Vibrotactile Exploration of Indoor Objects

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Abstract

This paper describes our study about how to make use of a tactile belt with 8 vibrators to present rich spatial information for blind and visually impaired people while exploring indoor environments. In order to conduct a Wizard-of-Oz evaluation with 12 sighted subjects, a tablet based application has been developed for setting indoor scenarios and exploration interaction. Two sets of tactile patterns for presentation of distance, direction and type of objects, have been evaluated based on one single actuator and multiple actuators, respectively. The results indicated that the subjects can acquire the rich object information through both of the two sets, and they were more sensitive on the vibration position than the vibration intensity.

Categories and Subject Descriptors

H 5.2 [User Interfaces]: Haptic I/O
K 4.2 [Social Issues]: Assistive technology for people with disabilities

General Terms

Design, Human Factors.

Keywords

Tactile Belt, Tacton, Indoor Exploration Tasks

1. Introduction

The tactile pin-matrix displays offer novel experiences for blind and visually impaired people to explore maps [1] and the surrounding obstacles [2], however, due to the cost expensively a large size of such display is not affordable for most of blind and visually impaired people. To support blind and visually impaired people to acquire simple spatial information, like navigation instructions, many low-cost vibrotactile displays has already been taken into account in several researches [3, 4, 5, 6]. People are able to perceive tactile stimulation changes and identify the location of them. As one of essential advantages for visually impaired people, tactile displays can represent the direction information quickly and intuitively, without disturbing visual and auditory perception. However, there are a few previous work focusing on presenting more complex spatial information through tactile vibrators, like various types of surrounding objects. Heuten et al. concluded a tactile display with vibrators worn as a belt is the most promising regarding to users' acceptance and perception [5]. Therefore in this preliminary study a tactile waist belt has been used as well.

The main aim of this work is how to support visually impaired people for exploration tasks within rooms or buildings by using a vibrotactile belt, and how to acquire object information via tactile patterns. The study focused on four types of common indoor objects: walls, doors, stairs and general obstacles. Additionally, a normal tablet based application has been developed to set a room layout and play corresponding tactile patterns conveniently. An evaluation with 12 sighted subjects in a Wizard-of-Oz (WoZ) study has been conducted. In the future, the tablet application should consider how to improve its accessibility and support blind and visually impaired people exploration by touching, rather than in a WoZ study.

2. Related Work

There have been many navigation aids with tactile feedback. In recent years, various approaches have been implemented and discussed. For example, a number of previous systems make use of a smartphone to offer tactile feedback, like PocketNavigator [7, 8], NaviRadar [9], Lund Time Machine [10] and NonVisNavi [11].

In order to provide richer tactile information, some systems employed multiple vibrators, such as a tactile vest and a tactile belt. The researchers in [3, 4] equipped a belt with 8 actuators, and the system proposed in [5] uses not only 6 actuators, but also activate two at the same time with different vibration intensities to interpolate a direction between them. Most of the related work focuses on presenting navigation instructions, like turning left or right in specific angles, however, there is a few studies focusing on presenting rich information of surrounding objects, except the study in [4] to recognition of landmarks. There are a few previous work which made use of a touch screen device and tactile vibrators to present spatial information about surrounding objects.

To display complex information by vibrators, the concept of *Tactons* has been introduced by Brewster *et al.*:

"*Tactons are structured, abstract messages that can be used to communicate complex concepts to users non-visually.*" [12]

Several design principles were presented in their work, especially the concept of "*Transformational Tactons*" which inspired this work. There, each property is assigned to its own parameter. As an example of this design principle, a 3-parameter has been used to notice users about upcoming appointment information [13].

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Figure 1. The tactile belt was built with 8 actuators. Each covers a range of 45° of the body of the user and is equipped with a LED to visualize the vibrations.

The presentation of highly complex properties is a challenge in the design of Tactons. There must be found a parameter with many distinguishable levels. Not every parameter is suitable for this. The researchers in [14] investigated the distinguishability of rhythms. As a result of their research, they've presented a set of 21 rhythms, which could be distinguished by fingers. Besides, the tests with a tactile belt in [6] indicated seven different rhythms were suitable for recognition tasks with a vibrotactile waist belt.

3. A Multi-vibrator Tactile Belt

In this work, a tactile waist belt from the company Elitac is used (see Figure 1). The detailed technical specifications can be found on their website[1]. The belt can be controlled by a host device (e.g. a smartphone or a tablet) via Bluetooth. The movements of the vibrators are transmitted by the corresponding haptic patterns that are previously defined in a XML-based file, and are saved on the host device. This format of haptic patterns allows to configure start time, intensity, duration and location of a vibration. For example, Figure 2 illustrates how to make one vibrator vibrated two times at 0 millisecond and 500 millisecond respectively.

The tactile waist belt is equipped with eight actuators, and each covers a range of 45° of the body of the user (see Figure 1). This configuration already has been used successfully in several prototypes and is valid for managing navigation [3, 4] and exploration tasks [6].

The tactile belt offers the developers various parameters. With their help information can be transmit to the wearer of the belt. The following parameters are available:

Position The 8 actuators are attached around the body of the subject in a horizontal plane. Each actuator occupies a fixed position, which can be linked to specific information. From the perspective of tactile perception 36 actuators on the belt are possible, corresponding to a resolution of 10 ° in the horizontal plane [4]. But the aim should always be to use actuators as little as necessary [5], in order not to inform users with so much unnecessary information.

```
<ArrayOfAction>
  <Action> <!-- first vibration -->
    <Time>0</Time> <!-- starting time -->
    <Address>1</Address> <!-- actuator number -->
    <!-- vibration intensity (0-15) -->
    <Intensity>11</Intensity>
    <!-- vibration duration in ms -->
    <Duration>250</Duration>
  </Action>
  <Action> <!-- second vibration -->
    <Time>500</Time>
    <Address>1</Address>
    <Intensity>11</Intensity>
    <Duration>250</Duration>
  </Action>
</ArrayOfAction>
```

Figure 2. An example of a XML-based description format for haptic patterns. In this case actuator 1 is activated twice for 250ms with an intensity of 11 (maximum is 15).

Rhythm Rhythms are generated by grouping vibrations with different durations and different intervals [13]. To create or manipulate a rhythm it is necessary to change the length or the number of the vibration pulses or the breaks between them [14]. From the perspective of perception, it is possible to design many different rhythms. But it should be noted that users make the more mistakes when distinguishing the more number of rhythms than less number of rhythms. Moreover, it is assumed that the frustration level increases significantly with a large number of different rhythms, since user have to operate a long learning curve to learn the rhythms.

Intensity By changing the amplitude of the sine wave different vibration levels can be generated. In [16] it is reported that intensities about 26 dB can be distinguished worse than ones with lower intensity values. Normally, the intensity value over 55 dB can cause pains to users [17]. To ensure the distinguishability of different intensities, not more than 4 stages should be used [7].

4. Designing Tactons for Exploration Tasks

An indoor assisted system with a room exploration functionality should allow visually impaired users to acquire rich spatial information of surrounded environments. In this study, three attributes of surrounded objects are presented:

- Type: Which object it is?
- Direction: In which direction the object is?
- Distance: How far away the object is located?

To convey such complex spatial information through haptic feedback, the design principles of the "*Transformational Tactons*" [12] have been employed adaptively. In this study each of the three object properties is encoded with its own parameter.

In the following, the mapping strategy between the object properties and the Tacton parameters is discussed separately.

4.1 Direction

The Tacton parameter for coding the direction is not difficult. The tactile belt is equipped with eight evenly distributed actuators, which are quite intuitively associated with a direction for users. This method was tested successfully by several researches. Thus,

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[1] http://elitac.nl/products/sciencesuit.html [28.08.2014]

the 8 vibrator position can simply indicate 8 different directions. It's true that the parameter level of direction could theoretically be increased to 36 levels [6] by adding additional actuators.

4.2 Distance

In previous studies, the frequency and the intensity were used for presenting distance information. At present, our belt does not provide the ability to change the frequency of a single vibration. Therefore we made use of the intensity to encode distance information. Theoretically, for a common vibrator 15 different intensities can be presented. But the preliminary tests and research work have shown that differences in intensity can be very poorly perceived. Therefore in our study the distance is encoded only with two levels: "near" (all objects with a distance less than two meters) and "far" (all objects with a distance more or equal than two meters).

4.3 Object type

In general there are various objects in rooms and buildings, but the focus of this work was on the four important ones for visually impaired people: walls, stairs, doors and obstacles. Thus, the parameter should cover at least four distinguishable stages for the 4 target types. In order to convey information about object types for users, two different haptic feedback based methods have been employed: a single actuator method and multiple actuator method.

4.3.1 Single-Actuator-Method

In the single-actuator method the tactile patterns are encoded via different rhythms on a single actuator. Four distinguishable rhythms were selected for this work, as shown in Figure 3. The grey areas represent vibration pulses, and the white fields show the vibration breaks. A rhythm takes a second and for a better recognition it is always played twice. As a basic metric, the 1/16 pulse is the shortest one and has a length of 62.5ms, and each pulse should be followed by a pause of at least 125ms, except the 1/16 pulse, where it is followed by a pause of at least 62,5ms. It is also possible to add additional object types in the future.

With the single-actuator method the characterizing rhythm is played on the pioneering actuator with the corresponding intensity. Therefore, in contrast to [6] all parameters are displayed simultaneously. This approach reduces the run time of the Tactons significantly and thus speed up the transmission of the information.

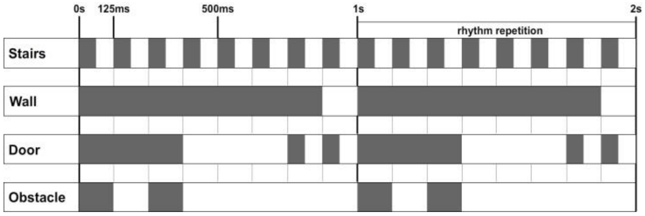


Figure 3. The different rhythms of the Single-Actuator-Method. The grey areas indicates the vibration, the white ones the breaks.

4.3.2 Multi-Actuator-Method

Within the multi-actuator-method actuators were always activated in pairs to indicate various types of objects. In the evaluation of [6], the method achieved even better recognition rate than the single-actuator-method if at the same time the direction was displayed. From the seven tested actuators pairs, the pairs 2-4, 2-8, 4-6 and 6-8 were selected for this work (see Figure 4), because they can be associated with directions (front, back, right, left) and thus may be easier to be learnt than the other ones. Within the vibrator pairs, the vibrator with a smaller serial number is the "pioneering" actuator. On both actuators the same rhythm was played: 12 repetitions of a 50ms pulse, followed by a 50ms vibration break. The Tacton had to be played in two successive phases, because the position parameter was assigned twice (for the direction and the type). The first phase showed users the direction. This pulse always had the same (median) intensity. After a gap of two seconds a weaker or stronger pulse (compared to the direction pulse) was played on a pair of actuators depending on the distance.

For a belt with eight actuators there are 12 pairs with a recognition rate of at least 80% [6]. Therefore, this method is well suited for encoding other objects in the future.

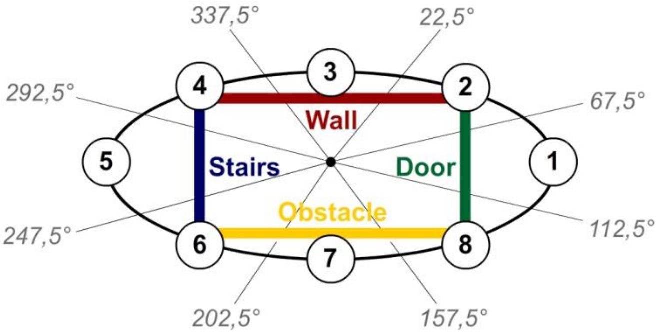


Figure 4. The different actuator pairs of the Multi-Actuator-Method, and always two actuators are activated simultaneously to indicate an object type.

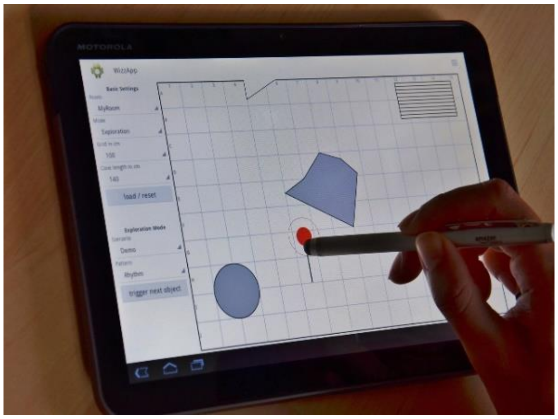
5 The Pilot Evaluation

To evaluate the designed Tactons we've developed a specific App, named WizzApp. 12 sighted subjects had been recruited for this evaluation.

5.1 "WizzApp": A Tablet Application

To evaluate the tactile patterns a simulation application for Android Tablets, called "WizzApp", has been developed (see Figure 5). The App was implemented on a Motorola Xoom tablet with a 10.1 inch display and the Android OS. In addition to setting the room size, it also allows set the layout of the objects. The App is able to provide virtual spatial information to subjects while walking and exploring the environments. In this study, we only used the Exploration Mode to test the proposed tactile patterns, and the position and the orientation of the subject were simulated by continuously touch input by a "Wizard".

To support a Wizard conveniently and precisely to simulate subjects' movements (i.e., position and heading direction), we developed a special touch interaction method, see Figure 6. In the App, it was easy to configure the test room with different types of objects, and the position and the heading direction of the subject was represented by a red point and a black line, respectively. When touching on the red point, an outer orientation ring is rendered. The Wizard can change the orientation by moving his finger around the user circle, but within the orientation ring. The Wizard also can simulate subjects' walking paths by moving the



Room
MyRoom
Mode
Exploration
Grid in cm
100
Line length in cm
140
Scenario
Demo
Pattern
Rhythm

Figure 5. The screenshot of the "WizzApp" on a tablet (the red point is the subjects' position, and the black line from the red point indicates the subjects' heading orientation.

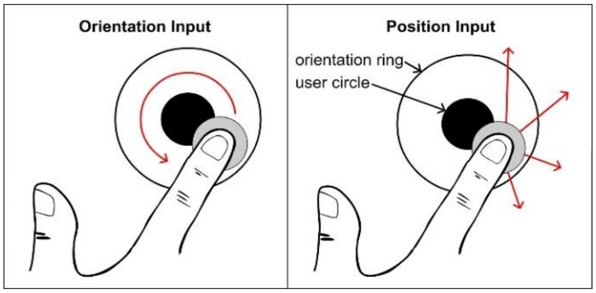


Figure 6. The touch interaction to simulate users' heading orientation and position

finger easily, like in the Walking Mode. With a double-tap on any object, the App sends the corresponding tactile patterns to the tactile belt, by calculating the direction and the distance of this object to users automatically.

Two rooms were simulated and each one had 12 or 13 objects from the four types (see Figure 7). The position and orientation of the subjects was the same and was fixed in each test. Additionally, the order of displaying the objects was fixed. Thus, all subjects had the same conditions.

5.2 Procedure

The test was performed with six male and six female individuals. Two subjects were 58 years old, the others were around 23 to 30 years old. Every subject tested the two sets of Tactons. The two rooms were tested in the same order for all subjects, but the order of the two sets of Tactons were different. Regarding to the test order, six subjects tested the single-actuator-method firstly, and the other six ones tested the multi-actuator-method firstly.

Each subject at first received a brief introduction to their tasks and the Tactons. Subsequently, a training phase was followed to learn the Tactons in a training setting. The real test didn't start until the subjects claimed they had learnt all. In real tests all objects were displayed one by one, triggered in the WizzApp by a Wizard. Note that, the subjects did not allow to watch the screen at any time during the test. The subjects were asked to loudly speak out the object type, the direction (i.e., eight cardinal directions) and the distance immediately once they recognized. The accuracy of these statements and the recognition time were noted. The subjects had to evaluate the two methods in the two test rooms accordingly, and the test arrangement was counterbalanced. In the end, the subjects had to fill in a questionnaire:

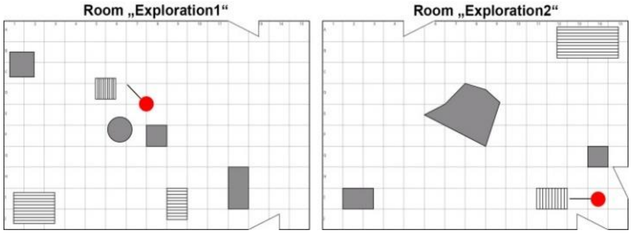


Figure 7. Two room simulations layouts for the evaluation of the designed Tactons

- Which method was easier to learn? Why?
- If you have to choose a method, which one would you choose? Why?

5.3 Results

The comparison of the results between the single-actuator-method and the multi-actuator-method is shown in Table 1. The two methods have achieved similar results for encoding the direction and the distance. The object type was detected better with the multi-actuator-method, as well as a better recognition performance of the whole Tacton[2]. For the two methods the direction and the object type have a very high recognition accuracy (more than 94%), while the recognition accuracy of the distance was less than identifying the object type. However, the overall recognition accuracy of the Tactons dropped to 78% for the single-actuator-method and 81% for the multi-actuator-method, responsively. Besides, the subjects spent 437ms and 634ms averagely to recognize one Tacton, accordingly.

Table 1. Average recognition rates of the designed tactile pattern.

Method	Property	Recognition accuracy
Single-Actuator	Type	94,67%
	Direction	97,33%
	Distance	85,33%
	Whole Tacton	78,00%
Multi-Actuator	Type	98,67%
	Direction	97,33%
	Distance	86,00%
	Whole Tacton	81,33%

The two-way MANOVA (at the 95% confidence level) revealed only the two methods had significant multivariate main effect for the recognition accuracy of object type, direction, distance, the whole Tacton and spending time, Wilks' $\lambda = 0.369$, $F(5, 16) = 5.47$, $p = 0.04$. Furthermore, the univariate ANOVA tests (at the 95% confidence level) only found the two methods had main

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[2] When all of the 3 attributes (i.e., type, direction, and distance) of one object were identified correctly, we countered the Tacton was recognized successfully.

effect for the spending time (F(1, 20) = 24.804, $p < 0.001$, and the interaction between the two methods and the test rooms had main effect for the recognition accuracy of a whole Tacton (F(1, 20) = 4.634, p = 0.044. The paired T-test (at the 95% confidence level) found the mean accuracy of distance recognition had significant differences to the mean accuracy of direction recognition (t = 4.252, $p < 0.001$) and the mean accuracy of type recognition (t = 4.684, $p < 0.001$) both.

The analysis of the questionnaires showed that, on one hand the multi-actuator-method was easier to learn for 7 of 12 subjects, because they felt "less complex", "easier perceptive", "shorter learning time", or "good spatial imagination"; on the other hand, there were still 7 subjects who chose for the single-actuator-method, because they thought the Tacton were "shorter", "more intuitive", "more memorable" and "more practicable".

5.4 Discussion

From the evaluation, it found the subjects were more sensitive to the position of vibrations (e.g. for presentation of direction and object type), than the intensity feature (e.g. for presentation of distance). It seems to be hard to distinguish the intensity of vibration because of users' clothes with different texture or fixing the belt with different strength. In order to inform users the distance information, a set of extra vibrators can be placed vertically on other body part, like on the arm, and the closer vibration means closer objects. Additionally, it might be also possible to change the vibration frequency for indicating the distance information.

In this study, due to only 4 different object types involved, the subjects spent more or less equal time to learn the tactile patterns. When more object types are involved, we expect users have to spend more time for learning the single-actuator method than the multi-actuator method, and we need to further tests to confirm that.

Due to lack of tactile feedback, blind and visually impaired people is hard to access spatial information (e.g., maps, layout of the surroundings) through common touchscreen devices. On one hand, many new displays, like the pin-matrix display and the under-developing BlindPad[3] system, have been used to improve the accessibility of spatial information. On the other hand, we think the vibrotactile feedback might be a low-cost solution to reach the goal by combining touchscreen displays. Specifically, the vibrotactile feedback also can be used while walking. Although in this evaluation we let a Wizard touch the display to trigger and simulate an exploration task of indoor objects, we think it is possible to allow blind and visually impaired people to explore by themselves after a few improvement of the WizzApp, like importing semantic sounds. Moreover, there should be no a large delay of vibrations when exploring on the touchscreen displays, otherwise, users might make mistakes to understand the position and direction information of objects.

6 Conclusion

For blind and visually impaired people, it is challenging to acquire spatial information of surrounding environments, like how many objects in front of them, as well as their properties. In this paper we presented how to make use of a tactile belt with 8 vibrators to convey spatial information of indoor objects (i.e., walls, stairs, doors and general obstacles) by pre-designed tactile patterns. In addition to rendering distance and direction information, we studied two different methods to inform users about object type information via a single actuator and multiple actuators, respectably.

Through a pilot WoZ evaluation with 12 sighted people, we found the subjects were able to acquire the spatial information of surrounding objects by both of the two methods. The subjects had more sensitive on the vibration position than the vibration intensity. Additionally, a tablet based application has been implemented to support the evaluation, for setting the room layout and exploring objects one by one.

In the future, in addition to evaluating the tactile patterns with blind and visually impaired individuals, it's important to evaluate the exploration task by blind and visually impaired people directly, rather than simulating the exploration behaviours by a sighted Wizard.

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