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ORIGINAL ARTICLE

Haptic Feedback Wristband for Tactile Graphics Reader

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ABSTRACT – Traditionally, blind and visually impaired (BVI) readers face challenges in interpreting tactile graphics due to the need for specialized skills, training, and often external assistance. Existing audio feedback systems also present limitations, including exposure to surrounding noise and imprecise guidance. Therefore, this paper presents the design of an assistive device for tactile graphics reader using a haptic feedback system. This device takes the form of a digital watch with an adjustable strap, ensuring compatibility with various wrist sizes. It incorporates four strategically placed mini-motor discs that deliver vibration signals to the user's hand when exploring the content of tactile graphic. Pilot testing involving blindfolded sighted readers was conducted to assess the effectiveness of this haptic feedback wristband. The results of the testing revealed that participants could successfully discern direction cues and distinguish varying levels of vibration intensity. Notably, the success rates exceeded 70% for navigation and 85% for vibration intensity recognition.

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INTRODUCTION

Blind and visually impaired (BVI) people perform poorly in Math and Science subjects [1]. This is because the topics have too many diagrams and illustrations. Thus, tactile graphics are crucial. Tactile graphics are embossed type drawings with engraved outlines, symbols and textured surface that help BVI individuals to perceive graphical information through touch. However, the interest of using the tactile graphics is still poor, especially at the special education school of the blind. Some of the issues are they are facing difficulties to read and comphrehend the information independently [2]. Thus, instruction and physical guidance is needed to help them understanding the information on the tactile graphics.

Haptic feedback has been employed drastically as one of the assistive mechanism for BVI individuals in reading the tactile graphics. To stimulate the sense of touch, it can be induced through vibration, force, a gust of air, and ultrasonic rays. When applied in the context of tactile graphics reading, the use of haptic devices can be a valuable enhancement for the BVI people to provide a more accessible and enriched experience, particularly for those encountering challenges in interpreting graphical content through traditional means.

Based on previous researches, we have proposed a haptic feedback system integrated with computer vision system that imitates the presence of physical guidance from the teacher when to read tactile graphics. It is expected that the proposed approach to be practical to overcome the raised issue. The remainder of this paper is organized as follows: Section 2 briefly presents the related works that have been identified to help the BVI people gain more access to graphical information through the use of haptic feedback system. Section 3 explains our current approach on designing the haptic feedback wristband and the experimental setting that have been conducted. Section 4 discusses the experimental results. Section 5 concludes the paper.

RELATED WORK

In order to gain a comprehensive understanding of the development of haptic feedback system within the present field of study, an extensive investigation is conducted through the existing scholarly literature. The articles and papers were sourced from four distinct databases, namely Google Scholar, the IEEE Xplore, the ACM Digital Library, and Science Direct. Initially, a total of 539 articles were gathered during the first round. Following a thorough process of inclusion and exclusion, a total of six publications were identified as being very significant to the field of building haptic technologies for the purpose of exploring tactile graphics.

Firstly, Oliveira et al. (2012) had designed a partially covered hand glove of the haptic device that employed 8 actuators that induced vibration in both cardinal and ordinal directions [3]. Similarly, Villamarin & Menendez (2021) had developed a fully covered haptic feedback glove but only utilized six mini motor discs [4]. Unlike Zhang's (2020) haptic device prototype namely Tapsonic, two linear actuators were used to be mounted on the top and bottom of the index and middle fingers [5]. Zhao et. al (2020) had identified that the back of the hand was more convenient to place four vibrating mini motor discs to deliver eight different vibrations patterns for the purpose of digital image exploration [6].

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In contrast to the previous four designs, Chase et al., (2020) used the skin-stretching technique to design the haptic device called PantoGuide [7]. They used a pantograph with a rounded tactor on the end effector to stimulate the vibational signal at the back of the user's hand. Despite using a glove form of haptic device, Chinello et al. (2017) designed a forearm haptic device that encompassed of four cylindrical end effectors. The actuactor were uniformly spaced around the forearm of the user to generate independent skin stretch stimul [8].

Based on the six type of haptic device designs, it is evident that some are more sophisticated and use more components. These variations resulted in different effect of BVI navigation when exploring tactile graphics. Table 1 shows the overview of the prior works.

Table 1. Related works to haptic feedback.

Articles	Hardware	Navigation techniques	Purpose	Subjects
Villamarín et al. (2021)	Mini motor disc (ADA1201)	Six motors used to indicate three directional axis	Watching TV	15 totally blind persons
Oliveira et al. (2012)	Actuator (Jameco part number 256241)	Eight directional cues	Inclusive Classroom	5 totally blind persons 23 sighted persons 2 instructors
Zhao et al. (2020)	Mini motor disc	Four vibrators for eight directional cues	Digital images on tablet	12 visually impairred person, 12 sighted persons
Zhang (2020)	Linear actuator (M1027)	Two directional movements	Digital images on tablet	4 congenital visually impairred person
Chase et al. (2020)	Pololu 6V 100:1 micro-metal DC gearmotors	Skin stretch for directional cues	Exploration of bar chart and tactile graphic	1 totally blind person
Chinello et al. (2017)	Cylindrical end effectors	Skin stretch for directional cues.	Not related to tactile graphics	10 sighted participants who had experience with haptic interfaces

METHODOLOGY

We first discovered that, a teacher typically guides and directs the BVI student's hand while providing explanations during the reading process. This pedagogical practice plays a pivotal role in assisting them to comprehend and interpret the information conveyed through tactile graphics. Therefore, our current focus lies on examining an alternative perspective: how does the integration of a haptic feedback system with a computer vision system could potentially facilitate independent exploration of tactile graphics for BVI students. We limited the application of the proposed system to only assist the BVI students in recognizing two-dimensional fundemental shapes. In general, this section explains the overview of our proposed system. It covers the design of the haptic feedback system that encompasses of component selection, haptic motor placement and configuration, and vibration control. In the subsequent section, we describe how the computer vision system monitors the hand movement while exploring the tactile graphics and communicates with the haptic feedback system. We also presented the experimental setup used to validate the suggested method.

SYSTEM DESIGN

Haptic feedback encompasses a variety of forms, including rotation, oscillation, resistance, motion, and force. This will afford individuals the opportunity to engage with virtual and artificial stimuli, thereby providing them with a tactile feedback experience. Our focus revolves around the development of a haptic assistive device that will offer an effective mechanism of haptic guidance for the tactile graphics reading. This concept draws inspiration from Chinello et al. (2017), who found that placing haptic feedback motors on the forearm yields positive results without adversely affecting the user's hand. Rather than positioning the vibrator components on the user's palm, we positioned on the wrist, to simulate the functionality of a wristwatch. In addition, this current works adopted the approach utilized by Zhao et al. (2020), which involves the use of four vibrators to output haptic feedback in eight different directions.

Various parameters have been considered throughout the component selection, including operating voltage, power rating, peak frequency, dimension, weight, speed, and cost. Based on prior research and the availability of market products, we have chosen X-Y axis coin vibrator motor, also called mini motor disc as the main haptic feedback component. It is compact and disc-shaped form, robust vibration capabilities, and lightweight nature, all of which are well-suited for integration into a wristwatch design. In addition to its specified features, the affordability of this component is crucial for ensuring the long-term sustainability and maintenance of the device.

There are four main components used in developing and integrating the haptic feedback system together with the computer vision system. We used the Raspberry Pi 400 as the microcomputer, a webcam, ULN2803 Darlington Transistor and four mini motor disc. Our approach of the haptic feedback system begins with hand detection and tracking which give result of the index fingertip coordinate. The feedback vibration will be generated as the fingertip moves towards the desired locations. The ULN2803 Darlington transistor operates as a switch and also amplifies in the actuator circuit. Figure 2 shows the schematic diagram of the haptic feedback system.

As for the computer vision system, we utilized the MediaPipe Hand Landmarker to identify and keep track of the motions of the reader's hand. As shown in Figure 3 the model is able to detects the keypoint localization of 21 handknuckle coordinates including the placement of the joints, fingers and palm. Throughout this approach, we can precisely monitor the reader's index fingertip motions and activities on the tactile graphics based the location and movement of these landmarks over time.

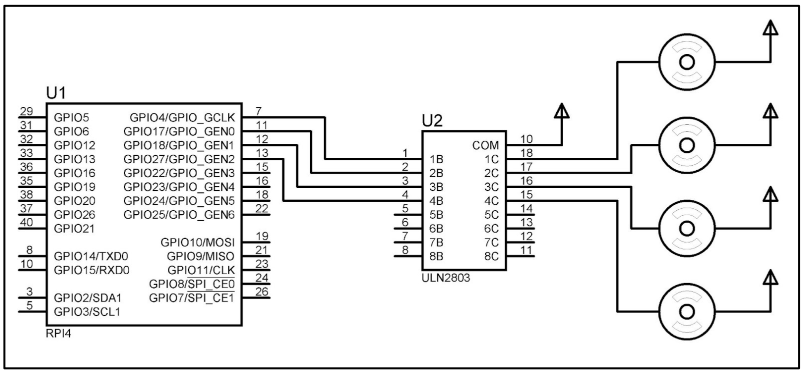

Figure 2. Schematic diagram of the proposed assistive devices that comprises of Raspberry Pi, Darlington Transistor and four mini motor discs.

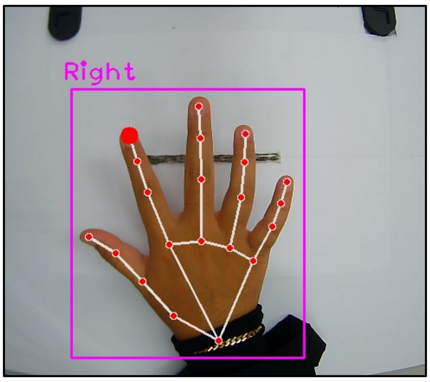

Figure 3. Hand detection and tracking using the MediaPipe Hand Landmarker. The index fingertip location has been tracked as input to the haptic feedback system.

Haptic feedback wristband design

Previous works found that, placing a haptic motor on the forearm works effectively without disrupting the user's hand. Therefore, our current approach was designing a haptic feedback wristband which also resembles the operation of a wristwatch. Figure 4 illustrates the 3-dimensional design of the wristband. There were three major requirement that have been examined for the design which are vibration transfer along the wristband, wrist size, and wrist shape. To ensure, the vibration can be effectively transfer to the exact location of the wrist, we have designed the haptic motor casing to be dome-shaped feature as shown in Figure 5.

To position the vibration motor evently on the user's wrist is a challenge, since there are variety of wrist size. Thus, our current design allows the position of the motor to be adjustable. By means, it can be rearranged along the elastic band and it allows the users to tighten or loosen the strap according to their wrist size. However, the motors need to be arranged according to the default layout as shown in Figure 6.

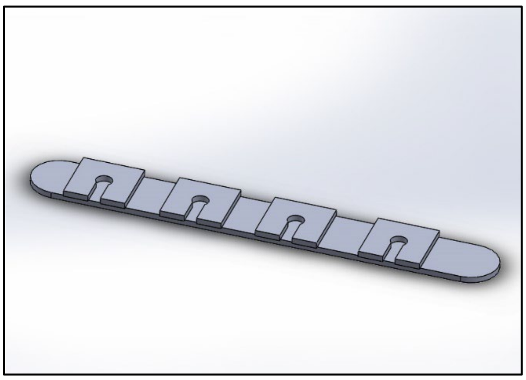

Figure 4. The design of haptic wristband.

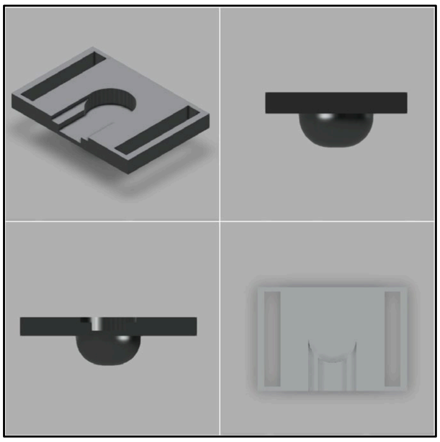

Figure 5. 3D design of dome shape for the motor casing.

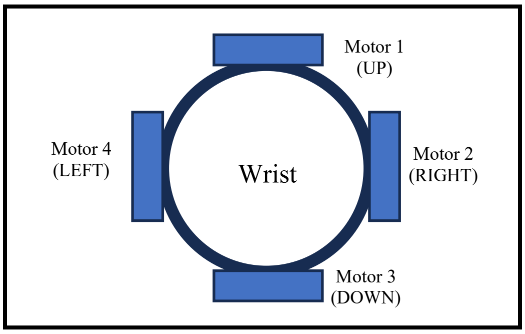

Figure 6. Layout of the wristband.

Vibration control

The configuration of the mini-motor disc's vibration is achieved by the utilization of the Pulse Width Modulation (PWM) signal. Three levels of vibration intensity low, medium, and high were configured, each corresponding to duty cycles of 39%, 78%, and 100%, respectively. To ensure the precision and reliability of this configuration, the voltage output at each motor was measured using a Multimeter, as illustrated in Table 2, allowing for the evaluation of its consistency. Particularly, the characteristics of each mini-motor disc gave varying voltage outputs even when subjected to the same 100% duty cycle PWM, as evidenced by the comparative data presented in Table 3. This assessment underscores the importance of fine-tuning the haptic feedback wristband's vibration configuration to achieve optimal performance and user experience.

Table 2. Comparison of voltage output from each motor at different duty cycle.

Duty cycle (%)	Motor	Voltage (V)	Average voltage (V)
25	1	0.92	0.88
	2	0.81	
	3	0.93	
	4	0.87	
50	1	2.02	1.82
	2	1.72	
	3	1.7	
	4	1.84	
75	1	2.55	2.61
	2	2.58	
	3	2.55	
	4	2.77	
100	1	4.04	3.71
	2	3.42	
	3	3.38	
	4	4.01	

Table 3. Comparison of output voltage measurements for each motor for four readings at 100% duty cycle.

Motor	Reading	Voltage (V)	Average voltage (V)
1	1	4.04	4.04
	2	4.06	
	3	4.01	
	4	4.04	
2	1	3.42	3.44
	2	3.44	
	3	3.43	
	4	3.46	
3	1	3.46	3.40
	2	3.38	
	3	3.38	
	4	3.38	
4	1	3.38	3.69
	2	3.38	
	3	4.01	
	4	3.97	

EXPERIMENTAL SETUP

There were two phases of experiments that have been conducted throughout this study. The initial step involves assessing the design of the haptic feedback system. Hence, we have carried out various tests to determine effectiveness of the haptic feedback wristband in guiding the reader's hand through vibration. The method used for this first phase of experiment is by pilot testing. The results obtained were analyzed for further design iterations and improvements. As for the second phase, we designed the experiment that simulate the scenario of BVI readers when reading tactile graphics. It was carried out to identify its functionality and usability of the overall proposed system for the BVI readers when reading tactile graphics.

First Phase: Pilot Testing

There were eight sighted students from the International Islamic University Malaysia (IIUM) that have been recruited for the pilot testing. This group consisted of four male and four female, ranging in age from 22 to 24 years old, whom volunteered in the study. The test began with pre-questionnaire session among the participants which survey on their acknowledgement about tactile graphics and experience in using any haptic feedback wristband. It is noteworthy that half of these participants knew about tactile graphics, and none of them had any prior experience in interpreting or reading tactile graphics.

Figure 7 shows the arrangement of the setup for the pilot testing. Every participant had been introduced to the task of the experiment, about the haptic feedback wristband and steps to wear it on the desired hand. After the wristband had been placed, the position of of each motor was adjusted to be in the right place. It is noteworthy that all participants have been blind-folded to experience the situation of the BVI readers.

Figure 7. Pilot testing setup.

The test comprised of two segments, namely the navigation and vibration intensity tests. The primary objectives were to assess the user's ability to identify the location of vibration among the eight directional cues and to determine between low, medium, and high vibration intensities using their sensing ability. Subsequent to completing the test, participants were prompted to respond to a Likert scale post-questionnaire survey. Figures 8 and 9 illustrate the procedural steps involved in conducting the pilot testing.

Figure 8. Vibration intensity test.

Figure 9. Navigation test.

Task 1: Navigation

The purpose of this task is to evaluate the participants' ability to navigate their hand by relying on the vibrating wristband as the directional indication. The test board with eight directional cues is shown in Figure 10. Participants were blind-folded, and a webcam was used to record their actions. During the test, the participants had received ten random vibration signals from the haptic device. Starting from the centre, which was designated as the initial position, they had to precisely move their hands in the correct directions to return to the initial position. The process was repeated until each participant got up to ten random vibration signals.

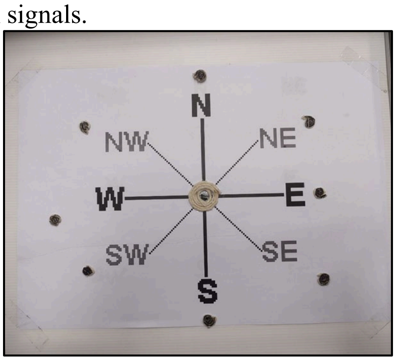

Figure 10. Test board for navigation test.

There are two types of directional cues namely cardinal and ordinal direction that have been configured into the system. Cardinal directions—north, south, east, and west (N, S, E, W)—constitute the primary compass points. Ordinal directions—Northeast (NE), Southeast (SE), Southwest (SW), and Northwest (NW)—intersect cardinal directions. The differentiation between ordinal and cardinal directions depends upon the number of vibrating motors and the location of vibration. For instance, if one motor vibrates, participants need to move their hand in any of the cardinal directions; if two motors vibrate simultaneously, participants need to move their hand in one of the four ordinal directions. Every action made by the participant was recorded and calculated the success rate of correctly identifying the direction out of 10 vibration signals based on the participants' cumulative attempts.

Task 2: Vibration intensity

The participant's ability to discriminate between various vibration intensities is the main emphasis of this task. There are three categories for vibration intensities: low, medium, and high. The test board for the second task consisted of three circular shape of varying sizes to represent the strength of vibration, is shown in Figure 11. When the participant was first blind-folded, their hand was placed at the starting point of the test board. Subsequently, they received ten random vibration signals from the haptic device, each with varying strengths.

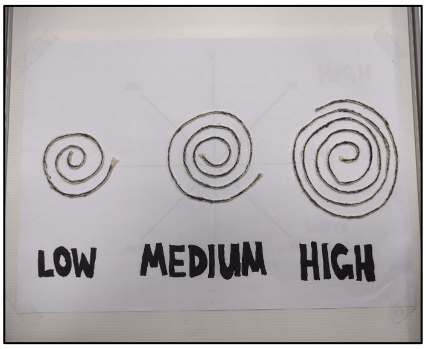

Figure 11. Test board for vibration intesity test.

Unlike the first test, the participants had been instructed to move their hand to a low, medium, or high circular shape form regardless of where the single motor vibrated. A strong vibration, for example, indicated that their hand should be moved to the largest circular shape. The effectiveness of the design was then measured based on the participants correctly identifying the ten random vibrations intensities that were given.

Questionnaire survey

After completing both tasks, the participants filled out a post-questionnaire survey featuring 15 Likert scale questions. The questions covered on the following aspects such as acceptance of vibration, navigation effectiveness, and device comfort. For the first section of the question, participants rated their ability to sense vibration at each motor location and their proficiency in differentiating vibration intensity. The ffectiveness of the navigation technique and the wristband's assistance in providing directional cues were also assessed in the following section. Finally, the comfort in wearing the device was rated, and the survey concluded with participants providing brief feedback or suggestions for system enhancement.

Second Phase: Exploring the Tactile Graphic with Haptic Feedback Wristband

Twenty sighted students from the International Islamic University Malaysia (IIUM) ranging in age between from 19 to 23 years old had participated in the second phase of experiment. The aim is to evaluate the performance of the haptic feedback device using the second approach of the navigation technique (refer to Task 1). There were equally ten male and ten female who volunteered in the second phase of the experiment. Again, it is noteworthy to mention that the experiment was conducted with all participants were being blind-folded to replicate the conditions of the BVI readers. Based on the innitial survey, only 33.3% of participants who knew about tactile graphics but more than half, or 66.7% who did not know about tactile graphics.

The experiment was conducted as the preliminary observations regarding the device's functionality and usability before proceeding with BVI readers in future. Although the perspectives of sighted individuals may not fully encompass the experiences of BVI readers, their feedback can be valuable in determining the most effective navigation technique. This technique will be subjected to further testing in forthcoming research.

Stimuli

In this experiment, the participants were asked to identify basic shapes based with only minimal tactile points given and solely follow the directional signals provided by the wristband-mounted vibrating motor. The shapes that have been used were straight line, triangle, rectangle and oval as shown in Figure 12. The selection of shapes as the stimuli serves the purpose of assessing the effectiveness of the chosen approach in aiding BVI readers who encounter challenges when identifying geometric shapes.

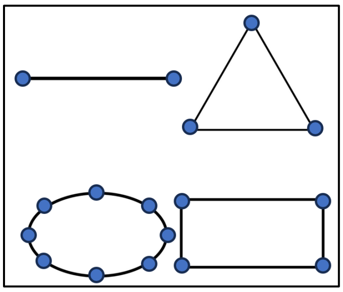

Figure 12. Selected basic shapes. The blue circles indicate the tactile points on the test board.

Procedure

This section outlines the experiment's procedures, with each participant undergoing a 20 to 30-minute session. Figure 13 illustrates the setup configuration, including the test board, a top-down-view webcam mounted to a frame, and the experimenter section. Initially, participants completed a pre-questionnaire survey concerning tactile graphics awareness and experience with haptic devices. Following this, participants received an explanation of the task and instructions on how to properly wear the haptic feedback wristband.

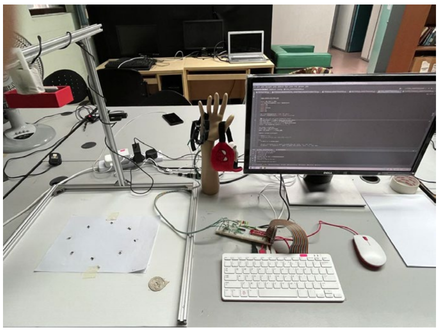

Figure 13. Experimental setup for second phase.

To ensure that the motor of the wristband was in the correct position, each motor had been vibrated and the participant needed to verify the position of the vibration. Subsequently, participants continued with the main task to assess their ability to navigate their hand accurately to determine the shapes given. After the experiment, the participants were required to answer a post-questionnaire survey using Likert Scale. Following the experiment, participants completed a post-questionnaire survey using a Likert scale. Figure 14 provides a flowchart of the overall experimental procedure, while Figure 15 shows the example scenery of conducting the experiment.

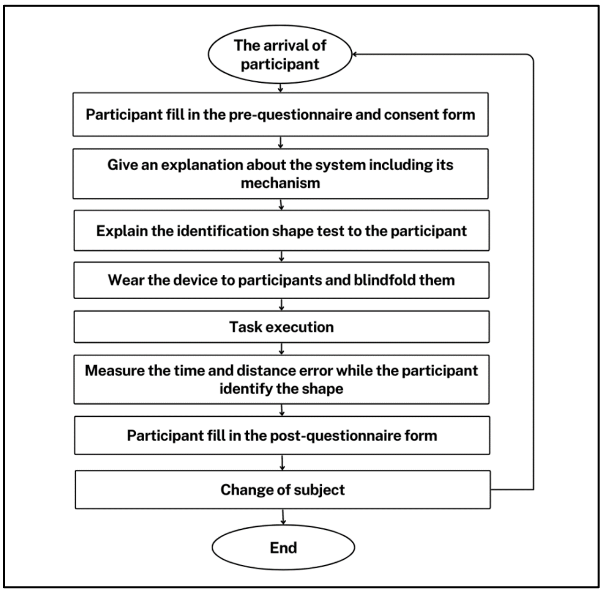

Figure 14. Flowchart of the experiment.

Figure 15. During the experiment, the participant was identifying the rectangle shape.

There are four types of basic shapes that the participants had to guess. But each shape was only provided with only minimal points of its characteristics. For example, a rectangle was indicated by only four points of its characteristics. In the beginning of the experiment, the participants need to position their reading hand at the designated innitial location on the board. The system promptly triggers the vibration on the wristband as the participants performed an index pointing gesture.

The navigation approach employed in this experiment, as previously stated, was established on the premise that when the index fingertip is away from the shape's line, the wristband vibrates. As a result, the participant's hand was forced to move based on where the motor that was vibrating.

For example, if the participants sensed the top motor was vibrating, the hand need to be moved upwards and the motors stopped vibrating as the index fingertip collided and moved along the virtual line of the shape. Once the participants had located all the points on the shape, they need to name the shape presented. Finally, they were required to answer the post-questionnaire survey in a Likert scale format to give feedback on the system proposed.

EXPERIMENTAL RESULT

This section discusses the result and analysis derived from the conducted experiment. As a recap, there were two parts of experiments that have been conducted, one focusing on the validation of the design of the haptic feedback wristband and the other on effectiveness of the proposed system in giving users the sense of direction when exploring basic shapes.

Directional cues

Prior to the first test, Table 4 shows the result of each participant to identify the direction based on the vibrational cues. Based on the results, all participants had scored correctly above 50% out of the ten vibration signals given. These results collectively indicate a strong ability among the participants for discerning direction based on the haptic cues, with an overall positive performance as evidenced by the average score of 71.3% across the group. The variation in individual scores, with participant number 3 demonstrated the highest accuracy and participant number 1, 7, and 8 achieved slightly lower scores, reflects the nuanced and diverse responses to the haptic guidance cues. These findings underscore the efficacy of the device in assisting participants in determining direction, setting the stage for further analyses regarding shape identification and participants feedback.

Table 4. Results for navigation test.

	Participant							
Direction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
North	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
South – East	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
South	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
North – West	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
East	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
East	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	TRUE
West	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE
North – East	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE
North	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE
South – West	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE
TRUE	6	7	9	8	7	8	6	6
FALSE	4	3	1	2	3	2	4	4
Success rate (%)	60	70	90	80	70	80	60	60

Next, Table 5 displays the success rates, expressed as percentages, for each direction based on the cumulative correct responses from all participants. Notably, two ordinal directions (Southeast and Northeast) and one cardinal direction (East) recorded success rates below 50%. The Northwest direction exhibited the lowest success rate at 25%. In contrast, the North direction achieved a perfect score of 100%, indicating correct direction identification by all participants. The average success rate across ten random vibrations stands at 71.25%. A noticeable results, indicating that participants encountered greater difficulty distinguishing ordinal directions (Northeast, Southeast, Southwest, and Northwest) compared to cardinal directions (North, South, West, and East).

Table 5. Percentage of success rate for navigation test. Each participant was given with same sequence of directional cues.

Direction	TRUE	FALSE	Success rate (%)
North	8	0	100
South – East	3	5	37.5
South	7	1	87.5
North – West	2	6	25
East	7	1	87.5
East	3	5	37.5
West	6	2	75
North – East	7	1	87.5
North	7	1	87.5
South – West	7	1	87.5

The reason is because of the motor's vibration inconsistency. It was identified that two motors produced slower vibrations compared to the other two, even when employing a similar duty cycle, as discussed in the methodology section. Particularly, the East direction exhibited a lower percentage of success rate even only one motor vibrates. This inconsistency of the two motors vibration had caused challenging situation for participants to accurately detect the direction.

Vibration intensity

In the second test, participants were tasked with distinguishing among three levels of vibration intensity—high, medium, and low. Table 6 presents the scores achieved by participants for the ten given vibration signals. Notably, all participants demonstrated a high capability to discern the level of vibration intensity, with most scores approaching 100%. The maximum score reached 100%, while the lowest was 90%, still considered a high percentage. The overall average percentage across all participants stood at 95%.

Table 5. Results for vibration intensity test.

	Participant							
Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Low	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
High	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Medium	TRUE	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE	TRUE
Medium	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Low	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
High	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
High	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
Low	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
High	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Medium	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
TRUE	10	9	9	9	9	10	10	10
FALSE	0	1	1	1	1	0	0	0
Success rate (%)	100	90	90	90	90	100	100	100

Furthermore, Table 6 provides an overview of the overall success rate in identifying vibration intensity across all participants. Notably, five distinct vibration levels achieved a perfect score of 100%. Even for the medium level that recorded the lowest percentage at 75%, still constitutes more than half of the maximum percentage. The average success rate for vibration intensity identification across the ten settings is 85%. This data indicates that participants generally exhibit a high ability in distinguishing between various levels of vibration strength.

Table 6. Success rate for vibration intensity test. Each participant was given with same sequence of vibration intesity.

Level	TRUE	FALSE	Success rate (%)
Low	8	0	100
High	8	0	100
Medium	6	2	75
Medium	8	0	100
Low	8	0	100
High	8	0	100
High	7	1	87.5
Low	7	1	87.5
High	8	0	100
Medium	8	0	100

Success rate of shape identification

In this phase, 20 participants were tasked with identifying basic geometrical shapes using only specific embossed points on paper. To determine the presented shape, they relied on guidance from the haptic feedback wristband, with shapes presented sequentially from easy to difficult—straight line, triangle, rectangle, and oval. The success rate for shape identification was categorized as True or False, is detailed in Table 7. It can be seen that, 60% of participants successfully identified all shapes, resulting in an average success rate of 88.75%. Table 8 provides a breakdown of the success rates for identifying each shape, with the straight-line shape achieving a perfect score of 100% correctness due to its simplicity, featuring only two points at each end.

Table 7. Success rate for shape identification of each participant.

Participant	Straight line	Triangle	Rectangle	Oval	TRUE	FALSE	Success rate (%)
1	TRUE	TRUE	TRUE	TRUE	4	0	100
2	TRUE	TRUE	TRUE	TRUE	4	0	100
3	TRUE	TRUE	TRUE	FALSE	3	1	75
4	TRUE	TRUE	FALSE	TRUE	3	1	75
5	TRUE	TRUE	TRUE	TRUE	4	0	100
6	TRUE	TRUE	TRUE	TRUE	4	0	100
7	TRUE	TRUE	TRUE	FALSE	3	1	75
8	TRUE	TRUE	TRUE	TRUE	4	0	100
9	TRUE	TRUE	TRUE	FALSE	3	1	75
10	TRUE	TRUE	TRUE	TRUE	4	0	100
11	TRUE	TRUE	TRUE	TRUE	4	0	100
12	TRUE	TRUE	TRUE	TRUE	4	0	100
13	TRUE	TRUE	TRUE	FALSE	3	1	75
14	TRUE	TRUE	TRUE	TRUE	4	0	100
15	TRUE	TRUE	TRUE	TRUE	4	0	100
16	TRUE	TRUE	TRUE	TRUE	4	0	100
17	TRUE	TRUE	TRUE	FALSE	3	1	75
18	TRUE	TRUE	TRUE	TRUE	4	0	100
19	TRUE	FALSE	TRUE	FALSE	2	2	50
20	TRUE	TRUE	TRUE	FALSE	3	1	75

Table 7. Success rate to identify each shape.

Shape	TRUE	FALSE	Success rate (%)
Straight line	20	0	100
Triangle	19	1	95
Rectangle	19	1	95
Oval	13	7	65

In contrast, the oval shape posed the most significant challenge, with only 65% of participants can successfully identifying it. The difficulty was caused from a misconception where participants incorrectly perceived the given physical points as sharp corners of the shape. It is crucial to recognize that an oval shape does not have any corner, contributing to a slightly lower success rate compared to other shapes. Additionally, the remaining two shapes (Triangle and Rectangle) demonstrated a high accuracy rate of 95%. Nevertheless, the overall accuracy percentages for all shapes were remarkably high, underscoring the efficacy of the haptic feedback wristband in aiding participants in accurately identifying the presented shapes.

Participants feedback

This section focuses on the post-questionnaire results of all participants. Regarding on the sensing the motors vibration, the participants have been asked on their ability to sense the vibration at each position. Most of the participants strongly agree that they can sense the generated vibration at the top, bottom and right part but only 85% of them were able to sense the vibration on the left part of the motor. Only 14 participants strongly agreed that they were able to differentiate the location of the vibration when using the haptic feedback wristband. For the rest, they felt confused to sense which part of the motor was vibrating.

In terms of shape identification, the participants exhibited different levels of proficiency in recognizing the four shapes, with the triangle and oval being particularly challenging. Some of participants were struggled to distinguish between a straight line and a triangle shape due to its inclined line characteristics. Yet, the straight line and rectangle shapes were generally well-recognized by participants because of the distinct geometric characteristics. Importantly, all participants agreed or strongly agreed that the proposed haptic feedback wristband played a vital role in navigating hand movements toward to identify the presented shapes. This highlights the effectiveness of the proposed assisitve system in assisting participants with shape identification.

CONCLUSION

This paper reports the proposed the design of an assistive device for tactile graphics reader using a haptic feedback system. The assistive device encompasses of haptic feedback wristband featuring four vibrating mini-motor discs strategically positioned at the top, bottom, left, and right of the wrist. The system is also integrated with a hand and finger tracking system, allowing the motor to induce vibrations that generate eight distinct cues of direction, encompassing both ordinal and cardinal directions based on the position of the index fingertip to the targeted location.

To evaluate the system, two experimental phases were executed. The first phase involved pilot testing, where participants were tasked with determining cues of direction and assessing the level of vibration intensity. This phase was instrumental in selecting the most suitable vibration intensity for subsequent experiments. The second phase aimed to test the device's effectiveness in providing participants with a sense of direction through the identification of geometric shapes.

Following the experimental phases, the participants provided valuable feedback through post-questionnaire surveys. These responses revealed that many participants encountered challenges in identifying which part of the motor was vibrating. Despite the presence of uncontrollable factors, our proposed system demonstrated its ability to guide participant’s hand movements accurately, with a success rate of over 70% for the navigation test and 85% for the vibration intensity test, based on participants scores. Future studies are warranted to further enhance the haptic feedback system, optimizing the generation of effective haptic guiding stimuli.

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