Tactile Representation of Landmark Types for Pedestrian Navigation: User Survey and Experimental Evaluation

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ABSTRACT
Our research investigates human-computer interaction aspects and representation techniques for spatial and related information associated with the design of tactile pedestrian navigation systems. In this short paper, we very briefly outline our research on tactile representation of landmarks to support urban navigation. We outline a user survey in which we identified and categorized landmarks used in the urban context. The results show commonalities of landmark use in urban spaces worldwide. We then used the results in an experimental study that compared two tactile techniques for landmark representation using one or two actuators. We compared the two techniques on 4 measures: distinguishability, learnability, memorability and user preferences. Results from our lab-based evaluation showed that users performed equally well using either technique to represent just landmarks, however, performance with the one-actuator technique was significantly reduced when landmark signals were presented together with directional signals while performance with the two-actuator approach remained unchanged. The results of this ongoing research programme may be used to help guide design for minimising clutter while presenting key landmark information on mobile navigation displays.

Categories and Subject Descriptors
H.5 Information interfaces and presentation: H.5.2 User Interfaces: Haptic I/O.

General Terms
Design, Experimentation, Verification.

Keywords
Landmarks, pedestrian navigation, mobile displays, visual clutter.

1. INTRODUCTION
Tactile navigation displays have the potential to be deployed as an alternative or complement to visual navigation displays. They have been reported to work effectively in environments where there are different forms of noise and environmental constraints and when users' attention, visibility and audibility may be limited, e.g. [12] [14] [3] [9].

Our eventual design goal is to create a spatial display that imposes fewer requirements for extensive transformations between frames of reference by a human operator and allows the user to achieve high task performance in challenging situations. Outstanding challenges with tactile displays for navigation systems include selection of spatial information types and their representation. In this paper, we describe two linked empirical studies. The first identifies contextually prioritised landmark categories important for different types of navigation. The second describes an experimental comparison of tactile representation techniques for such landmark categories on a wearable device for pedestrian navigation.

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2. USER SURVEY OF LANDMARK USE
Several researchers, e.g. [6] [2] [8] [4], have suggested that a navigation system's value could be improved by providing additional landmark information, however, there has been no reported use of landmark information in tactile navigation displays. Landmarks for human navigation can be any objects or places that are stationary, distinct and salient [6]. They serve as cues for active navigation (i.e. wayfinding) and building a mental representation of the area [7]. According to Allen [1], human wayfinding can be categorized into three types: traveling to a familiar destination (*commuting*); traveling to an unknown destination (*questing*); and exploring the area, which may or may not involve visiting important landmarks (*exploring*).

Based on human perception and memory limitations, previous research has recommended that the number of tactile patterns to be presented should not exceed seven [7]. These findings suggest an upper bound on the number of landmarks it may be useful to represent within a given navigation task and context. Given such a constraint, it is important to identify a small set of landmarks that are most likely to be useful. However, existing navigation systems typically present quite large sets of landmark information, e.g. [7], Nokia Maps™ 2.0; Garmin Nuvi™) (see *Appendix*). Our first study empirically identified and classified a set of landmarks or landmark types appropriate for use in tactile navigation systems that support the three navigation purposes, commuting, questing and exploring.

2.1 Online and face to face survey
Given our desire to include participants from different urban settings around the world, an online survey was an appropriate approach for this study. However, online surveys can be limited by their lack of direct interaction between interviewer and interviewee, therefore, we also conducted face-to-face interviews *in situ* with participants who had just been engaged in an urban pedestrian journey. The online and face-to-face surveys were intended to be different and complementary.

Table 1. Top Ranked Landmarks in Descending Order Based on a Summation of F, I and R Scores.

Purpose	Top Landmarks (Global Rating) From Online Responses	Top Landmarks (Global Ranking) From Online Responses	Top Landmarks (of One City) From face-to-face Responses
Commute	Mall and Market Traffic light Public transport Bridge Financial service	Well-known shops / business Mall and Market Traffic light Public transport ATM Educational institute Bridge	Monument and Memorial
Quest	Mall and Market Bridge Railway stations Tourist attraction Religious place Traffic light Restaurant	Mall and Market Well-known shops / business Bridge Tourist attraction Hotels Religious place Restaurant	Mall and Market Public transport River Religious place Bar and Pub Railway Station Monument and Memorial
Explore	Tourist attraction Hotels Mall and Market Bridge Monument and Memorial Religious place Public transport	Tourist attraction Hotels Mall and Market *Other unique landmarks* Monument and Memorial Railway station Religious place	Tourist attraction Railway station Museum and Gallery Monument and Memorial River Public transport Religious place

From the online participants, we collected 100 complete responses from different geographic locations, 40 males and 60 females. We conducted 60 face-to-face interviews in one UK city, 32 males and 28 females. 61% of online responses were from Asia; 33% were from Europe; 5% were from Africa and 1% was from Australia.

For the online version, each participant answered three parts of the questionnaire, corresponding to questions about using landmarks in pedestrian navigation for commuting, questing and exploring. In the face-to-face interviews, each participant first identified which of the three navigation purposes they had just been engaged in and then answered the questions only with respect to that purpose.

For each journey with a particular navigation purpose, each participant first identified: (1) a navigated area, (2) if they used landmarks, and (3) if such landmarks were in the physical space or on any guidance system, e.g. a map. They then rated each of the 50 landmarks in our reference set by their importance as navigational aids for the journey. Participants were given opportunities to specify other kinds of landmarks used that were not included in our set.

2.2 Results

Results from both online questionnaires and face-to-face interview were used to calculate: frequency (F), importance (I) and ranking (R) scores. The frequency (F) score is the number of times each landmark was used across respondents for a particular navigational purpose. The importance score is a summation of the weighted importance of each landmark across all respondents. The ranking score is a summation of weighted ranked scores of each landmark across all respondents.

Results are summarised in Table 1. If we have to choose a small set of landmarks for use in mobile pedestrian navigation aids, according to results of our study, the most suitable landmarks should be: mall and market, religious place, tourist attraction, public transportation, bridge, monument and memorial, and railway station.

In addition to generic landmarks, there is the ‘other unique landmark’ category that is crucial to navigation but is not generalisable. This category includes symbolic or iconic landmarks of the city or famous chain stores that are located in strategic areas or at important decision points on the route. For the symbolic landmarks type, they could be instances of the generic landmarks, e.g. *tourist attractions*.

Nonetheless, these top-ranked landmark categories might not be generalisable due to different morphologies of the surveyed cities. Religious places provide a good example. Some cities contain hundreds of landmarks of this category, e.g. temples in Bangkok that are highly visible and distinct from their environments, hence their high frequency of use as landmarks by our respondents. On the other hand, some other cities, e.g. London, contain hundreds of local churches that are not visually or structurally salient (see [4]) and our participants did not select such landmarks as cues for navigation in those cities.

The value of a particular category of landmarks varies from one situation to another. For example, tourist attractions offered little assistance to a quest journey while they were the main, if not sole, purpose of exploring. Thus, the same landmark may be used for different navigational purposes but have greater or lesser value for each of them.

3. TACTILE REPRESENTATION FOR LANDMARKS

Having empirically identified a small set of landmark types for supporting pedestrian navigation, we next investigated the tactile representation of these landmark types.

3.1 Tactile Representation Techniques

To create a distinguishable and learnable set of tactile stimuli, researchers have manipulated attributes, such as frequency, amplitude and duration of vibration signals, e.g. [5] [12] [13]. Ternes and MacLean [13] suggests that signal rhythms created by manipulating signal duration provide the most effective result. In this study, we closely followed design of Ternes and MacLean's heuristic tactile rhythms tactile stimuli (see Figure 1).

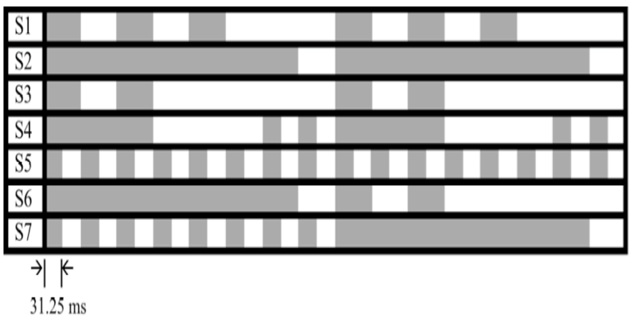

Figure 1. One-actuator Technique. Each row represents one bar, represented 2 times as a 2-second stimulus. Each note contains vibration on- (grey) and off-time (white) that separates it from the next.

Human skin adapts to continued pressure stimulation resulting in a decrease in sensory experience [10]. In a navigation system that provides both directional and landmark information, there is a possibility that a user might not be able to identify the differences between signals after her skin has been continually stimulated with similar vibrations. Schiffman [10] suggests that introducing *discontinuity* can help stabilise sensory perception of different types of signals. This discontinuity can be achieved by increasing the number of contact points on the body, e.g. using a combination of two or more actuators to generate unique stimuli. Also suggested, this technique had not been investigated, therefore, we also examined this technique in our experiment.

To summarise, this study involved investigating the following representation techniques: (1) manipulating signal rhythms, and (2) increasing the body contact areas (i.e. increasing the number of actuators used to display information). In this paper, we refer to the two techniques as the one-actuator and two-actuator techniques respectively. Both techniques for tactile representation of landmarks were presented alone and together with tactile directional signals.

3.2 Experimental evaluation

The wearable device consisted of 8 actuators mounted in a waist belt (Figure 2). Tasks involved the system generating tactile stimuli and participants identifying perceived directions (see [11]) or landmarks by choosing corresponding pictures of directions or landmarks on a touch screen tablet PC. There were 20 participants: 10 males and 10 females with an average age of 29. Participants were given training prior to each session.

Each directional tactile stimulus involved actuation of one motor and consisted of 12 repetitions of signals at 50-millisecond pulse and inter-pulse duration [11]. Figure 1 illustrates signal rhythms used in the one-actuator conditions.

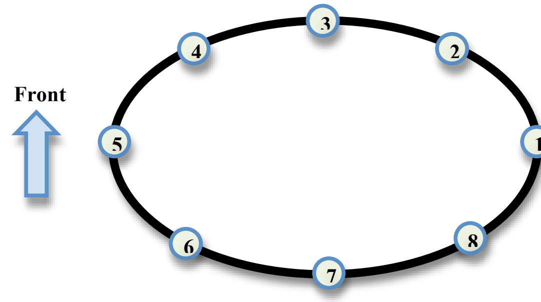

Figure 2. The Waist Belt Prototype (Motor number 3 is the front centre actuator.)

For the two-actuator conditions, the set of actuator pairs were (see Figure 2 for referents of actuator numbers):

- the 180° distance actuator pairs (were 3-7, 2-6, 1-5, and 4-8 pairs);
- the 90° distance actuator pairs (were 1-3, 2-4, 3-5, 4-6, 5-7, 6-8, 7-1 and 8-2 pairs);
- the 135° distance actuator pairs (were 1-4, 2-5, 3-6, 4-7, 5-8, 6-1, 7-2, and 8-3 pairs).

There were 5 experimental conditions: (1) direction, (2) landmark one-actuator, (3) landmark one-actuator + direction, (4) landmark two-actuator and (5) landmark two-actuator + direction signals. Measurements included learnability, memorability and distinguishability of landmark signals and their associations, and users' preferences. Conditions were counterbalanced across participants. Vibration signals in all conditions for each participant were generated in a pseudo-random order. In addition, vibration signals and meaning associations were counterbalanced amongst participants.

3.3 Results

For learnability, results indicated that training requirements for both landmark representation techniques were significantly more than those for direction representation. No significant difference was found in learnability between the one-actuator and the two-actuator techniques ($p > .05$).

In order to measure memorability, we distracted participants with interviewing and questionnaire sessions before asking them to repeat conditions 2 and 4. Results indicated that there was no significant difference in forgetting rates between the two landmark representation techniques ($p > .05$).

With respect to distinguishability, participants performed equally well in terms of accuracy (approximately 80%) and response time (average 4 seconds per signal) with either landmark representation technique in experimental conditions 2 and 4 (in which landmark signals alone were displayed).

However, when the landmarks were presented together with directional information (in conditions 3 and 5), participants performed significantly better with the two-actuator technique

(81% accuracy) than with the one-actuator technique (68% accuracy), $p < .01$.

As for subjective preference between the two landmark representation techniques, 12 participants (60%) preferred the two-actuator to the one-actuator techniques.

In conclusion, results suggested that overall the two-actuator technique was better than the one-actuator technique. In addition to being preferred by participants, the two-actuator technique provided better performance when landmarks were presented together with directional signals. This is crucial to the development of a tactile pedestrian navigation system that provides both directional and landmark information.

4. SUMMARY AND NEXT STEPS

The empirical studies reported briefly in this paper form part of an ongoing research programme investigating the use of tactile displays to support pedestrian navigation. The user-based survey was used to identify and classify the use of various types of landmarks for different navigation purposes (see Table 1). Following on from this study, the experimental study implemented and evaluated a prototype wearable tactile interface for indicating direction and type of landmarks. Results suggest that using a two-actuator approach to representing landmarks and directions on a wearable device for pedestrian navigation may be fruitful.

Our next steps are to refine the tactile navigation prototype for use in field trials in an urban area. Through these investigations, we will evaluate the design and address performance-related benefits and challenges of our tactile pedestrian navigation system.

5. APPENDIX: The set of landmark types used in the user survey study

Airports, Amusement parks, At the water (ocean and sea) , Attractions/Tourist attractions, Bars and Pubs , Bridges, Camping areas, Car rentals, Cash dispensers (ATM), Casinos, Cinemas, Educational institutes, Fairs & Conventions, Ferries, Financial services (Banks), First aids, Golf courses, Government facilities, Hospital healthcares, Hotels, Internet/Wi-Fi , Libraries, Malls and Markets (shopping centre, supermarket), Monuments & Memorials, Mountains, Music & Culture venues, Museums & Galleries, Natural barriers (any object that prevent you from moving forward, e.g. roads.), Parking, Party & Clubbing, Pedestrian lights, Petrol stations, Police, Post office, Public transports (bus/tram/boat stations), Railway stations, Recreation grounds, Religious places (church/cathedral/etc), Restaurants, River, Sports facilities, Stadiums (sports), Taxis, Theatres, Toilets, Travel agencies, Traffic lights, Tourist information, Tunnels, Other landmarks

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