Received January 7, 2013; Accepted March 19, 2013

International Journal of Asia Digital Art & Design

A Design Study for the Haptic Vest as a Navigation System

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Abstract
Along with the arrival of the information age, people have started to pay attention to user experience design based on the human sensory organs. Instead of traditional user experience design based on vision and hearing, the experience based on tactile feedback has gradually become the mainstream in the field of product design. With this paper, we're discussing the designing and production of the haptic vest, originating in our development of the haptic navigation system. We aim to actualize "symbolization" or "implication" of the haptic information. Haptic vest is a design of conveying electronic information using tactile feedback, with 60 actuators. Through these actuators, haptic vest provides users with navigational information. Thus, the vest not only serves as the medium for the actuators, the experience of tactility here comes from the vibrations of the actuators and the information it attempts to convey.

Keywords: Haptic Vest, Vibration, Navigation

1. Introduction

In the background of experience economy, tactile experience has been gradually replacing the visual and auditory sense in the design field based on the human sensory organs, becoming the new mainstream of design. The background of the electronic information age makes the experience of tactile design not only refer to the users touching the material texture, such as soft or hard, the information product technology also makes tactile design more widely and deeply used in various fields.

This paper mainly introduces our design of the Haptic Vest as a navigation system based on tactile feedback. The basic design idea is that users get the directional information through feeling the vibrations coming from the 60 actuators which are attached to the vest. We introduce from the design concept and prototype, to the experiments of user experience and the discussion, and we propose to actualize "symbolization" or "implication" of the haptic information and apply it into future design and works.

2. Related Works

As more and more researchers treat tactile sensation as a means of presenting information, there have been a lot of researches research about the tactile experiences in personality development and cultural patterning of tactile experiences and so on[1]. Also, there are researches about the conditions influencing tactile feedback [2] and how to control and enhance the tactile feedback with different methods [3] [4].
And there have been many application of tactile sensation in various fields. For example, there are researches that study the transmission of haptic information in the form of tele-presence by using sofa as the medium [5]. Other haptic examples also like touch screen operation of smartphones and tele-surgery in the medical field [6].

3. Design Concept

Going from the previous examples, we felt tactile sensation is important and promising and decided to research it more in-depth.

First, we discussed haptic actuation and brainstormed several ideas:

- Horror Theater Chair: Chairs with actuators stimulate spectators in tandem to the movie in order to generate scares.
- Human Darts: In this game, you are the target and you can experience darts sticking in your body.
- Breaking Watermelon: Through haptic information, the player is guided to a watermelon in order to break it.

In fact, there have been some applications of haptic technology in navigation fields, like the wearable haptic navigation guidance system [7], also application based on chair [8] .
And in order to bring these ideas to fruition, we considered it to be important to design a device that can stimulate the torso area. We therefore decided that a vest would be an appropriate device for the prototype. The vest's actuators are able to simulate 3 forms of output, which are "time", "strength" and the "mapping" of the actuators. In this research, we focused on the possibility of using haptic stimuli for navigation. This paper discusses the design of the wearable device "haptic vest".

4. Prototype Design

4-1 Material of the Vest

In our research, the important point is to convey direction by the means of vibratory stimulations to the user. We consider that it is important to stick the device to the body as tight as possible when the user wears it. In addition, by taking account of the actuators attached in it, we also consider that it is necessary to prepare a material with an acceptable amount of strength and elasticity. As the best material for these conditions, we chose a wet suit.

The wet suit to be used in seawater is extremely elastic. It fits the body and is a very durable material that has a certain thickness to maintain body temperature. So, it can be easily processed, put on, and taken off, we adopted the "BREAKEROUT _DTSVEST_FZIP", which is a vest type wet suit with a frontal zipper.

4-2 Actuators Arrangement

As the main element in our device, we have to carefully select the actuator. As described in section 2-1, to add three elements to the haptic vest, it is necessary to make patterns of vibrations by using multiple actuators. Therefore, we used small disk-shaped vibration motor (FM34F) manufactured by TPC, seeing Figure 1, which is commonly used in mobile phones and so on, and we attached 60 of those to the vest.

With regard to the arrangement, we placed them in a 12×5 array to the entire torso so each vibrator has equal intervals, seeing Figure 2. By applying this arrangement, we assume that the interpolation effect such as apparent motion and phantom vibration can be obtained. This interpolation effect has been demonstrated experimentally in the research report "Surround Haptics" by Disney Research [10, 11], so additional performance would be expected in our research, as well.

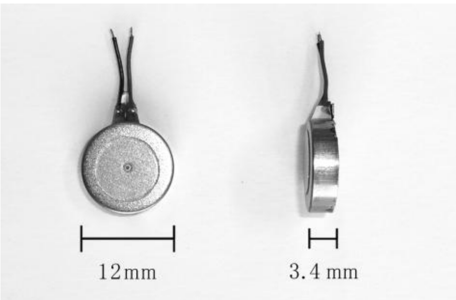


Figure 1 Small disk-shaped vibration motor FM34F

Figure 2 Placed actuators

4-3 Wiring and Implementation

We had to do the wiring to assemble the device. In order to connect each actuator to the vest, we needed a lot of conductive wires. On the other hand, to effectively convey the vibration, anything that could stimulate the body other than the actuators should be eliminated in the inner side of the vest. Therefore, we tried to use the conductive thread as conductive wire. However, the line did not conduct well because the resistance of the conductive thread was much higher than we thought. Therefore, we used conductive wires for all lines. Furthermore, to prevent uneven surface that is caused by overlapping conductive wires, we pull the wires ends of the actuators out of the vest and all wires were arranged on the outside to make it safe; the wires are not directly in contact with the skin.

Earlier we noted a point that the vest is elastic, however the wires are not. We checked on the level of expansion and contraction of the vest when it is worn. We confirmed that vertically fiber has little stretch, but horizontally it has considerable stretch when the user wore the vest. We referenced aforesaid data as well, and made the wiring as shown in the figure 3.

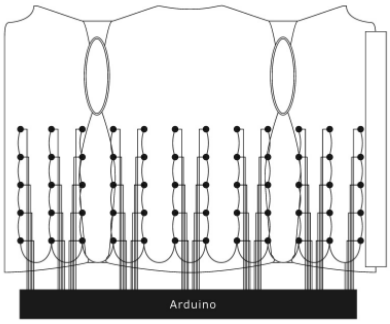


Figure 3 Wiring diagram

4-4 Controller and Operating Procedure

We utilized Arduino Uno as a controller to control all of the vibrations. Furthermore, we implemented the Arduino IDE as the coding environment. Due to Arduino's smooth communication with the processing software "Processing", it has brought about easy development of original applications for controlling hardwares. To make it possible to actuate 60 vibrations by a single Arduino, we arranged 16 connections to the channels of the LED driver which is shown in Figure 4.

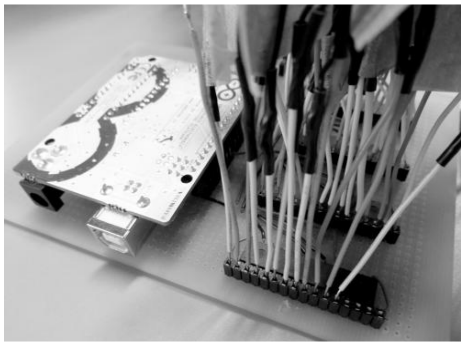


Figure 4 LED driver and Arduino

The interface design to control the actuators is quite simple with only threee basic functions, i.e.: to configure which actuator to control, to control the duration of the vibration, and how many voltage needs to be applied. We use the an array of actuators on the vest as the controller screen to provide an intuitive mental model of how the hardware and software are connected. In addtion, we quantify the degree of voltage in 15 levels and express it by different color intensities. It makes us comprehend the entire posittion and level of voltage of the actuators intuitively, seeing Figure 5.

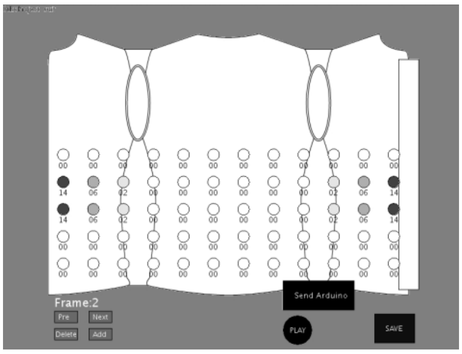


Figure 5 LED driver and Arduino

5. Experiments

Purpose

We made different vibration patterns for users to test how the users feel about the vibrations and what information they can get from feeling the vibrations. We hope to find out the better way to transfer the vibrations into navigation information, and to actualize "symbolization" or "implication" of the haptic information and apply it into future design and works.

Participants

We solicited 4 college students as participants, 1 male and 3 female.

Scene Settings

The participant doesn't know the way to the destination he/she wants to go to. Fortunately he/she wears the haptic vest, which can tell the right direction and right way to go by vibrations. With the help of haptic vest, the participants are able to get to the destination.

Test Process

The participants wear the haptic vest and, while feeling the different vibration sets, answer the questions and write down the feeling. Wearing haptic vest is as Figure 6 shows.

Figure 6 haptic vest

Test Content

We have set 30 different vibration patterns telling which direction to go. These include 7 going frontal (shown in Figure 7), 7 going back (shown in Figure 8), 8 going left (shown in Figure 9), and 8 going right (shown in Figure 10).

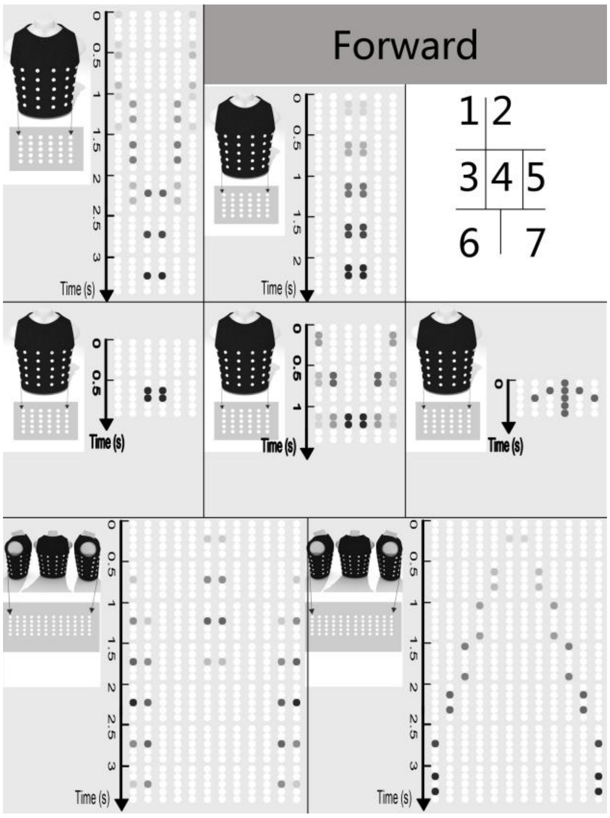


Figure 7 Patterns Going frontal (1~7)

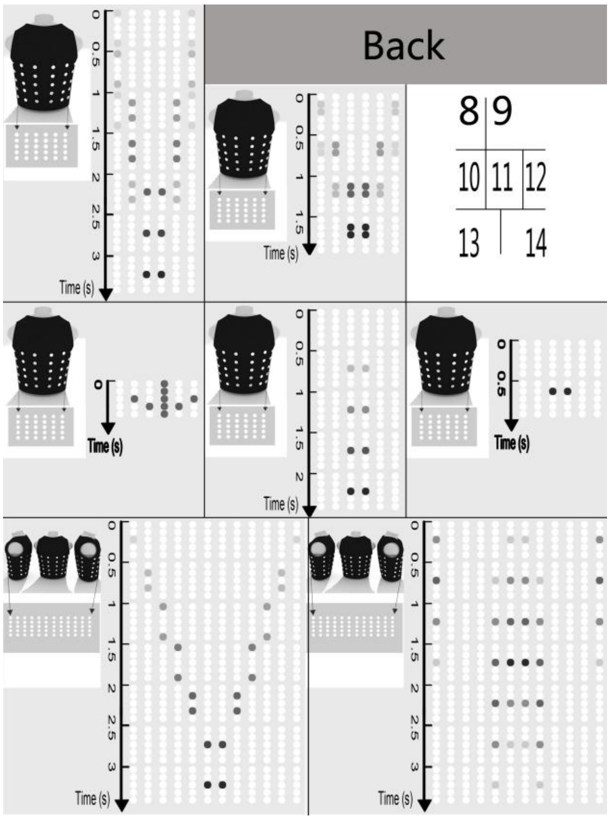


Figure 8 Patterns Going Back (8~14)

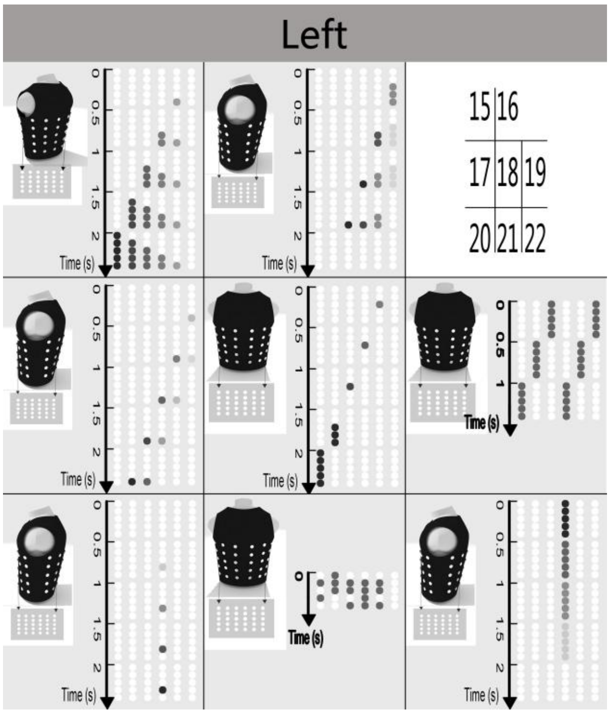


Figure 9 Patterns Going Left (15~22)

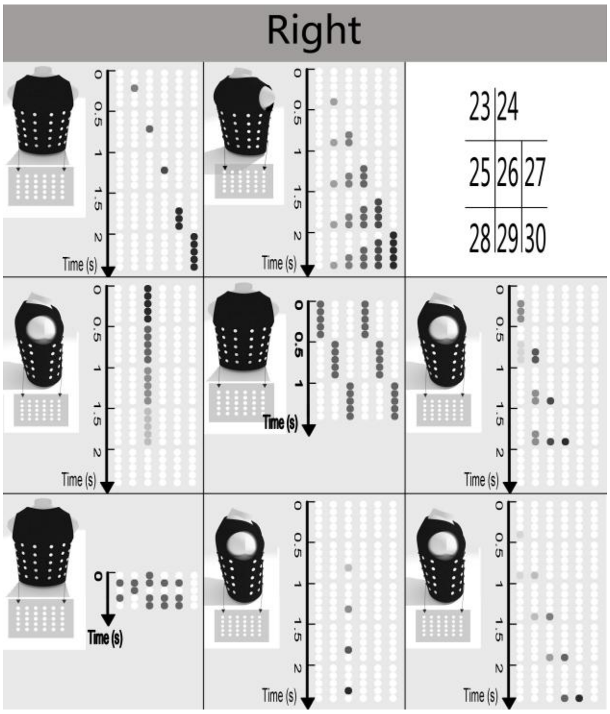


Figure 10 Patterns Going Right (23~30)

In every pattern, we set some actuators to vibrate at the same time or in order, and each of the vibrations has the same or different strength.

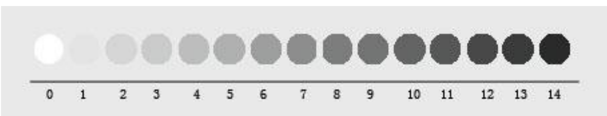


Figure 11 15 Kinds of Strength

The amount of strength is expressed by a value ranging from 0(weak) to 14(strong). Figure 11 shows the 15 kinds of strength expressed by different colors in this paper.

Tasks

While doing the test, the participants need to answer three questions:

a. Which direction does the sample want to convey?

b. Do you think it's easy to understand the meaning? Choose between 1(very difficult) to 5(very easy).

c. Do you feel comfortable while it vibrates? Choose between 1(very uncomfortable) to 5(very comfortable).

Results

We analyzed the results from the aspects based on the three questions mentioned above; the result is shown in Table 1. In Table 1, we show the pattern number, the intended direction of the pattern, the number of participants getting the right answer, the easiness and the comfort level of each pattern.

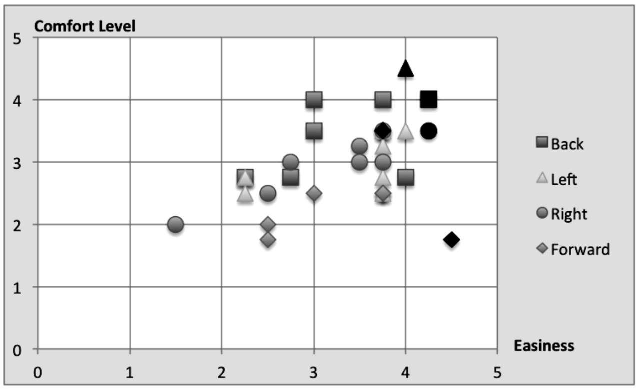
Table1 Results

Pattern	Direction	The number of participants getting right answer	Easiness	Comfort Level
1	Frontal	3	3.75	3.5
2	Frontal	2	2.5	1.75
3	Frontal	3	3.75	2.5
4	Frontal	4	4.5	1.75
5	Frontal	4	3.75	2.5
6	Frontal	4	2.5	2
7	Frontal	4	3	2.5
8	Back	4	3	4
9	Back	4	4.25	4
10	Back	3	2.75	2.75
11	Back	3	3	3.5
12	Back	2	3.75	4
13	Back	4	4	2.75
14	Back	3	2.25	2.75
15	Left	4	3.75	2.75
16	Left	4	4	3.5
17	Left	4	3.75	3.5
18	Left	4	3.75	3.25
19	Left	2	2.25	2.75
20	Left	4	4	4.5
21	Left	2	2.25	2.5
22	Left	4	3.75	2.5
23	Right	4	3.5	3
24	Right	4	3.75	3
25	Right	4	4.25	3.5
26	Right	2	1.5	2
27	Right	4	3.5	3.25
28	Right	1	2.75	3
29	Right	4	3.75	3.5
30	Right	2	2.5	2.5

Discussion

The result using graph type in Table 2 shows the best pattern in each group (i.e. going frontal, going back, going left and going right), which are highlighted in table 1.

Table 2 The Analysis of Total Data



a. Frontal and Back

Depending on the level of easiness, the best vibration pattern of the group "going frontal" is pattern 4. However, while depending on the level of comfort, the best pattern of the group "going frontal" is pattern 1. Among the group going frontal, pattern 1 and pattern 4 have similar order, strength and moving actuators. The best vibration pattern of the group "going back" is pattern 9, which also almost the same. Both pattern 4 and pattern 9 change from weak to strong and have two rows of actuators vibrating at the same time. Also, in these patterns, the moving actuators are only in the front or in the back of the vest.

We also set three other types in the two groups. One has all the set actuators moving at the same time, at different strengths. The second type also has the actuators moving at the same time, but their strength remains constant. The last type has both the actuators in the front and the back moving in the same pattern. We found that type 1, 4 and 9, having a better user experience.

However, from Table 1 we can see that pattern 4 is especially difficult to understand. Also taking into account the comments of the users, it's difficult to understand the going frontal information, and some of the uses even think it means to stop. In turns out it's really hard to distinguish between them. Especially, regarding the pattern "going frontal", we need more research and testing.

b. Left and Right

The best vibration pattern of the group going left is pattern 20, while the best vibration pattern of the group going right is pattern 25.

Among the groups left and right, the following types employ similar patterns; pattern 15 and pattern 24, pattern 16 and pattern 27, pattern 17 and pattern 30, pattern 18 and pattern 23, pattern 19 and pattern 26, pattern 20 and pattern 29, pattern 21 and pattern 28, pattern 22 and pattern 25. Among all the patterns, we set one type in which all the moving actuators were moving in order at different strengths. Another type has the actuators moving at the same time, while their strength remains constant.

However, according to Table 1, regarding the pattern with the best user experience, we get different results. Comparing the two types, we can see the right one is much easier to be understood, while the left one has a higher comfort level. The differences between them is that the left one has only one actuator vibrating, while the right one has an array of five actuators vibrating at the same time. One other difference is that the actuator's strength of the left one changes from weak to strong, while the actuators' strength of the right one changes from strong to weak.

From the patterns analyzed before, we can see that the changing of the vibration's strength is a very important and useful method to give out direction information as a navigation system using actuators.

Furthermore, there are some differences between indicating different directions. The left direction and right direction can use the same vibration type, while the frontal and back directions have to use different vibration types. Especially, when designing the vibration type of going frontal, it's important to pay attention to the differences between stopping and going frontal.

Also, as the users commented, the different parts of the body experience the vibrations in different ways. For example, when given the same strength of vibration, the frontal one is experienced to be weaker. Therefore, the easier the vibration type is, the easier it is to be understood. In this aspect, there is a further need for testing the vest's user experience, rather than relying on theory.

5-2 User Testing on Vibrotactile Navigation

Based on the results of experiment 5-1, we continued the research with experiment 5-2,testing the vibrotactile navigation.

Purpose

・make sure if it is possible to navigate people using only vibrotactile stimuli through the haptic vest.
・measure how precise it can navigate.
・analyze if we can convey haptic information correctly.

Participants

All of the Participants are 21 or 22 years old and healthy university students (two males and one female.)

Environment

At first, we prepared a field like Figure 12 and 13 with the following conditions;
・a 50m by 50m space.
・put 10x10 markers 5 meters apart.
・markers' role: to mark routes and corners.

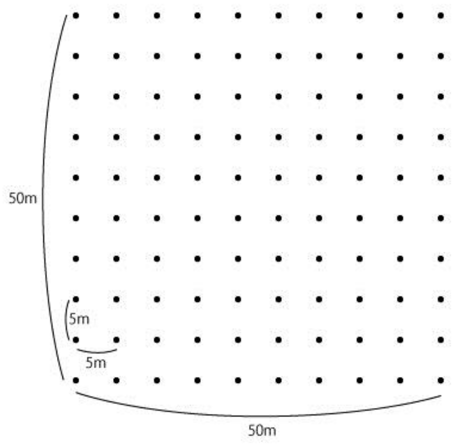


Figure12: “Setting the field”

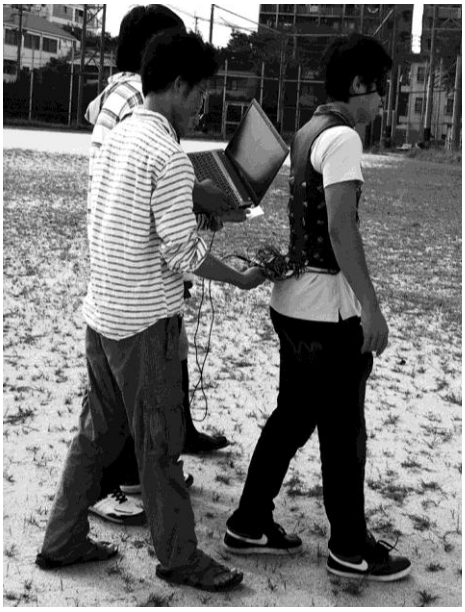


Figure 13: Scene of the experiment

In the future, we’ll extend the experiment to a larger field than that of the preliminary experiment and we aim to test the device in the streets.

Furthermore, we also set up two cases: one using a blindfold and one without. In the latter case, we made sure of the usability for blind people by using the following method.

Setting the route

Next, we set the routes on the field. Subjects wore the haptic vest and walked along the routes following vibration patterns sent by the vest. We analyzed whether users can correctly understand directional patterns and walk according to those. Furthermore, we measured how precise our navigation system using vibration patterns is able to lead users.

Then, we set up two routes like Figure 14. In route 1, users walked without a blindfold. Its course, consisting out of the directions right, left, right, left, right respectively, consists out of five turning points and the total distance is 55m. In route 2, by making users put on a blindfold, we tested the haptic vest’s validity for visually handicapped people. Route 2’s course is left, right, right, left respectively, consisting out of four turning points and the total distance is 50m.

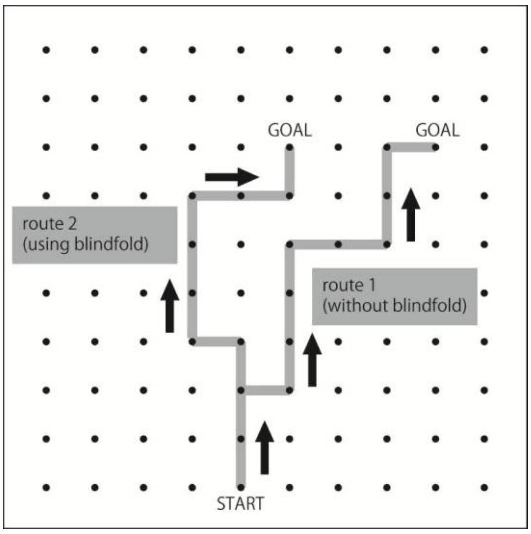


Figure14: “Setting navigation routes”

Directional vibration patterns

We sent users the four vibration patterns (frontal, back, left and right) and indicated directions by the result of experiment 5-1.

Each vibration pattern is as follows:

・Frontal (pattern 4, as we think the easiness of a pattern is important than the Comfort Level, so we choose pattern 4 to do the next experiment, instead of pattern 1)

Vibrations given by the actuators are moving from the underarm to the chest area and its power becomes stronger over time. By repeating this motion, the haptic vest gives users the illusion as if they were pulled forward.

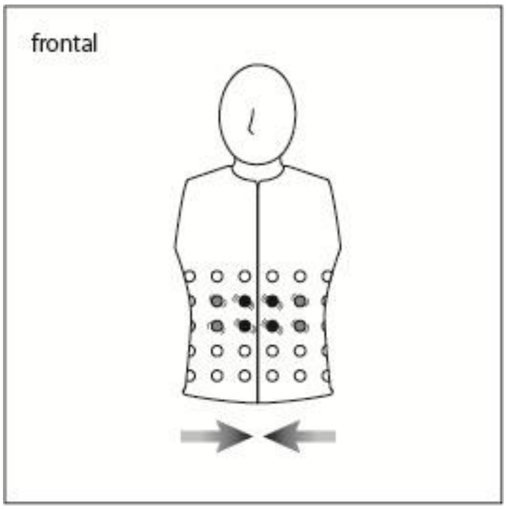


Figure15: “Frontal vibration”

・Back (pattern 9)

As opposed to the ‘frontal’ pattern, the vibrations are moving from the underarm to the back area. Its power becomes stronger over time and this motion is continuously repeated. By this, users will feel as if they were pulled backward.

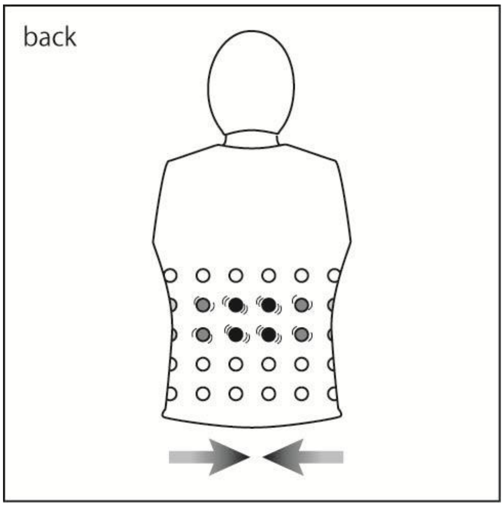


Figure16: "Back vibration"

・Left (Based on the result of experiment 5-1, the best pattern of group going left and going right is pattern 20 and pattern 25, and based on the two patterns we made new patterns to do the next experiment as follows)
Actuators vibrate below the stomach area in the left, becoming weaker over time. The pattern itself remains static and continues repeatedly.

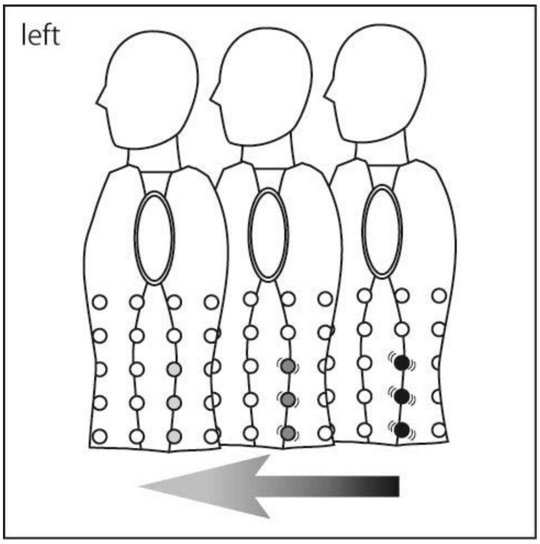


Figure17: "Left vibration"

・Right
As opposed to the 'left' pattern, actuators vibrate below the stomach in the right, becoming weaker over time. Just like the 'left' pattern, it remains static and repeats continuously.

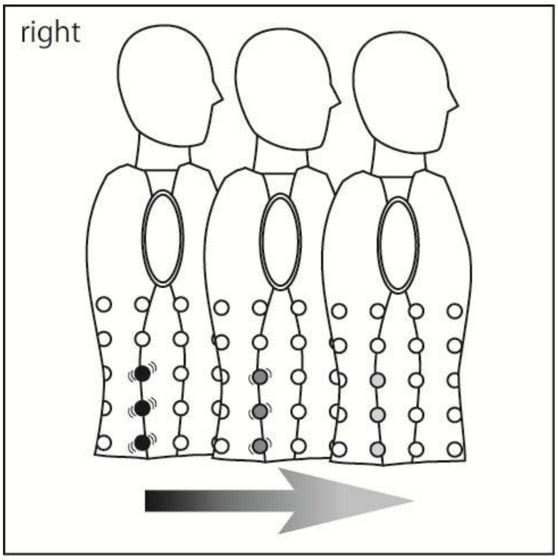


Figure18: "Right vibration"

Furthermore, while users are going straight on a straight route, we continuously send them the 'frontal' vibration pattern through the haptic vest. If they need to turn a corner, it sends them the 'left' or 'right' vibration pattern until users finish turning. We gave them the information of which way to go, by controlling Arduino and Processing manually. In addition, if users go the wrong way, we corrected them without telling them anything. In order to do this, we would send the correct directional vibration each time and lead them to the goal. Through the means described above, we investigated the accuracy of this navigation method, the rate of users' misunderstanding and the difference from visual or auditory navigation in the 50m by 50m field.

Test Process
Before starting this experiment, we explained two things to the users; the navigation is only through vibrotactile feedback and corners are marked through markers. First we made them take route 1. After that, we had users put on the blindfold and made them take route 2. In either route, we didn't teach them which direction the vibration pattern stood for, for the purpose of investigating whether they can correctly understand the meaning of the vibration pattern.

Results and Discussion
Figure 19 is a result of the non-blindfold navigation, where the users could see the markers on the field. A heavy gray line is the set route, other lines are the paths traced by the three subjects. In this route, no one needed to be corrected due to stray off the set route. We concluded that all of the users understood the meaning of the directional stimulation by vibration correctly. As shown in Figure 19, users sometimes slightly went off-route. This is caused by a time lag on the data sent between Processing and Arduino or a response time of users recognizing the directional vibration patterns. These problems can be solved by sending vibration patterns earlier. In conclusions, we found that the navigation system using the

haptic vest can guide users accurately enough under these conditions.

Figure 20 is a result of navigating using a blindfold. Users walked depending only on vibrotactile feedback from the haptic vest. Like in figure 8, the set route is marked by a thick gray line, whereas the users' routes are marked with the other lines. In route 2, due to the blindfold, users sometimes went off-course. It was difficult for users to go straight or make angled turns with the blindfold. Though, through correcting their course each and every time, they could arrive at the goal easily. According this experiment, even if the vision is shut off, through vibrotactile feedback people were able to navigate correctly. Moreover, we confirmed the effectiveness of the haptic vest when used with visually impaired users.

Through a survey, users mentioned that arriving at the goal was not difficult. They commented they can use the haptic vest to pay attention to other visual or auditory information.

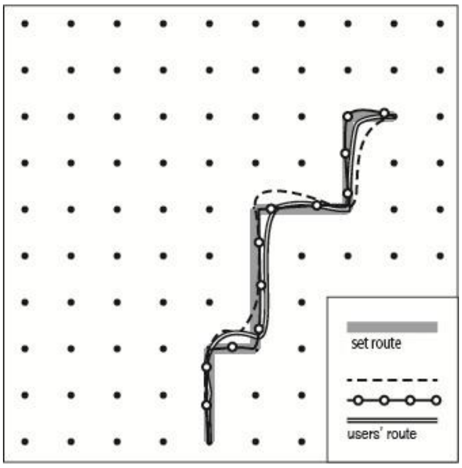


Figure19: "Result of route 1"

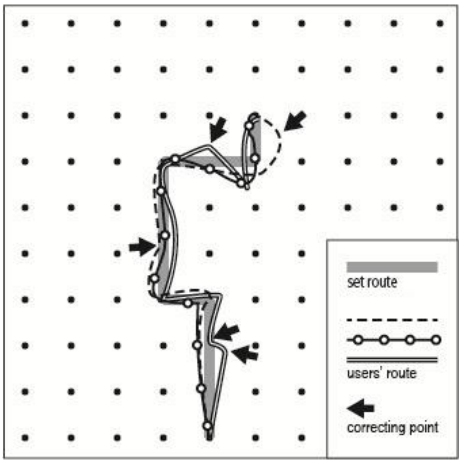


Figure20: "Result of route 2 with a blindfold"

6. Evaluation

Based on the two experiments, we can see that the tactile information by the haptic vest is useful as a navigation system and it succeeded to convey the vibrotactile information to users effectively. It shows the possibility of "symbolization" and "implication" of haptic information, which was our initial goal.

At the same time, there are also many problems need to been solved. As in experiment 5-1, based on the 30 patterns we've made and the user's comments and experience in the experiment, we'd like to improve new patterns to try to get better user experience. And also we will invite more subjects to take part in the experiment in order to get better results. And then get the best patterns of each group to apply them into experiment 5-2. And in experiment 5-2, we'll experiment in larger fields or streets and improve the precision of the navigation system, not only will it be possible to have hands-free navigation and invite more subjects. We'll also think about to convey the directional information more accurately.

7. Future Works

Next, we aim to do more user testing to make the research more in-depth. Also, in order to apply it better into various fields, we are surviving to add GPS mode and wireless mode into this system. Furthermore, we aim to apply this technology to other products as well, rather than just the vest. And in the future, we hope this system can be applied into many fields, such as game design, products for disability people, and also navigation system.

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