Understanding Indoor Orientation through Wearable Vibrotactile Feedback

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ABSTRACT

The main goal of this work is to better understand how vibrotactile feedback obtained through wearable actuators can support indoor orientation in unfamiliar buildings. We designed different wearable vibrotactile prototypes (two bracelets, a flexible/rigid glove, one bracelet, a cap and a two-bands bracelet), and we analysed them in a preliminary test to identify the design aspects that are most relevant for a solution guiding a person indoor. We describe the design and evaluation process, and discuss some lessons learnt that can be useful for developers who want to use this technology within applications that need support for indoor orientation.

CCS CONCEPTS

• Human-centered computing • Human computer interaction (HCI) • Interaction devices • Haptic devices

KEYWORDS

Vibrotactile, Orientation & Navigation, Usability

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1 Introduction

Vibrotactile stimulation is often considered in Human-Computer Interaction (HCI) [1, 3, 6]. Its specific features make it suitable to provide users with relevant feedback without requiring attention through other modalities. Vibrations may vary according to several parameters, such as intensity, frequency, waveform, duration, rhythm of temporal patterns, and spatial location on the body. However, the set of vibrational cues that can actually be exploited is limited due to some factors, such as the type of vibrotactile motors used (that should be suitable for wearable and cost-effective solutions), and the vibrotactile stimulations that can actually be perceived by humans. In this study we focus on the use of vibrotactile feedback to support user orientation inside unfamiliar buildings (e.g. hospitals, museums, public institutions) where GPS does not work [15]. Vibrotactile feedback is less intrusive in capturing user's attention than other interaction modalities (e.g. vocal), and users enjoy the advantage of having their eyes and hands free and still being able to perceive the surroundings and accomplish real world tasks [6]. Even if vocal cues can be integrated with haptics for encoding complex indications (e.g. the presence of obstacles), repetition of vocal messages can be annoying in a public context [7].
Our study aims to understand the potential of vibrotactile modality in supporting indoor navigation without using any other modality (such as audio or visual). For this goal, we reviewed the relevant literature, designed and tested several wearable devices able to transmit vibrotactile indications to the user.

2 Related Work

Vibrotactile messages can be *pictorial* (direct, self-explanatory) or *codified* (where the relation between the stimulus and its meaning is encoded by an alphabet) [1]. Pictorial coding of vibrotactile feedback can be suitable for orienting a person because users can easily associate the vibration locations with the direction to take (e.g. a vibration on the left/right side can be intuitively interpreted as an indication to turn left/right). Since the frequencies of vibration actuators could interfere with each other [2], some studies [1, 2] suggest placing sufficiently distant the actuators to distinguish the different signals. Some authors show that people can easily locate vibrations if they are applied to the right/left, back/front of the body [1]. Another study shows that vibrotactile stimuli can be recognized by a blindfolded person (accompanied by someone) guided by vibrotactile stimuli of each actuator placed on an arm by a velcro strap [3] within a limited labyrinth. The study in [4] shows the immediacy of pictorial coding used on a car seat where a vibration on the left/right leg indicated a left/right turn, and the rhythm coded the distance. But, when the vibrotactile and visual modes were both available, response times were slower than using vibrotactile alone [8]. A study [9] indicated that directional tactile stimuli are more effective and faster to understand than the verbal ones.

Compared to previous studies [1, 2, 3, 4, 8, 9] our goal is to analyse solutions for indoor orientation that are easily wearable, support users to reach a destination inside a public building (such as museums, hospitals) through vibrotactile feedback, without any other sensorial channels and without a preliminary training. Some studies show that the sense of touch may be advantageous when visual modality is less appropriate. However, many of these experiments [11, 12, 14] were executed outdoor, where further support is generally available (e.g. GPS). Some authors [13] evaluated vibrotactile devices for pedestrian (such as sock bandages, wristband, belt, insole matrix layout, side wall of the shoe) and their relative feedback at different areas of the body: however, since the context was an urban environment, simple vibrotactile feedback might not be sufficient for guidance. Previous work [16] proposes a navigation system with a video camera, but it focuses on open spaces. Other authors analysed the combination of vibrotactile feedback with audio, which is especially useful for people with visual impairments [7, 10].

So, the analysis of literature shows a gap in easy to use (i.e. without the need of training) indoor solutions based only on vibrotactile feedback, which we aim to fill.

3 Design

In this section, we describe the requirements and the methodology we used to design the planned indoor navigator solution.

3.1 The Requirements

An effective guidance system should reveal successive levels of information ("progressive disclosure"), i.e. provide only the information necessary to guide the visitor to the next decision-making point, to avoid information overloading. Turn-by-turn navigation is useful e.g. for assisting people with visual impairments during mobility as it reduces the cognitive load of having to simultaneously sense, localize and plan [17].

We report some relevant requirements we gathered by analyzing previous studies [1, 2, 3, 4, 9, 11, 12] on navigation enhanced by vibrotactile feedback, according to discussions within the project[1]:

- the vibrotactile feedback must clearly communicate to the user the direction to follow (i.e. forward, backward, left, right);
- the vibrotactile feedback must provide indications on the direction to take, in a way that is intuitive, easy to decode for the user and non-annoying;
- the vibro-tactile indications must be easily distinguishable and will vary according to e.g. the frequency of vibration repetition, the number of vibrations, the time between two vibrations, the duration and the spatial position on the body;
- if the user takes a direction not complying with the one suggested, the interface must inform the user and then provide instructions associated with the newly recalculated route;
- the system must be able to detect the position of the user (and give next indication) with an accuracy of the order of meters;
- on the route, vibrotactile feedback should reassure the users that they are proceeding in the right direction;
- the vibrotactile feedback must clearly indicate to the user that has reached the destination;
- the device supplied to the user must be non-invasive, easy to handle or wear, and have as small a size and weight as possible;
- the device must be equipped with an independent power supply with rechargeable batteries having sufficient autonomy.

3.2 The Methodology

Our approach has been structured into a number of steps. After an initial phase of market analysis evaluating costs and issues associated with the communication technologies currently available e.g. WiFi, ZigBee, UWB (Ultra Wide Band) for the LAN and LoRa for the LPWAN network, we decided using Estimote Bluetooth Low Energy (BLE) beacons[2], since they are small, cheap, easily installable, and provide a sufficient level of accuracy for the goals of the indoor navigation support to develop. In addition, they are equipped with a SDK for their easy programmability.

Some beacons were placed in the corridors of the building. Whenever the user comes near a beacon, the latter transmits its identification (ID) via Bluetooth to the user's smartphone, and the application on the smartphone processes the position of the beacon by connecting to the server where the position of the beacons within a grid had been saved. The smartphone's function was only as an intermediary Bluetooth device to manage the communication between the beacon and the server. Once the position of the beacon along the path is "understood" by the application, the smartphone sends the directions coded in the form of vibrotactile pulses to the prototype worn. In comparison with some other approaches [9, 11, 14] we did not need a compass.

Several prototypes were developed to test the usability and effectiveness of vibrotactile feedbacks, simulating the information coming from the control system. The test phases took place in the corridors of a large research Institute. A first evaluation (see section 5) involved 7 users and it was useful to gather information to improve the first version of the prototypes. At the end of this phase, we selected only two prototypes that seemed more appropriate for the final evaluation. Then, a user test was carried out with 36 users of various ages and different cultural/technological profiles, to verify both the effectiveness and the intuitiveness of the two solutions.

4 The Prototypes

Several prototypes were developed: 1) two bracelets, 2) a flexible four-motor glove, 3) a rigid four-motor glove, 4) one bracelet, 5) a cap and 6) a two-bands bracelet.

4.1 Two Bracelets

Each bracelet (Figure 1a) contains one vibrating motor Parallax 9000 RPM 3VDC [5], 1 cm in diameter x 0.27cm thickness.

Figure 1: (a) The two bracelets; the smartphone applications: (b) 4 directions; (c) 8 directions.

[1] http://hiis.isti.cnr.it/FITS.ME/

[2] www.estimote.com

The left and right directional indications are given respectively by the vibration on the left or on the right bracelet, while the forward or backward directions are indicated by applying simultaneous vibrations to the two bracelets. Differences on the vibration between the forward and backward directions depend from the parameters inserted in the mobile application.

4.2 Flexible and Rigid Glove

The flexible glove (Figures 2a) contains four actuators: the left and right directions are indicated respectively by the vibration on the little finger or the thumb (or vice versa, depending on the hand used), while the forward and backward directions are given respectively by the vibration on the middle finger and on the wrist. Another version of the glove with a rigid structure was developed (Figures 2b) to understand whether it supported better perception of the vibrotactile impulses on the hand and wrist.

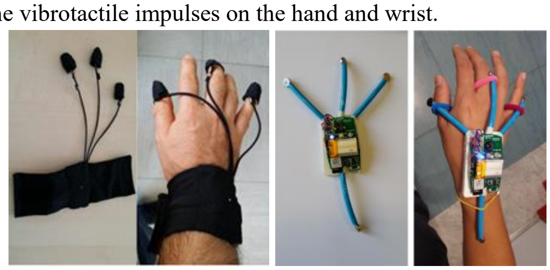

Figure 2: (a) The flexible glove (b) the rigid glove.

4.3 One Bracelet

A configuration was also envisioned in which four actuators are positioned on the top, bottom and sides of the wrist (Figure 3a, 3b), so a vibration on the top, left, right or bottom side of the wrist indicates go forward, turn left, turn right or turn back.

Figure 3: (a, b) Bracelet; (c) Cap; (d) Two band bracelet.

We also designed other prototypes. Considering the improvement in perception when actuators are distant from each other [1, 2], we experimented a new version of the bracelet, splitting the four actuators in two bands. Taking inspiration from the bracelet having four actuators (one for each side of the wrist), we designed also a cap to space the four actuators more.

4.4 The Two Bands Bracelet

Instead of one bracelet we also considered two bands and we placed the four actuators in such a way to augment the distance between the actuators and hopefully the perception of the users. The actuators associated with the forward and back directions were on the top and bottom side of the wrist band, respectively, while the actuators associated with the left and right directions were on the sides of the forearm band (Figure 3d).

4.5 The Cap

The four actuators have been placed on the sides of the cap (Figure 3c), and a vibration in front, on the left, on the right or on the back, indicates to go forward, turn left, turn right and turn back.

5 The Preliminary Evaluation

First we performed a preliminary test with 7 persons (3 females) of average age 38.1 years (min=25, max=50) and SD=10.4. It aimed to identify benefits and drawbacks of each solution, choosing the best ones in terms of usability and directional perception. Such tests were carried out within authors' research centre, which has a quite complex structure. The 7 participants did not know beforehand the test location and they experimented many paths. All 7 participants played the role of the "visitor" wearing each prototype, while they were guided towards an unknown destination by a person who acted as a "navigator", sending directional vibrotactile impulses (via Bluetooth) to reach the next waypoint on the route by using a mobile application which provided impulses indicating four directions (left, right, back, forward, Figure 1b). Another version of the application supported eight cues (Figure 1c), thus including diagonal directions to investigate ambiguous cases such as very close doors or entrances near a turning point: each diagonal was indicated by two vibrating impulses (e.g. straight and right for a right-up diagonal). Diagonal directions were not easy to be perceived and created confusion.

5.1 Two Bracelets

Benefits. They were considered the most intuitive prototype for understanding left and right directions (vibrations on one wrist) and also the indications for going forward (both bracelets vibrating at same time) was clearly perceived.

Drawbacks. The vibrating frequencies chosen for the forward and back directions by the smartphone application have to be very different. This solution was judged a bit cumbersome because it consists of two objects (bracelets) instead of just one (as the glove).

5.2 Flexible and Rigid Glove

Benefits. The glove-based solutions engage only one hand. Besides, the 'back' direction (on the wrist) was perceived more clearly than the solution with two bracelets.

Drawbacks. The glove hand could hinder other activities (e.g. opening doors, holding bags). In addition, an extra cognitive user effort is needed to associate the vibration received on a finger with the direction to follow. Depending on whether the arm is held parallel to the body or straight ahead of the body, and/or the palm is facing down or up, the direction decoding may not be always intuitive for users. Thus we discarded the glove solutions. Also because is less practical to wear.

5.3 One Bracelet

Benefits. The bracelet solution was judged favourably for its wearability and ergonomics aspects.

Drawbacks. If the actuators are not placed in position that accounts for the wrist size, users could not clearly distinguish the directions (i.e. the four actuators could be too close).

5.4 The Two-band Bracelet

Benefits. Most users found the same benefits as one bracelet.
Drawbacks. This solution brings no added value to the perception of the direction, and it can even introduce an extra mental effort for decoding the directions due to the two bands.

5.5 The Cap

Benefits. Very intuitive in each direction because of the distance of the four actuators.
Drawbacks. The vibration on the head was considered annoying.

6 Final Evaluation

At the end of this preliminary evaluation only two prototypes were considered suitable (the two bracelets and the one bracelet), while the others were discarded. To understand the effectiveness of the two prototypes, we conducted a user test in the same research centre with 36 new subjects (15 females) of average age 42.94 years (ranging from 24 to 70) and SD=12.46. Twelve users had a PhD, 12 users had a master degree, 4 users had a bachelor's degree, and 8 users had a high school diploma. In the final test, we considered just flat environments (e.g. no multi floor buildings), and indications were automatically provided by the system.

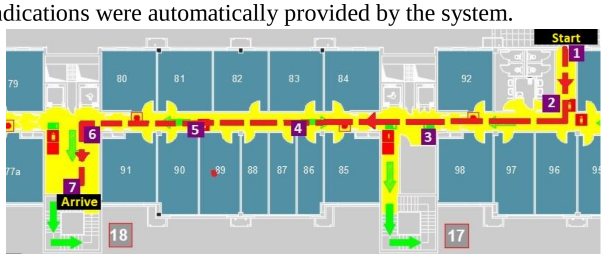

Figure 4: The path considered in the test.

To balance learning effects, users first tested one solution (1 bracelet or 2 bracelets) then the other one, in an order that was always different from that of the previous user. All users had to follow the same fixed path (Figure 4) unknown to them, relying only on the vibrotactile indications they received by the device until they reached the destination (we notified them about it). If a user walked in a wrong direction, the system provided proper indications. We created a path of about 66 meters, with 7 Estimote beacons in it. After the test, users filled in a questionnaire.

6.1 Results

One important aspect was that every user successfully reached the destination in both conditions, which is a non-obvious, satisfactory outcome. The results of the test show that 66.7% of the users preferred the single bracelet, in contrast with results from literature [1, 2] that indicate that directionality is better perceived when the left and right vibrotactile impulses on the skin are distant from each other.

The preference of the single bracelet instead of two does not reflect the data gathered through the users' confidence question. In fact, for the two bracelets solution, on a scale of 1 to 7 (7="very sure of going in the right direction", 1=" totally unsure" and 4=" neutral value"), Min=4, Max=7, Median=7. For a single bracelet Min=3, Max=7, Median=7. The Wilcoxon test applied on the evaluation of each solution by the user sample, resulted in a p-value of 0.73 (> 0.05) showing that there is no significant difference between the two solutions. To the general question "How reliable is the system for the proposed indoor navigation", 94.4% users expressed a very high value regardless of the vibrotactile solution proposed, while, in another question, 91.7% of users would trust the proposed vibrotactile navigation system while wearing a device.

7 Discussion and Conclusions

Although the gathered data did not show a significant difference between the two solutions, the preference for the single bracelet rather than the two bracelets highlights that users tend to prefer a minimally invasive solution. One aspect that could have affected this choice could also be the fact that, using the two bracelets, the forward direction was given by simultaneously providing signals on the two wrists. This not only requires from users a bit more attention (because users should pay attention to two parts of the body rather than just one part). Also, since the feedback associated with the forward direction was the same used for reassuring users going in the right direction, in some cases users might receive too frequent vibrations which can be perceived as annoying and even distract them from their main task. Still for the two bracelet solution, while the simultaneous vibrations seem appropriate for conveying the backward direction (typically associated with an 'error' situation, thus requiring more attention from users), the 'reassuring' indication could be better supported by a more discreet vibration, which should be easily distinguishable from the other, truly directional indications.

Another aspect to highlight is the fact that the provided navigation solution appeared natural to users who, apart from a brief initial explanation about the directional vibrations supported, did not need to carry out any specific training on the use of the device before the test; this was a sign that the provided indications were simple, clear and intuitively communicated to users. Since we target first-time visitors, this was another positive outcome of the test. Finally, for several users, the fact of not having to look at the screen to be guided to a destination in real time (as it happens with common navigators) was greatly appreciated. Again, being one of our goals. we were satisfied by this result.

To conclude, the aim of this study is to better understand design concepts for vibrotactile feedback supporting user orientation during indoor navigation in unfamiliar buildings. Preliminary trials have provided useful indications for the most suitable prototypes and showed the effectiveness of vibrotactile support in guiding users toward an unknown destination. Future work will investigate indoor navigation system based on vibrotactile adaptive applications from a longer term user perspective, and also taking into account the emotional status of the user.

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APPENDIX

We report the Questionnaire about the evaluation of the two devices selected after the preliminary evaluation:

Personal Informations

1) Please indicate your gender (Male or Female):

2) Indicate your age:

3) Indicate your qualification:

    - Middle school diploma
    - High school diploma
    - Bachelor's degree
    - Master degree
    - PhD

4) For which purposes or applications did you use vibrotactile technology?

EVALUATION AFTER TESTING THE TWO SOLUTIONS

5) Which vibrotactile device do you prefer among those proposed (Two Bracelets or One Bracelet)?

6) For which reason (explain your answer to question 5)?

7) Did you arrive at the end of the route using two bracelets (Yes or No)?

8) The vibrotactile directional commands of the solution with two bracelets were clear (for example, did you understand that you had to turn left at a turn)? Yes or No

9) Explain why and how would you improve them (only if you answered "no" to question 8):

10) How confident did you feel to go in the right direction along the route (for the solution with two bracelets)?

    Lost 1 2 3 4 5 6 7 Very confident

11) Please provide some more details about your navigation experience with two bracelets (for example, you felt comfortable, etc.).

12) Did you arrive at the end of the route using one bracelet (Yes or No)?

13) The vibrotactile directional commands of the solution with one bracelet were clear (for example, did you understand that you had to turn left at a turn)? Yes or No

14) Explain why and how would you improve them (only if you answered "no" to question 13):

15) How confident did you feel to go in the right direction along the route (for the solution with one bracelet)?

    Lost 1 2 3 4 5 6 7 Very confident

16) Please provide some more details about your navigation experience with one bracelet (for example, you felt comfortable, etc.).

OVERALL EVALUATION OF THE PROPOSED SYSTEM

17) How reliable is the proposed indoor navigation system?

    Very unreliable 1 2 3 4 5 6 7 Very reliable

18) Would you use the vibrotactile navigation system while wearing a device (Yes or No)?

19) For which reason (explain only if you answered "no" to question 18)?

20) What did you like most during the test?

21) What did you like less during the test?

22) Write your suggestions on how to improve the proposed system or on any other aspect:

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