What's Around Me? Multi-Actuator Haptic Feedback on the Wrist

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Abstract

We present the design, implementation and evaluation of a novel wrist-based vibrotactile multi-actuator bracelet, based on a co-planar circular configuration of actuators, for the provision of intuitive and informative haptic feedback for navigation tasks. A two-phase evaluation was conducted in order to assess the perception of the vibrotactile feedback provided by the bracelet and in particular, the ability of users to discriminate a range of vibrotactile patterns. First, a pilot study designed to test perception of different kinds of pattern was conducted with the aim of both refining the pattern design and aiding the choice of a discriminable set of patterns. Second, an identification experiment with the previously chosen set of patterns was conducted with the aim of conveying navigational directions and points of interest to the user. Results highlighted the difficulties in identifying the number of activated actuators as well as their position on the wrist, which subsequently had an impact on the pattern recognition. It was found that one-way horizontal and vertical movements were difficult to perceive correctly, however, less specific movements such as circular or alternating lateral movements and rhythm proved to be suitable parameters for the perception of patterns as long as the patterns were not too similar in design.

Index Terms: H.5.2 [Information Interfaces and Presentation (e.g., HCI) (I.7)]: User Interfaces (D.2.2, H.1.2, I.3.6)—Haptic I/O, Evaluation/methodology

1 Introduction

Eyes-free interaction has become increasingly relevant as the computer has moved off of the desktop and out into the mobile world, where user's vision is often overloaded. Navigation systems have traditionally tended to rely on the user's visual and aural attention to provide navigation cues and little has been produced in the commercial world in terms of vibration or haptic feedback designed to provide navigational information. The highly variable context of mobile device use means that the visual sense and more often than not, the audio sense, are required for more safety critical tasks such as avoiding obstacles. This applies equally to both indoor and outdoor navigation. In outdoor situations where it is desirable for the user to pay more attention to their environment, such as crossing the street or navigation in a tourist location, the use of subtle tactile cues that are able to communicate appropriate navigational information are likely to be beneficial both in terms of safety and general user experience of the world around them. Similarly, for indoor navigation, i.e. in large buildings, museums, train stations or other public spaces where visual or aural cues may not be appropriate or socially acceptable, the use of tactile navigation cues could prove to be beneficial.

With these concerns in mind, we have developed a novel wearable vibrotactile bracelet that mimicks a common wristwatch. It delivers tactile cues on the top of the wrist through six electromagnetic actuators arranged in a compass-like circle. The wristband form was chosen for two main reasons: 1) its familiarity and social acceptability to the user, and 2) the possibility it creates for the design of both eyes-free and hands-free interaction. We present the details of its novel design and implementation, as well as the results of an evaluation of the perception of patterns designed to provide users of an indoor navigation system with passive tactile indications of directions and points of interest.

2 Related Work

2.1 Existing Tactile Systems For Navigation

The use of tactile feedback has been widely investigated for the transmission of information, in particular for navigation. This has resulted in a number of systems including tactile vests [4, 17, 9, 7], suits [6, 15, 9], seats [20], belts [6, 21, 9, 19, 5], shoes [22] and embedded feedback from mobile phones [13] developed for different uses, such as aiding the navigation of blind and visually impaired users [4], general pedestrian navigation [7, 19, 5, 12, 13], helicopter landing [6], flying [15, 21] or driving [20, 21]. These systems mostly encoded (cardinal or exact) directions [4, 21, 7, 22, 19, 5, 12, 13], quantitative information, such as altitude and groundspeed [6, 15] or distance [20, 21] and sometimes qualitative messages such as emotions [22] or actions [7]. However, except for Srikulwong and O'Neill work on conveying landmarks with a tactile belt [16], little research has been conducted on providing qualitative messages on points of interest.

The transmission of tactile information is often successful, even when used alone, and has been shown to not only improve efficiency and safety but also to reduce distraction from the surrounding environment [13]. In their large-scale in-situ study of tactile feedback for pedestrian navigation systems [13], users interacted significantly less with the touch screen, looked less often at the display, and turned off the screen more often. However, a number of authors have reported comfort issues with their prototypes [15, 5]. In this respect, a discrete and light wrist-based tactile display could, we believe, provide a more comfortable and yet just as effective alternative.

2.2 Wrist-Based Tactile Systems

The use of the wrist as a location for haptic feedback has rarely been investigated despite its potential for use with light-weight, comfortable and socially acceptable watch-like devices. This can be explained by the fact that this body location raises several concerns. First, perception on the wrist and forearm is usually less accurate than on other body locations, such as the back or waist due to the smaller space available for distributing actuators. Oakley et al. [10] describe experiments designed to examine the limitations of a vibrotactile display placed on the forearm, concluding that different arrangements of tactors on a 3 by 3 grid can result in different levels

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of performance and that increasing the size of the area of skin experiencing the vibration results in an increased perception of intensity. Their overall conclusion about the use of this part of the body for tactile input is rather positive. Second, the hands and arms are commonly used in daily interactions and having a display located there could impede the user in accomplishing these. For this reason, Rekimoto et al. [14], who developed GestureWrist, a wristband-type gesture input device, noted that a device on the wrist should not hinder performance of daily tasks so as long as it does not alter the appearance of normal clothing or accessories.

A number of wrist-based tactile systems have been developed. Bosman et al. [1] presented a wearable wrist-band system composed of two vibrotactile devices with a single actuator mounted on each wrist. An experiment showed that the system was helpful and is an intuitive means to deliver directional information for pedestrians indoors. Compared to standard signage, it helped reducing the number of errors to reach the destination. Pasquero et al. [11] implemented a haptic-enabled wristwatch with a single custom-made actuator to support eyes-free communication with a mobile device. They focused on enabling gesture-based active interactions where users could get information about the activity of their inbox by touching the wristwatch face. They could also modulate the delivery rate according to the pressure exerted. In their study, they reached an overall accuracy of 73.6% for identifying the number of pulses delivered, with most errors made at the fastest delivery rate. Moreover, participants commented positively on the informative tactile feedback.

Concerning multi-actuator devices, Tsetserukou and Tachi [18] introduced BraTact, a tactile wristband with six symmetrically arranged vibration motors linked by an elastic band. They developed patterns with varying levels of intensity (static or time-varying), with variable activation of the actuators (all or some) and with variable duration. The objective was to convey the shape and stiffness of any colliding object teleoperation. After testing them in static and dynamic conditions, they found that the dynamic presentation of patterns was more intuitive and consequently resulted in a higher level of discrimination accuracy. Weber et al. [23] evaluated VibroTac, a system similar to BraTact, for providing spatial guidance (translation and rotation of the hand). In particular, they focused on the encoding of direction, using the actuator location for the translation direction or using a clockwise movement for rotation to the right (and counterclockwise for left). Participants achieved similar performance for the translational task and better performance for the rotational task when using VibroTac and when compared to a verbal condition. The authors concluded that vibrotactile feedback on the wrist is valuable, in particular when the auditory modality is not available or appropriate such as in noisy environments.

Most of these multi-actuator wrist-based systems use actuators that are equally distributed along the circumference of the wrist. On the contrary, Lee et al. [8] used a three-motor tactile device, placed on the side of the palm. They conducted studies with a distraction task and compared the tactile wrist device to a mobile phone display; they found that the information transfer in perceiving alerts is higher with the wrist device than with the mobile phone. Moreover, they showed that the reaction time to perceive them on the wrist was not deteriorated by visual distraction, thus making wrist-mounted tactile displays appropriate for enabling mobile multitasking.

In line with previous work, we have developed a novel design for a wrist-based tactile device, with co-planar actuators, similar to a wristwatch, in order to ensure wearability and social acceptance. This device is not only used to convey navigation cues but also qualitative information on points of interest. The details of our implementation and evaluation, in this case, in the indoor navigation context, are described below.

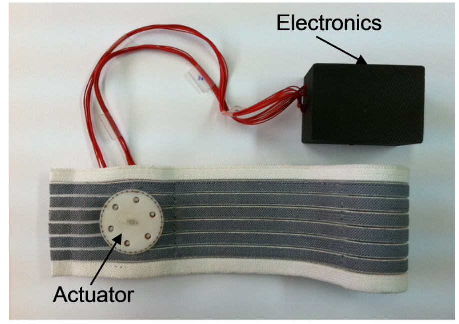
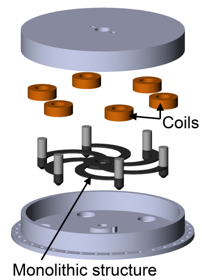


Figure 1: Tactile bracelet with six actuators placed on a wristband



(a) Concept schematic

(b) Real monolithic structure

Figure 2: Monolithic structure with six lever beams and stimulators at each extremity

3 The Tactile Bracelet

The tactile bracelet was designed to resemble a compass as can be seen from Figure 1, with the aim of providing basic navigational cues as well as other potentially useful information. This design was intended to test the feasibility of using a watch-like shape with co-planar actuators for providing discriminable vibrations. Electromagnetic actuators were chosen as the preferred actuation technology due to their large dynamic range and ease of integration. As depicted in Figure 2a, the device consists of six individual actuators and a monolithic structure of six cantilever bars, respectively (Figure 2b), with tactile stimulators on one side of each extremity. Permanent magnets glued to the other side of each extremity produce an interaction with a coil, which displaces the individual cantilever beams and results in a vibration. As the system is normally decoupled from the human body by a wristband support structure, a level of amplitude has to be reached before stimulation takes place. This reduces the damping behaviour of the human skin applied to the actuator and allows precise control of each actuator with improved tactile stimulation.

Finite element simulations were carried out in order to determine the geometrical aspects of the monolithic structure with regard to the cantilever's first Eigenmode as shown in Figure 3. The structure was optimized for the first resonance frequency creating out-of-plane motion around 100 Hz. Even though Pacinian recep-

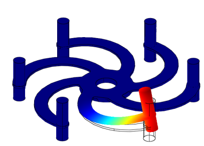


Figure 3: Eigenmode simulation of the monolithic structure with a first resonant frequency around 100 Hz.

tors are known to be most sensitive around 250 Hz, preliminary user testing highlighted that this frequency was considered too harsh and thus unpleasant. The six coils, one for each beam, are driven with alternating binary signals provided by a microcontroller in order to set various output frequencies and amplitudes.

According to the literature [10], localisation rates for vibrotactile stimuli are rather variable. The average rate reported for stimuli placed 2.5 cm apart is 46% and increases to 66% for 5 cm. Given the limitation in size for our wristband display (2.6 cm wide, limited by the width of the wrist), if it is to mimic the size and feel of a real watch, this could prove to be a limiting factor. Previous work though does highlight higher localisation rates of up to 80% at bodily landmarks i.e. joints on the arm, with the wrist specifically mentioned as a 'point of mobility'. The closer a stimulus to one of these points, the better the absolute localisation [3]. Therefore, we conducted pattern identification studies to explore which types of patterns can be effectively provided by the wristband.

4 User Studies

Our user studies aimed to assess the perception of vibrations and in particular the discrimination and recognition of patterns using the tactile bracelet. This represents the first step in evaluating the feasibility of using such a device in a navigation context. The evaluation was conducted in two stages: first a pilot study to aid in the design and selection of a set of patterns; then, an identification experiment using the chosen set.

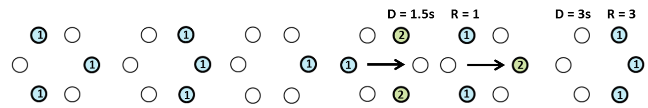
4.1 Preliminary Study: Static vs Dynamic Patterns

4.1.1 Pattern Design

Our patterns were designed to convey both navigational information and information on points of interest in an indoor navigation context. Eleven categories were selected because of their importance for indoor navigation: left, right, front, back, stop, elevator, stairs up, stairs down, toilets, door and emergency exit.

We focused on conveying abstract tactile messages (similar to tactons [2]) through a combination of activated actuators and physical parameters. These parameters include vibration duration, pauses between actuator activation and repetition, frequency, with up to five levels (25, 50, 75, 100 and 125 Hz), amplitude (low and high) and position and number of activated actuators. Patterns can be either *static*, i.e. in which a specific configuration is vibrated for a set duration, or *dynamic*, whereby some sense of movement or rhythm is conveyed by changing the actuator configuration within a single pattern. Thus, for each category several designs are possible, for example the right pattern (see Figure 4) can be conveyed using various static patterns, such as by vibrating the right actuator alone or the right half of the bracelet (see Figure 4a) or through dynamic patterns, such as by using a movement to the right or simply repeating a static configuration (see Figure 4b). This resulted in the design of a preliminary set of 21 static patterns and 22 dynamic by the authors, for all 11 categories, by drawing inspiration from patterns in the literature [8, 7]. For half of the patterns, several possibilities were associated with a single meaning (see the example in Figure 4). The static patterns were played for 3s with a high amplitude and at 100 Hz, only the spatial position of the vibration varied, whereas the dynamic patterns varied in frequency (mostly using 100Hz and 75Hz), duration (from 300ms to 6s overall, and with time-varying activations) and spatial position of the activated actuators. Six of them included three repetitions.

Given the novelty of the device and the close arrangements of actuators, the relevant literature was not informative enough to aid with the design of a discriminable pattern. Hence the preliminary study was conducted to provide some insight on the design of discriminable patterns for this tactile bracelet.



(a) Static right patterns (b) Dynamic right patterns

Figure 4: Possibilities tested for the right pattern in the static and dynamic conditions (D=duration; R=repetitions).

4.1.2 Participants and Procedure

14 participants (12m/2f), aged 21 to 56 years (M=31), were recruited at the Sensorial and Ambient Interfaces Laboratory (SAIL), and were divided into two groups, each testing either the set of *static* or *dynamic* patterns. They were wearing the bracelet on their non-dominant hand along with headphones playing white noise to mask any audio feedback generated by the actuators.

The study started with a familiarisation phase where each actuator was vibrated one after the other to aid localisation. The patterns were then played to the participants, each repeated three times and in random order, and the participants were asked to match them to the most appropriate of the 11 categories. If none were adequate, an additional "I don't know" category was available. A single pattern could be associated to several categories and a category could be associated to several patterns. Participants could also ask for a pattern to be repeated. At the end, each pattern was replayed without the headset and participants were questioned about their association choices, their perception and eventual suggestions.

4.1.3 Results

For the static condition, some categories were matched with many patterns (up to 17) that were themselves matched with many other categories. Additionally, there were many categories that participants did not associate with any pattern at all; for example six participants for *door*, five for *exit* and *toilets* and three for *elevator* and *stairs down*. This shows that the static patterns were not clearly perceived or distinguished at all. In fact, participants commented that even when only one or few actuators were activated, they felt like the whole bracelet was vibrating. Given that the only discriminable factor was the spatial location of actuators, the results were very poor for static patterns.

On the contrary, participants had less difficulty distinguishing the dynamic patterns. In particular, though accurate localisation was difficult, it was noted that the movement, rhythm and frequency aided discrimination. In particular, dynamic triangular shapes (see the first two of Figure 4b) were most associated with left/right directional cues (75%). For the front/back directions, several matches were made but the most associated pattern was the movement up/down (about 25%), while stop was mostly linked to patterns where all the actuators were vibrating (46%). The elevator was most linked to a circular movement where each actuator was vibrating one after the other (30%). Toilet was most linked to a pattern where all actuators were quickly activated one after the other in a non-circular movement (25%) and, as one participant commented, was similar to a tingling feeling. Emergency exit was most linked to a pattern where the actuators were divided by the diagonal and each half was vibrated one after the other, similar to an alarm. As for the rest of the patterns, they all had many associations.

This preliminary study has shown us that the static patterns are not usable with the tactile bracelet due to its topology (the actuators are too close to each other) and the perception that the vibration was propagating to the whole base. However, the dynamic patterns are a good solution as long as the main parameters for discrimination are movement, rhythm and frequency. Though the associations had low percentages, the most frequent associations provided us with guide-

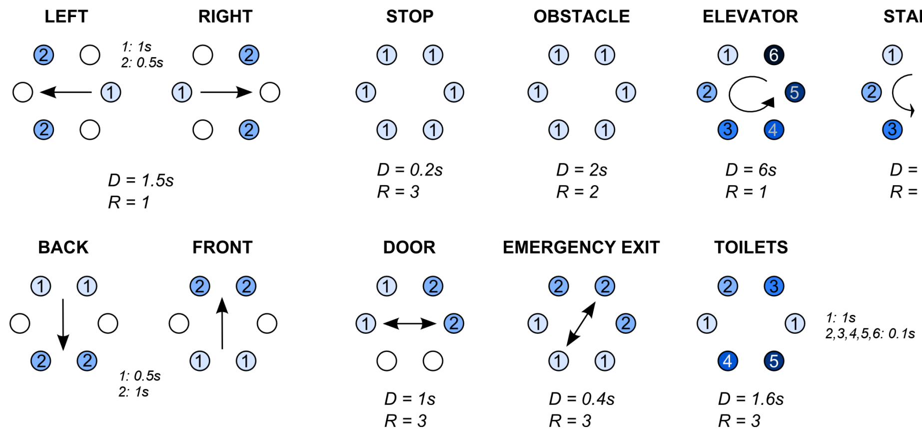


Figure 5: Final Patterns selected with their durations in seconds (D) and the number of repetitions constituting the pattern (R)

lines to choose a set of patterns for the subsequent evaluation. The categories *stairs up/down* were replaced with *stairs* and a category *obstacle* was added. The final patterns are depicted in Figure 5.

4.2 Main Study: Pattern Identification

The aim of this experiment was to both evaluate the ability of our selected tactile patterns to indicate navigational directions and points of interest and to assess their acceptability. The goal was not only to highlight the design characteristics that will facilitate their recognition, but also to collect initial results about the feasibility of using such patterns and the device on which they are displayed for providing haptic cues.

4.2.1 Participants and Procedure

40 participants (18m/22f) with various occupations, who had not taken part in the preliminary study, were recruited at SAIL. 34 were right-handed and 6 left-handed. Their ages varied from 22 to 55 yrs (M=33,7). Similarly to the preliminary study, participants wore the bracelet on their non-dominant hand and were wearing headphones with white noise to mask any sounds produced by the device. A Samsung tablet running Windows 7 was used to display the experimental interface and to communicate via Bluetooth to the bracelet.

The experiment started with a familiarisation phase where each actuator vibrated in turn to help localise the vibration and adjust the bracelet to each person so they could comfortably feel the stimuli. Participants were divided into four groups, each testing a set of seven patterns:

- Group 1: the four directional patterns (right, left, front, back) and elevator, obstacle and stop
- Group 2: the four directional patterns, stairs, door and emergency exit
- Group 3: the four directional patterns, stairs, toilets and stop
- Group 4: elevator, obstacle, stop, stairs, door, emergency exit, door

The methodology was the same for each group and consisted of a training phase and an identification test that were each repeated twice, before answering a questionnaire to collect the participants' feedback. During the training phase, a verbal description was first given for each pattern explaining the pattern's associated meaning and its movement before repeating it three times, with a 3s break in between repetitions. An identification test followed where each pattern was played only once with four occurrences (4*7=28 patterns). Participants were asked to choose an answer (i.e. click on

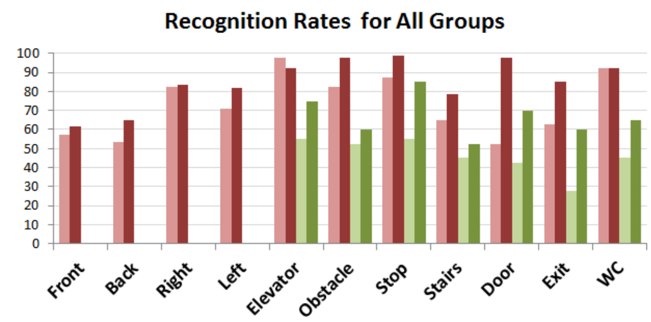


Figure 6: Recognitions rates for all groups for both iterations, with iterations of groups 1,2,3 in red colors and group 4 in green colors.

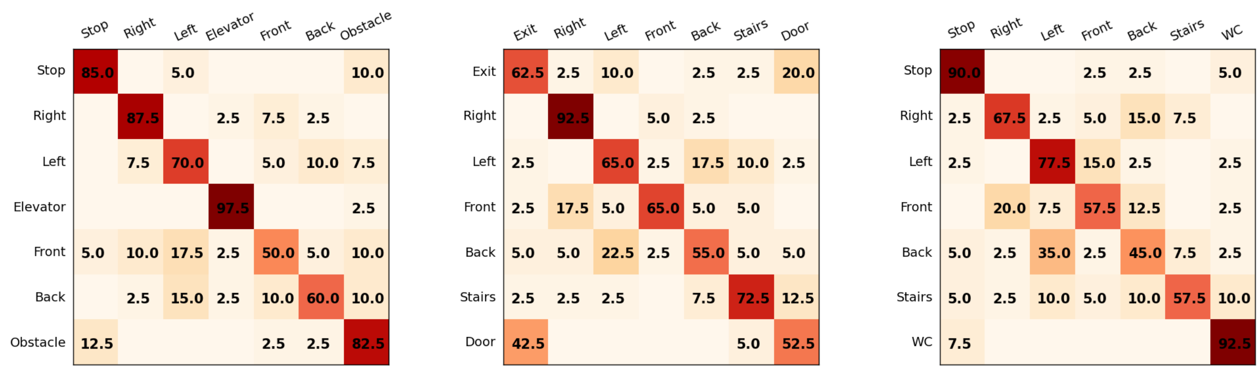
the corresponding icon on the interface) as soon as they recognized the pattern with certainty. Only the first answer was taken into account. Both the accuracy of and the time to answer were measured. If needed, the participant could take short breaks in between answering and playing the next pattern.

The second iteration of training and identification were exactly the same except that there were no verbal explanations during training. This iteration was meant to monitor the expected improvement in the recognition rates due to short-term memorization.

4.2.2 Results and Discussion

Overall Identification Rates Overall for groups 1,2 and 3 (see Figure 6), the directional patterns were more difficult to identify than the patterns for the points of interest (averaged rates of 66 vs 77.1% for iteration 1 and 72.9 vs 91.8% for iteration 2), and in particular *front* and *back* with identification rates inferior to 60%. It is particularly striking for the second iteration where all the other patterns have identification rates superior to 78%.

This can be explained by a difficulty in recognising the direction of movement, which relied on localising the spatial positions of the beginning and the end of the movement. The recognition of the patterns for the points of interest relied instead on other parameters such as rhythm, intensity and movement that required less accurate localisation. Indeed, the space between the six actuators is too small to accurately distinguish and localise them, even when combined with a dynamic movement. Moreover, Piateski and Jones [12] showed that patterns that moved across the width of the forearm were easier to identify than those moving along its length. This was confirmed for our configuration of actuators as the identification rates for *front* and *back* were worse than *right* and *left*.



(a) Group 1 (b) Group 2 (c) Group 3

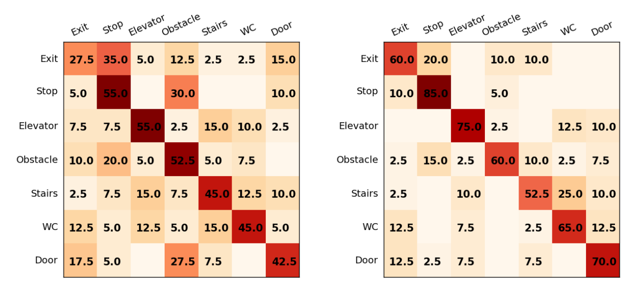
Figure 7: Confusion matrices for the different groups for the first iteration.

The average recognition rates for group 4, which tested only the patterns for the points of interest, were lower than the ones of groups 1, 2 and 3 (see Figure 6) with scores below 60% for the first iteration and below 85% for the second. Though it appears that this would contradict the results from groups 1,2 and 3 that patterns for points of interest were easier to distinguish than directional patterns, these results are most probably due to a perceptional, attentional and short-term memory overload. For the first three groups, there were four to five different combinations to perceive, treat and memorise as the directional patterns were designed in pairs and the only differentiating factor in the design was the direction of movement (up-down, left-right). For group 4, on the contrary, there were seven different designs and some being similar enough to create higher confusion. These are exhibited in the confusion matrices in Figure 7 and 8 and detailed below.

Confusion Matrices The confusion matrices from Figure 7 and 8 show the identification rates as well as the percentage of confusion with other patterns. Regarding the directional patterns (see Figure 7), they were often confused with each other (up to 35% in the worst case), which reinforces the issue about accurately localizing the direction of movement (across or side-to-side). Regarding the rest of patterns, for groups 1,2 and 3, *exit* was often mistaken with door (20%) and vice versa (45%). As can be seen from Figure 5, these patterns both have an alternating rapid movement, one from a diagonal up-down and the other from left-right. The rest of the patterns were less confused with each other (confusion rates up to 12.5%) such as *stop* and *obstacle*, except for *stairs* which was also mistaken with directions. The confusion for these patterns is more apparent with results from group 4 (see Figure 8).

In group 4, *exit* was most often confused with *stop*, *obstacle* and *door*. And *stop* and *obstacle* were most often confused with each other. These last two only differ by their duration and number of repetitions. *Exit* was mistaken with these two as the movement was sometimes not felt by the participants and instead perceived as if all the actuators were vibrating, like in the *stop* and *obstacle* patterns. This issue was already exhibited during the pilot study. Perhaps a less rapid movement could help improve the recognition as the rates for the pattern *door*, also mistaken with *obstacle* are higher. *Stairs* and *elevator* were mistaken for each other up to 15%, which again could be due to the fact that these two patterns started the exact same way for the first three vibrations. A naive solution to differentiate them could be to start the movement clockwise for *stairs*, for example.

Questionnaire A questionnaire evaluated the participants' overall satisfaction with the patterns and the device. According to the participants, the main characteristics that played a role in the correct identification of the patterns were the movement, the rhythm and the amplitude. Different recognition strategies were reported for groups 1, 2, 3 and group 4. For the first three groups the set of patterns included directional patterns and points of interest patterns, which could be distinguished by their timing as the directional patterns were shorter than the rest. Participants focused mostly on the physical characteristics. On the other hand, for group 4, as all patterns were designed differently and had a more complex combination of characteristics, participants also tried to associate these with everyday metaphors. For instance, the alternating movement for *door* was associated with the opening and closing of a real door knob. *Stop* was associated to a red light, while *WC* was associated with a tingling sensation and the circular movement of *elevator* was associated to the rotating 'waiting' symbol in a video game.



(a) Iteration 1 (b) Iteration 2

Figure 8: Confusion matrices for group 4 for both iterations. The patterns are displayed in the following order: exit, stop, elevator, obstacle, stairs, WC, door.

Concerning the overall pattern score, groups 1,2 and 3 rated the directional patterns between 6 and 7.2 out of 10 and the points of interest between 6.9 and 9.2, highlighting a preference for the design of the latter patterns. Group 4 rated the patterns between 5.5 and 7.35 out of 10. These scores support earlier results; as directional patterns were more difficult to perceive due to the required localisation precision, they obtained lower scores. In group 4, the scores were lower overall than in groups 1, 2 and 3. This can be explained by the higher cognitive load in identification and memorisation and the similarity between some patterns which made the identification more challenging.

4.3 General Discussion and Recommendations

The results from the pilot study underlined that static patterns are not suitable for this type of tactile bracelet, due to the short distance between the actuators. In fact, it is difficult to accurately localise the vibrating actuator(s) and therefore find the number of activated actuators, the only parameter available for static patterns, as opposed to dynamic patterns that use movement and rhythm.

However, even for dynamic patterns, accurate localisation is still difficult even when combined with dynamic movement. In fact, directional patterns were more difficult to perceive than the patterns for the points of interest in groups 1,2 and 3 and were more easily confused. In order to differentiate them, it was necessary to precisely localise the direction of movement, which is difficult with the current device layout, where actuators are still too close to each other for such accurate spatial localisation. Making the patterns more distinct between one another or within a pair of patterns (left-right, up-down) using rhythm or relying on a less accurate movement could be a solution. Another solution would be to change the layout of the device by reducing again the number of actuators to four or to add a reference point in the middle for horizontal and vertical movements. The layout could also be changed to an elliptical arrangement of the actuators. This would not only enable all actuators to be in contact with the skin at all time, which is currently difficult in particular with small wrists, but also enable to increase the distance between the two furthest actuators along the arm length, which may improve the perception of up/down movements.

It has also been shown here that use of an appropriate metaphor is important in order to reduce the confusion errors and improve their perception, as exhibited by results from group 4. For instance, using only the number of repetitions is not a good enough parameter to distinguish many of the patterns, as in the *stop* and *obstacle* examples. However, by using rhythm, this becomes possible.

5 Conclusion

This paper presented the design, implementation and evaluation of a tactile bracelet prototype, comprised of six independent actuators that are located on a horizontal plane on top of the wrist. The evaluation of pattern perception in the context of indoor navigation, showed that static patterns are not well recognised with this prototype as opposed to dynamic patterns. This is primarily due to the difficulty of accurately localising the activated actuator(s) and the difficulty in perceiving the number of activated actuators (one or two vibrating actuators often felt the same as if all were vibrating). These are both consequences of the small spatial resolution of our actuators. The accurate localisation issue also impacts on the recognition of one-way horizontal and vertical dynamic movements (used for directional patterns). However, circular and alternating lateral movements and rhythm enable good perception of patterns so as long as the patterns are designed quite distinctively from one another.

The next step for this research will involve the re-design of a more appropriate set of patterns based on the results of the evaluation, and testing the new set of patterns in more realistic contexts, whilst mobile, for example and during navigational tasks.

While this device was designed principally with navigation applications in mind, there are many other possibilities including the delivery of general information from a connected mobile device, for example. With the design of an effective set of tactile patterns, it should be possible to indicate a new email, SMS or call or even convey emotions with an appropriate arrangement of patterns.

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