conclusions and Future Work

This paper presents a smartphone-based haptic feedback approach to assisting visually impaired people with understanding graphic content. A prototyped smartphone application providing haptic-enabled basic geometry shapes was developed. Through experiments, it was found that the blindfolded participants were able to correctly recognize the shapes provided by the prototype. Also, it was revealed that by only scanning the screen for the shapes' edges, without having to precisely follow them, the participants tended to recognize the shapes more quickly. Future works will focus on fine-tuning the training procedure with respect to the aforementioned findings and extending the prototype to more realistic use cases such as navigation, reading graphs and charts, etc.

6. Acknowledgment

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