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HAPTIC GLOVE FOR TACTILE GRAPHICS READER

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Abstract— Tactile graphics is commonly used by the blind and visually impaired (BVI) students to access graphical information in STEM subjects. However, to read graphical information using haptic senses is challenging compared to visual-based reading. It is a cognitive overload task due to the complexity of graphical information is represented in a tactile format. Without any guidance or assistance from a sighted person, the BVI reader will not “read” and unable to comprehend the tactile graphics independently. This study aims to design the assistive device that uses a haptic feedback method to provide artificial directional cues provided by four vibrating mini motor discs.

Exploratory test has been performed with 10 blindfolded (BF) participants has been conducted to investigate several design factors and configurations of the haptic glove of the assistive device. Promising results has been showed that the most effective configuration for the current design is when the four mini motor discs are placed at the hand palm and are set to high-intensity vibration for the cues.

I. Introduction

Tactile graphics are two-dimensional embossed content that has been generally used by BVI people to gain information from visual content such as pictures, graphs, and maps. In special education schools for the blind, where the BVI students use tactile graphics, especially for learning science, technology, engineering, and mathematics (STEM) subjects. Unlike printed graphics, tactile graphics are not accessible to every BVI student who has a different circumstance in their visual impairment (e.g., low vision, congenital or late blindness) and also have different cognitive abilities in understanding the content of tactile information. To read tactile graphics requires a certain kind of skills to interpret information, which comes with experience, and also exposure [1]. The density and complexity of information presented also contribute to the factors of perception of tactile graphics [2]. Thus, the teachers' assistance is vital to reduce cognitive overload and to help them fully comprehend the graphical information presented. The teachers assist the BVI students by guiding their hands to certain parts of the graphic, to touch and feel the raised surfaces, tracing along the path for shape recognition, and then verbally explaining the information [3].

This method of learning causes the BVI students still highly relying upon the presence of a sighted person to provide instructions and systematic guide to exploring and reading tactile graphics. Previous research has explored various approaches to develop assistive devices for BVI people to access tactile graphics. For instance, there are assistive devices that use audio feedback to convey information about the tactile graphics when the user's hand moves and touches the specific areas of interest [4][5][6]. Although the audio feedback method has the potential to assist the BVI, it is still less effective for precise guidance [7]. Alongside with this, there are researchers that have explored the potential of the haptic feedback method with different configurations and distinctive features. A few works focused on tactile cues and kinesthetic feedback to provide directional cues for the BVI people in exploring graphical content. At this point of time, most of the works that have been identified are focusing on digital contents [8][9][10] rather than on tactile graphics [7].

We hypothesized that the haptic feedback method has the potential to be one of the complementary features to guide BVI people's hands during tactile graphic exploration. This paper presents an initial prototype of an assistive device that with a haptic feedback method to provide artificial directional cues provided by four vibrating mini-motor discs. This device has been developed using a Raspberry Pi microcomputer together with a hand glove that has been embedded with the haptic motors. An exploratory test with ten blindfolded (BF) participants has been conducted to investigate the functionality of the device and to determine the best configuration of the haptic motors. From this work, it was found that these three main features of the haptic glove showed a promising result for the directional cues to the participants during tactile exploration which are; i) a square configuration layout of haptic motors, ii) a high-intensity vibration for the directional cues, and iii) placing the haptic motors at the hand palm. Throughout these initial findings, the exploratory test will be continued with BVI students in the future. It is aimed that the proposed device can be an assistive tool for teachers in special education schools for the blind and help the BVI students to read and comprehend the existing tactile graphics independently.

The rest of this paper is organized as follows: The following section provides the information on previous studies that have been identified related to this current research. Section III provides an overview of the proposed system design which comprises of the system's architecture and how it has been developed. Section IV explains how the experiment was done and Section V discusses about the data that been collected. Finally, conclusion and future work are discussed in Section VI.

II. Related Works

This section summarizes the assistive devices that use the haptic feedback method to help BVI people to read tactile graphics. The related works that have been identified are not only focused on assisting tactile graphics exploration but also related to assisting digital graphic exploration. Oliveira et. al [11] have developed a Haptic Deictic System that comprises of haptic glove paired with a computer vision-based tracking system to instruct and communicate with BVI students in reading raised-line tactile graphics. Two cameras were used to track the instructor's pointing behavior on a printed graphic and observe the BVI student's hand-reading position respectively. To navigate the reader's hand towards the instructor's pointing location, eight vibrators were used to convey cardinal and ordinal directions. These actuators were controlled individually by a microprocessor to employ varying pulse widths for different vibration intensities.

Zhang [9] has demonstrated Tapsonic, a finger-mounted device that utilized haptic feedback and auditory method to allow BVI people to access digital statistical information specifically line charts. The Tapsonic device was developed using two linear actuators mounted on the top and bottom of the second phalanx segment of the index finger which can induce a unidimensional movement (horizontal) and bidirectional haptics (vertical). The system is also comprised of a web-based line chart interface and an tablet as the interactive medium that detect touch gesture and produce voiceover.

Zhao et al. [10] adopted a participatory design approach where they co-operated with BVI people and special education teachers in designing the haptic device called VibHand. They hypothesised that the back of the hand is the best place for tactile cues during the exploration of the tactile graphic. The VibHand has been developed using Arduino as the microcontroller and the position of four vibrators was fixed at the back of the user's hand based on Finger-Hand Square Layout. The device employed spatiotemporal vibrotactile patterns to provide eight directional cues. The VibHand also utilized a tablet to display simple geometrical and non-figurative graphics. As soon as the user touches a line on the graphic, the direction cues will be triggered which indicated that the user needs to follow the line till the end.

Villamarín and Menéndez, [12] have developed a haptic glove for BVI people to experience the TV soccer broadcast. The movement of the soccer ball within the field can be felt through the haptic glove in the axis of X, Y, and Z synchronized with the video reception. There are five motors located at the fingertips of the hand glove that indicate the X-axis, and its varying intensity expresses the Y-axis. One motor at the back of the hand indicates the height of the soccer ball in the Z-axis ball at three levels of vibration intensity. The vibrations (low, medium, and high) were regulated by a haptic controller breakout connected to a microcontroller. Even though their works are not related to exploring tactile or digital graphics, the proposed method can be considered in designing the haptic device in this project.

In contrast to the four designs above, which use vibration as the mean of haptic, the design of PantoGuide by Chase et al. [7] exploited the advantages of the skin-stretching method in their design. The device consists of a pantograph with a rounded tactor on the end effector, which provides directional cues by contacting the back of the user's hand. Teensy LC microcontroller was used to control two DC gear motors through a motor driver. The angle of motors is controlled using Proportional-Integral-Derivative (PID) controller, where the measurement is done by rear shaft-mounted magnetic encoders. The design provides two types of guidance strategies, point-to-point, and continuous guidance which offer flexibility.

In summary, researchers have explored the use of vibration and skin-stretch methods to develop the haptic feedback system for the BVI people. Table 1 shows the summary of previous works that have been identified. The proposed designs are different in terms of the complexity and the components used, which might give different results in navigating BVI people while exploring information. However, there is still a lack of work focusing on facilitating BVI people on existing tactile graphics.

Table 1: Summary of previous works

Authors	Type of content	Haptic Approach	Navigation Strategies	Components of The Haptic Device
[7]	Tactile graphics	Skin-stretch	Cardinal and ordinal directions	Pantograph with a rounded tactor
[9]	Digital graphics	Vibration	2-dimensional directions (X and Y axes)	Two linear actuators
[10]	Digital graphics	Vibration	Cardinal and ordinal directions	Four vibrating mini motor discs
[11]	Tactile graphics	Vibration	Cardinal and ordinal directions	Eight vibrating motors
[12]	Digital graphics	Vibration	3-dimensional directions (X, Y, and Z axes)	Six vibrating mini motor discs

III. System Design

In this section, we present our proposed assistive system for BVI people to explore the existing tactile graphics. The proposed design of the system is based on the works [11][10] where system consists of a haptic glove to navigate the hand movement of the reader and a webcam to monitor the behavior. Figure 1 shows an overview of the proposed system. Currently, the system is still at the preliminary stage and has been tested with ten blindfolded sighted participants to investigate the best location for the placement of the haptic motors, whether at the palm or the back of the hand.

A Raspberry Pi 400 has been chosen because of its capability for computer vision applications and to control electronic components. In this current work, it is used for controlling the haptic device and providing the video feed on the hand movement. A graphical user interface (GUI) as shown in Figure 2 has been designed to assist the experimental works such as controlling the haptic device, recording video, and storing observations data.

Part A of the GUI is the panel to store the experiment's information. Part B is the panel for navigating the hand movement which can vary in terms of the vibration levels and the directional cues. Part C is to record the observation's status (True or False) based on the reader's hand movement after the directional cues are given. Part D is to save the recorded instructions and video to the chosen directory and close the GUI.

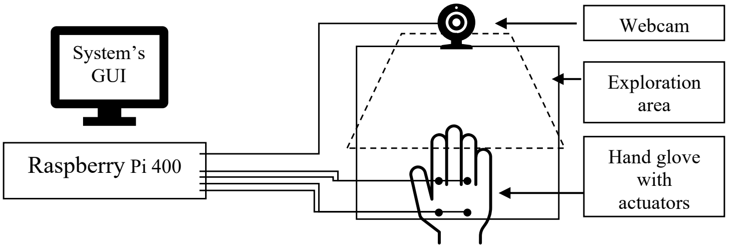

Figure 1: System architecture

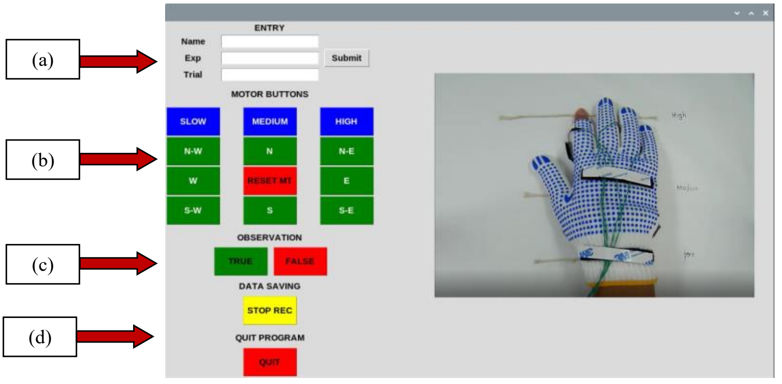

Figure 2: System's GUI

For designing the haptic feedback glove, we used four mini motor discs to provide eight directional cues [10]. The four mini motor discs can vibrate individually or simultaneously. The vibration intensity of the haptic motor is controlled using Pulse Width Modulation (PWM) signal. For this project, it was decided to use three levels of vibration intensity which are low, medium, and high, with the duty cycles of 50%, 70%, and 90%, respectively. It is known that the Raspberry Pi 400 pinout has an output voltage of 3.3V. Thus, the average output voltage for the three vibration levels was calculated to be 1.65V, 2.31V, and 2.97V respectively. The higher the average output voltage, the stronger the mini motor disc vibrates.

The haptic feedback glove that has been made is for single-hand exploration, as shown in Figure 3. Two gloves have been made; Glove 1 (G1): Mini motor discs are attached to the palm (Figure 3(a)) and Glove 2 (G2): Mini motor discs are attached on top of the hand (Figure 3(b)). The mini motor discs were soldered to sufficiently long jumper wires with the same diameter and connected to the Raspberry Pi 400. They were attached to the glove using Velcro tapes so they can be easily attached and removed. The layout configuration is the hand-finger square layout [10]. The layout refers to the two motors mounted on the second phalanx segment of the index and ring finger, while the other two motors are mounted on the bottom right and left of the hand.

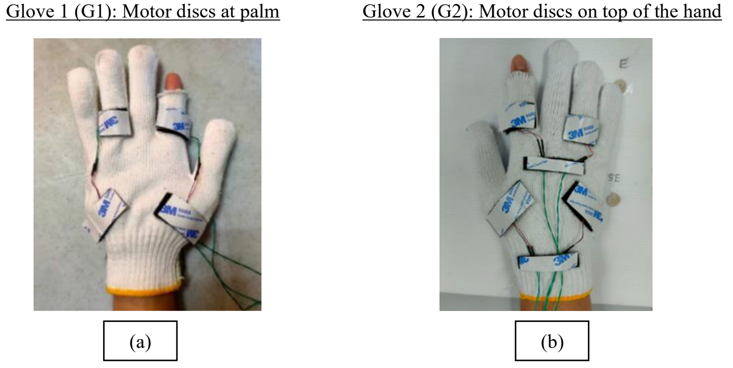

Figure 3: Design of haptic feedback glove

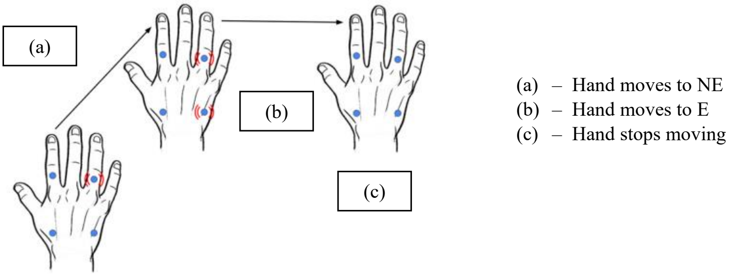

Figure 4: Illustration of hand movements induces by vibrating mini motor discs

Figure 4(a) shows the illustration of the mapping between actuated mini motor discs and 8 directional cues for the square layout. Single motor vibration indicates that the hand needs to be moved to the ordinal directions between Northeast (NE), Southeast (SE), Southwest (SW), and Northwest (NW) where the vibration is felt. While two motors' vibrations indicate the cardinal direction between North (N), East (E), South (S), and West (W). Figure 4 shows the scene of the vibrating motor disc and the expected hand movement behaviors. The fingertip of the index finger is the reference point of the movement. As the motor disc at the ring finger vibrates, the hand should move in the Northeast direction as shown in Figure 4(a).

Next, as the motor discs at the ring finger at the bottom right of the hand vibrate simultaneously, the hand should move in the East direction as shown in Figure 4(b). The hand stops moving when no vibration can be sensed as shown in Figure 4(c).

IV. Experimental Setup

To identify the best configuration and functionality of the proposed haptic device design, an exploratory test has been conducted. A room or a space with steady lighting conditions has been chosen to ensure constant illumination for the video recording to run smoothly with a good resolution during the experiment. Next, is to place the webcam mounted on a fixed stand and the test board at a fixed position as shown in Figure 5. The participants will sit in front of the researcher. The field view of the webcam should cover the whole area of the test board and there is no external object sighted nearby. ten sighted International Islamic University Malaysia (IIUM) students have been recruited to be the participants in the test. There were eight males and two females, and the range of ages are from 23 to 25 years old.

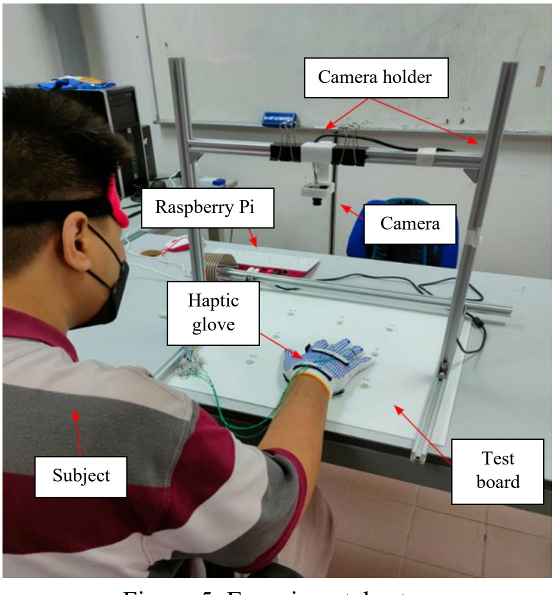

Figure 5: Experimental setup

The test consists of two tasks for two different hand glove configurations. The aim is to assess whether the designed haptic device functions as expected or not and to determine which configuration is better, between the mini motor disc attached to the palm (G1) or on top of the hand (G2). The goal of task 1 is to investigate the ability of the participant to distinguish the eight directions cues when using the haptic glove. The second task examines whether the participants can identify the different intensities of the vibration while using a haptic glove. During the test, the participants were blindfolded and wore the glove on their right hand. In the first round, the participants wore the haptic glove that consists of mini motor discs that are placed on the palm (G1) and need to complete the two tasks. For the second round, similar tasks will be repeated but the participant wore the haptic glove that has motor discs placed on top of the hand (G2). The test completed after the participants were tested with both configurations. Finally, the participants were required to answer a Likert Scale questionnaire survey. Figure 6 shows the flowchart of the exploratory test.

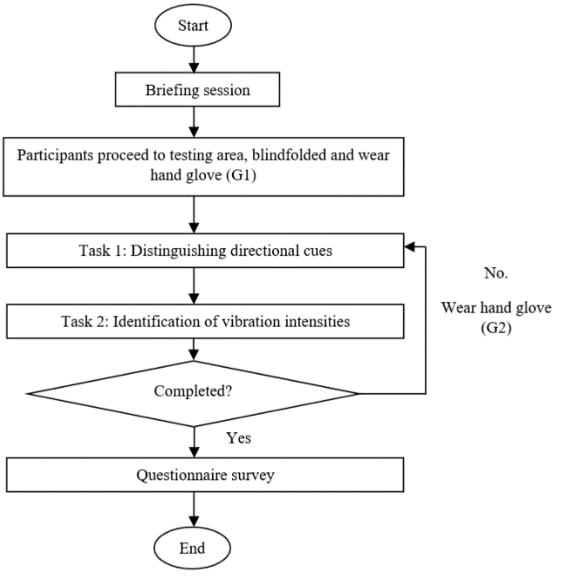

Figure 6: Flowchart of the exploratory test

Figure 7 shows the test board that was used, and the illustration of the first task. The researcher gave 15 random signals to the haptic device and the participants were instructed to move their hands in the corresponding directions accurately starting from the center. If one of the motors vibrates, the participants need to move their hand diagonally to the direction where the vibration is felt. If two motors vibrate simultaneously, the participants need to move their hands vertically or horizontally where the vibration is felt. There were two trials using two different vibration intensities, which were medium and high. The researcher observed and recorded every correct and false direction that has been made by the participants.

Figure 8 shows the test board that was used, and the illustration of the second task. The test board consists of three lines to indicate the level of vibration intensities (low, medium, and high). At the beginning of the task, the participants placed their hands at the starting point of the test board. There were 15 random vibration intensities that were sent through the haptic device and the participants need to move forward (North (N)) their hands to the specific line accordingly. For example, high vibration intensity indicates that the participants need to move their hands to the farthest line from the starting point. The score was taken based on the correct placement of the participant's hand.

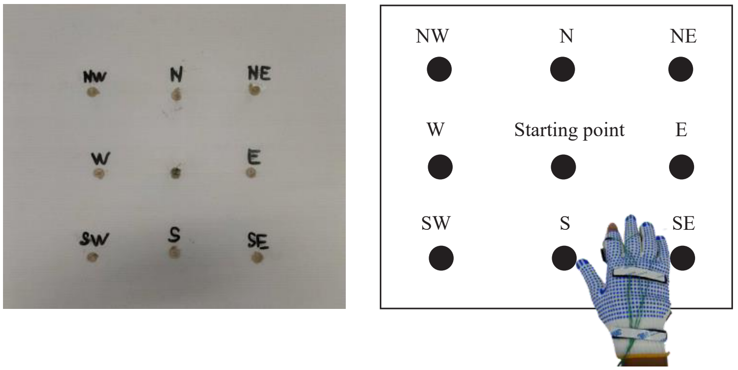

Figure 7: Test board and illustration of the first task

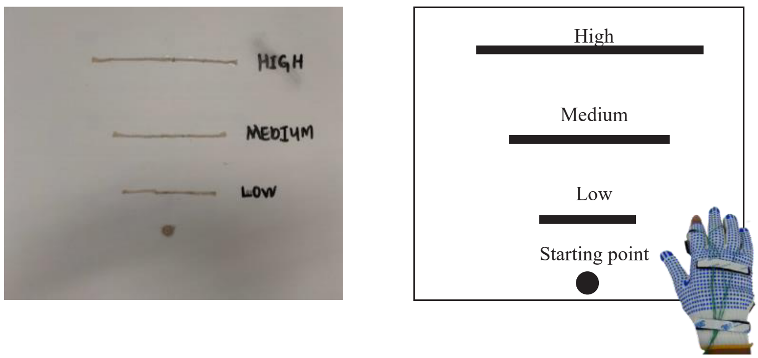

Figure 8: Test board and illustration of the second task

V. Results and Discussion

Figure 9 shows the line charts of the participants' scores between the two haptic glove configurations for the first task when the vibration mode was set to high. Most of the participants perform better when using the G1 hand glove where the mini motor discs are attached to the palm rather than the G2 hand glove where the mini motor discs are attached on top of the hand. For example, participant 4 scored correctly higher (over 80%) to sense the direction based on the vibrating mini motor discs using the G1 hand glove compared to the score collected (less than 80%) when using the G2 hand glove. It is believed that the palmer aspect of the hand contains more sensory receptors than the dorsal aspect of the hand [13]. Plus, the mini motor discs were also pressured by the weight of the participant's hand which make the vibration feels even more.

Figure 10 shows the bar chart of the score obtained by the participants between two vibration intensity modes (medium and high) for the first task. Both modes were compared using the G1 hand glove. The trend of the line charts implies that nearly all participants perform better when the haptic device uses high vibration intensity compared to medium vibration intensity to sense the directional cues. For instance, the first participant was able to get a perfect score (100%) when sensing the high vibration mode compared to sensing the medium vibration mode. Meanwhile, Figure 11 shows the score collected by the participants between two configurations for the second task. While there is no noticeable difference between the configurations, the trend shows that participants were able to score at least 50% of a correct response. This indicates that they were able to differentiate the vibration intensities.

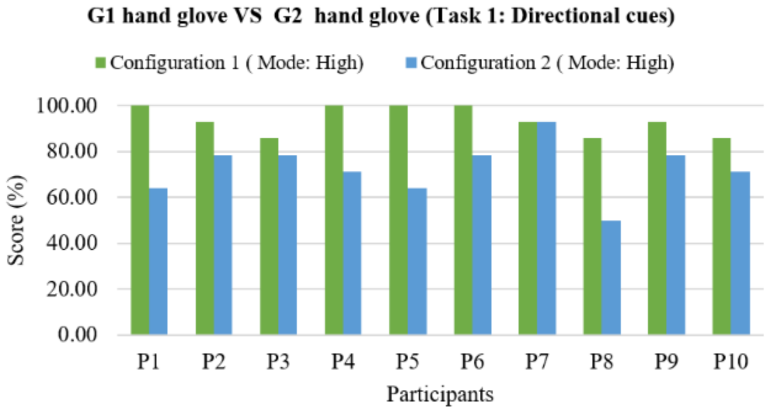

Figure 9: Participants' score chart when using the G1 hand glove and the G2 hand glove to sense directional cues at high vibration mode

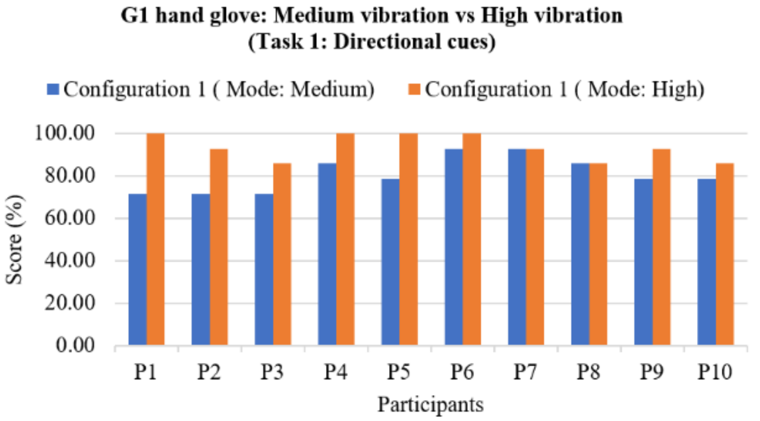

Figure 10: Participants' score chart when using the G1 hand glove to sense directional cues at medium and high vibration mode

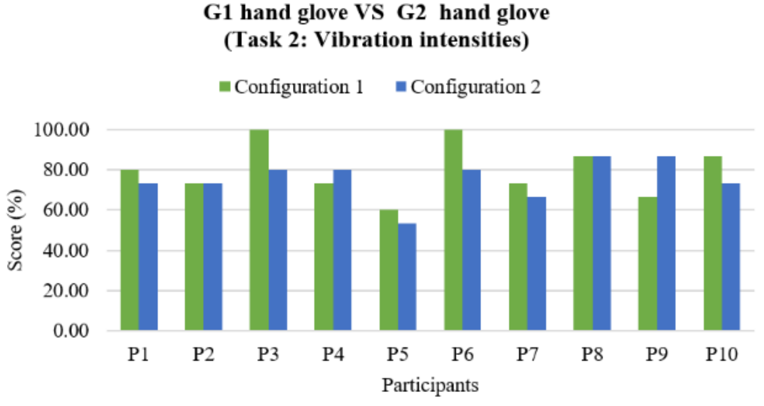

Figure 11: Participants' score chart when using the G1 hand glove (Green bar) and the G2 hand glove (Blue bar) to sense the vibration intensity

Figures 12, 13, and 14 show the feedback of the participants in comparison to the vibration intensities between low, medium, and high. Firstly, for the low vibration with the duty cycle of 50%, participants find it too low and recommended that vibration needs to be increased. Next, for the medium vibration with the duty cycle of 70%, most of the participants find it decent while a few participants recommended that the vibration needs to have an increase and decrease vibrational tempo. Finally, for the high vibration with the duty cycle of 90%, nearly all the participants find the vibration felt just right. Figure 15 also shows the participants' preference between the two hand gloves. Hence, it is concluded that three levels of vibration are acceptable but an adjustment on the range of intensities is supported and placing the vibrating motor discs on the palm is the best configuration for the haptic feedback glove.

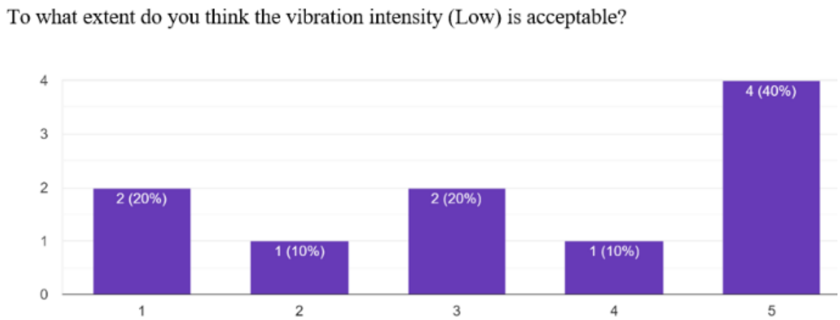

Figure 12: Participants' feedback on the low vibration

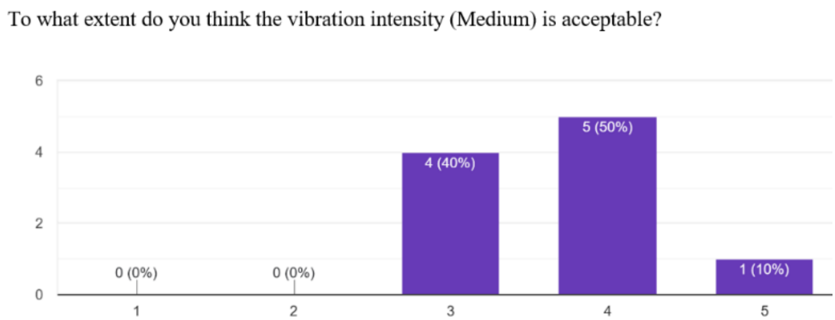

Figure 13: Participants' feedback on the medium vibration

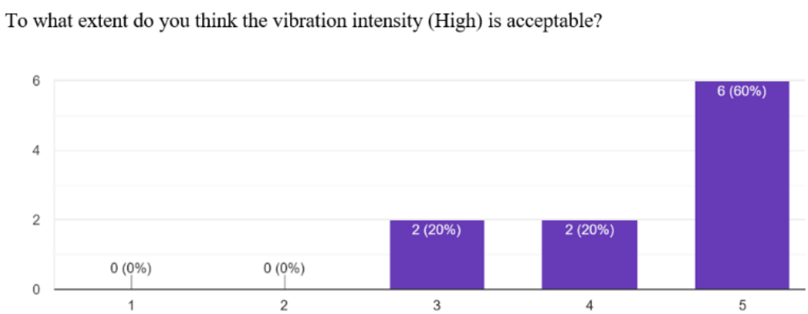

Figure 14: Participants' feedback on the high vibration

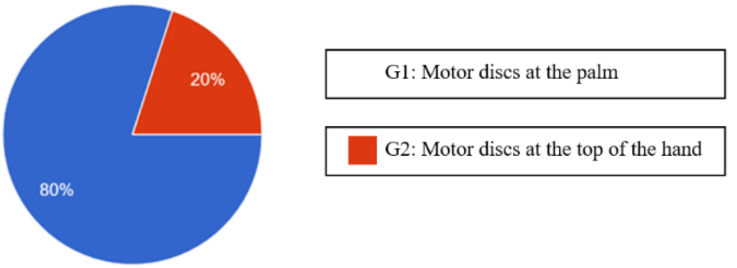

Figure 15: Controller Block

VI. Conclusion

In conclusion, this paper has presented the design of a haptic feedback glove with four vibrating mini motor discs to be used for assisting BVI people in reading tactile graphics. The haptic glove applied a hand-finger square layout configuration to give eight (8) directional cues and has three pre-determined vibration intensity levels, low, medium, and high, controlled using a PWM signal. In addition, a graphical user interface (GUI) with a video recording function was built using Raspberry Pi 400. With the help of the GUI, the pilot testing was conducted involving two tasks using two different configurations, where the motors are attached to the palm or the back of a right hand. The purpose of the exploratory test is to investigate the performance of haptic glove users when using the two configurations. The two tasks were constructed to investigate the best haptic motor configurations and the acceptable range of vibration intensity.

Results showed that the first configuration with high vibration mode (G1) was the best option for directional cues. Moreover, based on the participants' feedback, they suggested that the vibration intensity should be increased, and the placement of the vibrating mini motor discs must be at an adequate distance from each other. While there were some uncontrolled variables presented such as inconsistent vibration intensity between motors, the haptic glove was able to guide the user's hand to the specific direction as instructed with an over 65% success rate. However, the system is currently limited to using only one method of haptic motor configuration and future studies need to be done.

For future research, it is proposed to work on designing and developing a better haptic device using several different methods. For example, using rings and straps embedded with vibrating mini motor discs to make equipping easier. Another example is a haptic glove with motor placement on the hand using the cross-shape layout method. Furthermore, a study on vibration modes and vibration intensity control will be done in more detail in the future. For instance, the vibration modes can be in a form of pre-set sequences for direction with consistent vibration intensity for each motor or a higher number of input instructions for an accurate and precise result. Lastly, it is suggested for the exploratory test to be conducted with BVI people to gain more insight on improving the performance and the reliability of haptic gloves in practical use.

VII. Acknowledgement

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