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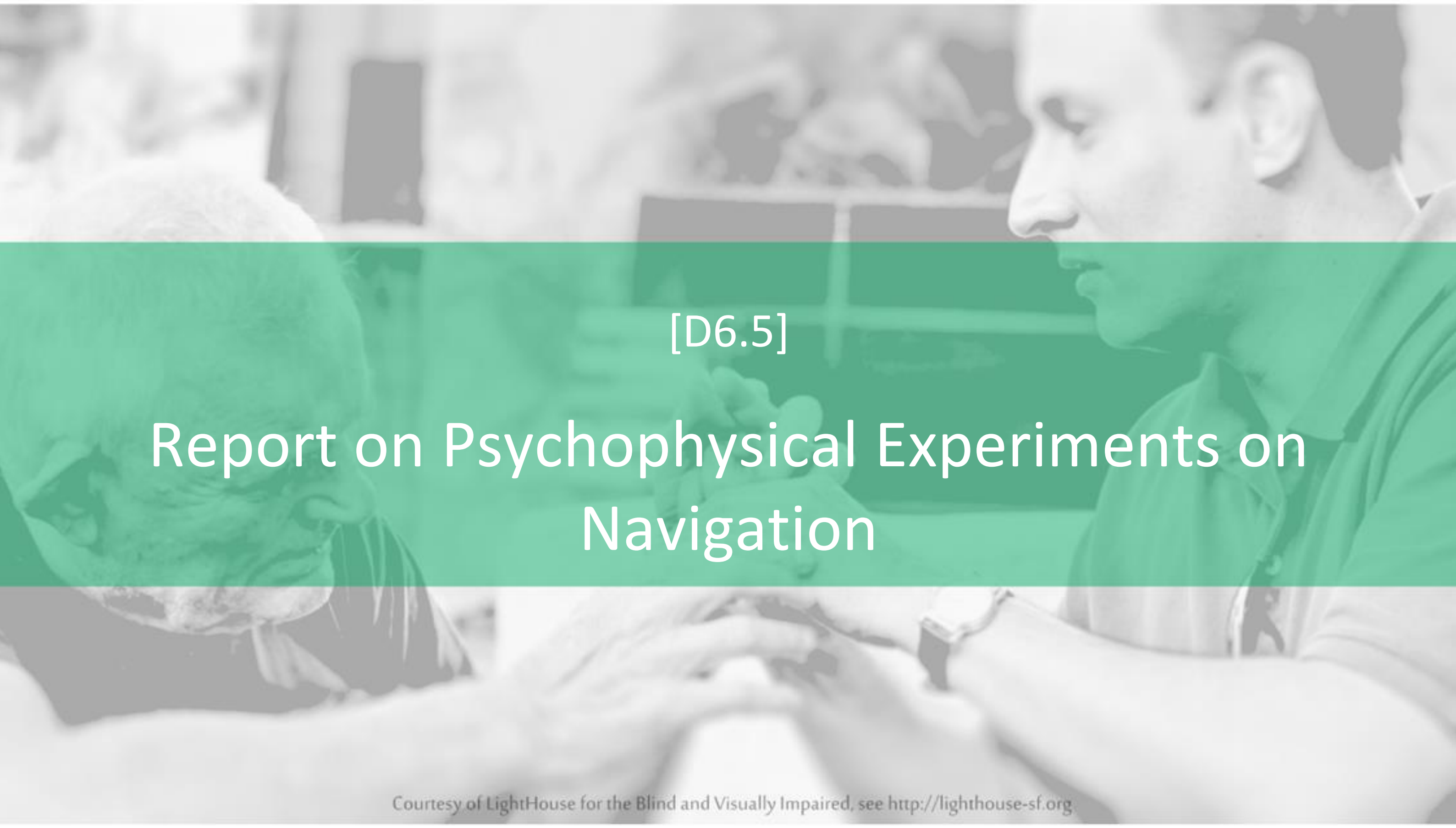
SUITCEYES

1 Jan 2018 - 31 Dec 2020

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces



[D6.5]

Report on Psychophysical Experiments on Navigation

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
PU	PUBLIC, fully open, e.g. web	X
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R	Document, report (excluding the periodic and final reports)	X
DEM	Demonstrator, pilot, prototype, plan designs	
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OTHER	Software, technical diagram, etc.	

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Glossary	
Abbr./ Acronym	**Meaning**
HIPI	Haptic Intelligent Personalised Interface
QB	Quadrant-Based
TBT	Turn-by-Turn

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Executive Summary

The focus of WP6 is on establishing and evaluating the use of haptic signals in an exemplar navigation task. Previous deliverables in this work package have established the spacing and arrangement of vibrotactile motors to provide a variety of haptic signals, including vibrotactile haptograms – signs drawn on the back using an array of vibration motors. The focus of this deliverable is on evaluating the use of such haptograms for navigation purposes through a pilot experiment using the prototype HIPI developed in D4.3. The deliverable first provides an overview of the literature on the use of haptic signals for navigation while walking. The experiment presented compares two navigation approaches to guide the HIPI user to a target location or object. The first approach provides a turn-by-turn guidance to the user and the second approach divides the space into a grid system where the HIPI user receives information about his/her relative location in the room and the relative location of the target. Two haptic feedback mechanisms are considered in testing both navigation approaches; a vibrotactile belt on the waist area; and a vibrating grid on the back area. It is found that both haptic feedback methods are feasible for navigation, though the tactile belt was found to be more intuitive and reliable. Turn-by-Turn navigation using both feedback methods was found to be more intuitive and initially faster than the grid-based approach, but the grid-based approach offered better self-orientation for the user and showed significant improvements in time with practice.

Introduction

This report describes the experiments carried to explore the use of the HIPI developed in D4.3 for delivering haptic signals for navigation purposes. The report begins with an overview of existing literature on the subject, before moving on to describe the experiments themselves. The experiments compare a conventional tactile-belt based approach to navigation, with more novel approaches – delivering social haptic signals for direction via the HIPI's vibrotactile back array; and an approached based around giving co-ordinates to aid the user in producing a mental map to orient themselves in the environment. The report finishes by discussing potential future work that could build upon this. With COVID-19 lockdown restrictions having restricted access to both laboratory facilities and participants, the testing presented here is necessarily limited, but it demonstrates a number of promising routes for future exploration.

Literature Review of Haptic Navigation Aids for Walking

Background

There have been many Electronic Travel Aids developed in the last two decades, particularly as technologies such as smartphones have made location services such as GPS more accessible. Combining such devices with haptic feedback in order to aid people with visual impairments in navigating their environments has received a lot of attention in the academic literature. In order to inform the development of the Haptic Intelligent Personalised Interface (HIPI) in the SUITCEYES project, a review of the literature on haptic navigation aids for walking was undertaken. The methods and summaries of the papers identified are given in Annex A. This section will focus on the lessons learned from the review.

Insights

The most common approach to haptic navigation for walking identified was the vibrotactile belt: where an array of vibration motors are arranged around the waist or torso, and a given column of the array is actuated to indicate direction. Out of a total of 40 papers identified for detailed review, 22 referred to some variant of this approach. In all but one case, the direction was intended to be the direction in which the user should travel. The exception was Wang et al [39], where vibration indicated the direction of obstacles to be avoided. The precise format of the vibrotactile signals varied, with some attempting to indicate both distance and direction, though this was found to reduce successful recognition of signals. Three studies explored the use of "waves", where a sequence of vibration motors around the belt would be triggered to indicate the direction to turn, but these were found to be less successful than a single motor or column indicating the direction [5,6,8].

Other approaches were identified, but none nearly as common as the vibrotactile belt. Four papers studied the use of tactile feedback on the shoulders, with a stimulus on the corresponding shoulder indicating whether to turn left or right and either both shoulders or an additional actuator between the shoulders to indicate the need to move forwards. The stimuli were delivered variously through vibration motors [25], contact speakers [26,27] or pneumatic air bags [34]. One paper studied a similar use of vibration motors attached to the forefinger and thumb when holding a PDA, and vibrating one digit or the other to indicate the direction to turn [13]. Two papers explored a similar use of vibration motors attached to each wrist [2] or each forearm [4] and actuating the motor on the left or right arm to indicate the need to turn in the given direction. Three papers explored the use of a single cuff or bracelet whereby a clockwise or counterclockwise rotating signal could be sent to indicate which direction to turn, though these a variety of methods of tactile stimulation: DC motors sliding a cuff [3], an array of vibration motors indicating direction through their sequence [29] or an array of foam brushes attached to small DC motors to provide a brushing rather than vibrating stimulus [33]. One paper [30] described a more unusual, shape-changing device that had a physical arrow pointing towards the target destination.

Several papers report devices based around a square array of vibration motors on the back [11, 18, 31] or foot [38]. In most cases, directions were given by actuating each column or row in turn, generating a movement in the direction the user needed to move (left, right, forwards or backwards). Only one paper compared these with the vibrotactile belt approach [31] but found that the belt was more effective at giving recognizable directions than the array.

All papers reported that users were able to follow these haptic signals to reach a destination and that they could be learned without extensive training. Where these were compared with visual guidance (signs or map apps), it was found that the tactile aids imposed lower cognitive load [24,25] than visual or audio instructions. In all cases, the aim was wayfinding, steering the user towards a target destination, either at a detailed level by trying to keep them on a specified path, or at a higher level by steering them towards given waypoints.

Conclusions

Tactile belts indicating the direction to turn are well-established and have proven to be intuitive and effective as a method of haptic guidance for navigation while walking. While recognition of signals is less successful when in motion compared with static experiments, they have still been used successfully in multiple field tests to navigate a walking individual to a destination, with few errors. The use of more simple signals through a back matrix has also been attempted, though when compared with a tactile belt this was found to be less successful. Accordingly, we will take the tactile belt as an effective baseline to incorporate into the HIPI for direction signaling, with which to compare alternative strategies.

One noticeable absence in the literature was information to convey to the user where they are, rather than just where the target is relative to them. The devices all aimed to keep the user on a given route, or heading towards a target, but gave no information to help the user orient themselves with respect to the environment. Based on information from the WP2 interviews, and discussions with the members of our advisory board who were deafblind, the ability to identify where they were in the environment was important, and was therefore something we wished to incorporate in our study.

Navigation Experiments

The navigation experiments' aim is to examine the viability of using haptics to guide people with deafblindness to navigate toward a point of interest. Two experimental setups (modes) are designed to examine the use of tactile signals for navigation. The two modes differ in the frequency and nature of information communicated to the user. The first approach (turn-by-turn) is based on communicating directional haptic signals and the second approach (grid) is based on communicating relative position signals.

The turn-by-turn approach represents a conventional approach used in many of the tactile belt studies and represents an egocentric frame of reference (identifying where things are in relation to yourself). By contrast the grid-based approach represents an attempt to replicate the method of sketching out an environment used in Social Haptic Communication approaches developed by Russ Palmer and Riitta Lahtinen on our advisory board. In their approach, the walls of a room are drawn on the back of the person with deafblindness using a finger, and their own location and points of interest (windows, doors, where given individuals are. etc) is indicated by drawing signs in relevant positions on the back, allowing the person with deafblindness to develop a mental map of the space around them. This represents an allocentric frame of reference (identifying where things are and where one is in relation to the environment). Such detailed sketching is impossible with the haptic feedback at our disposal, so we proposed a coordinate-based approach, whereby a space would be divided into a grid of quadrants and co-ordinates be conveyed haptically as described below, to aid the user in developing a mental map.

The trials are designed in the format of treasure hunt games where the user enters a room and locates a predefined object that was randomly placed inside the room. Two HIPI-embedded tactile mechanisms (belt and back array) were examined for each navigation approach. The performance was assessed quantitively using the navigation time and path length, and qualitatively through direct monitoring and post-experiment discussions with participants. Haptic signals were sent by the experimenter, using a "Wizard of Oz" approach.

Methods

Four different trials were tested with each participant:

a. Turn-by-turn navigation using vibration around waist (TBT-Belt).
b. Turn-by-turn navigation using a vibrating grid on the back (TBT-Matrix).
c. Quadrant based navigation using vibration around waist (QB-Belt).
d. Quadrant based navigation using a vibrating grid on the back (QB-Matrix).

The navigation setup for (a, b) and (c, d) is shown in figure 1. In each trial, the user started outside the room, with ears and eyes covered, until receiving a start signal to enter the room and search for the target object. The object used in these trials was a standard size water bottle that is placed in a number of possible places inside the room. These placement points and obstacles configuration were not shared with participants beforehand.

In quadrant mode, illustrated in figure 1 (Right) the space is divided into quadrants. In a typical room size, a single layer of sectioning might be sufficient. In a slightly larger room, more layers of sectioning can be done. In the example shown in the figure, which was used in trials, uses two layers, denoted by global (G1-G4) and local (L1-L4) quadrants. A counter-clockwise convention for the quadrant order is selected and fixed throughout the trials. The order of the quadrants was communicated to participants before the trials to help them navigate using position data. The user could ask the system about his/her current location, the target location, and what is in front? These queries help the user localize himself/herself with respect to the room and its borders and with respect to the target. The user was updated haptically when crossing from one quadrant to the next or when a query is sent. Only the global quadrant was displayed if the user was not in the same global quadrant as the target. If the user entered the target global quadrant, subsequent quadrant updates were based on the local frame (L1-L4).

The turn-by-turn mode assumed continuous guidance to the user. To avoid confusing the user, a new haptic signal was sent only to trigger a change in direction or avoiding obstacles. When the target was within the range of the user's hand, an 'arrived!' signal was communicated to advise the participants to move their hand to grab the object. Each haptic sequence consists of an initialization and a message. The user could interact with the system using a set of pre-defined queries. Table 1 lists the possible commands and HIPI user queries for each navigation mode.

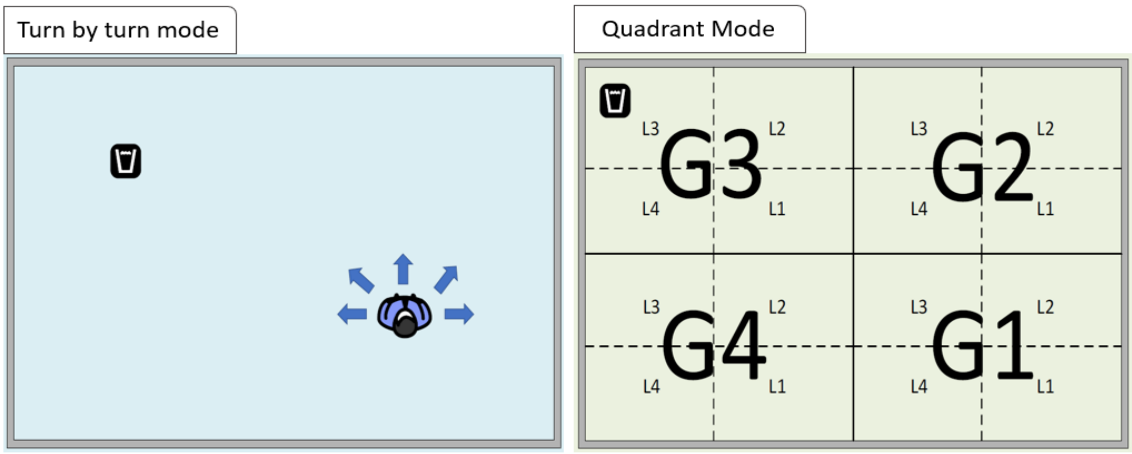


Figure 1: Navigation Modes: Turn by turn mode (Left) and Quadrant mode (Right)

Mode	Initialization	Message	Remarks	Allowed Queries
Turn by turn	Change of direction	Forward	Default	Can you repeat?
		Slightly Left	Smoother turn	
		Slightly Right	Smoother turn	
		Right	Sharp turn	
		Left	Sharp turn	
		Stop	Wall or obstacle	
		Arrived	Target reached	
Quadrant (Grid)	Relative quadrant (local or global)	Quadrant 1	Room entrance	Can you repeat? Where am I? Where is the 'target'? What is in front of me?
		Quadrant 2	Next to Q1 in CCW direction	
		Quadrant 3	Next to Q2 in CCW direction	
		Quadrant 4	Next to Q3 in CCW direction	
		Stop	Wall or obstacle	
		Arrived	Target Reached	

Table 1: Navigation Haptic Sequences Sent to the User and Queries Received from the User

Participants

The trials were carried out in the Affective Engineering Lab at the University of Leeds. Five people participated in the tests, all male and with no known visual or auditory impairments. Two participants were lab members; they were familiar with the room dimensions and general features, but they were not aware of how objects and obstacles inside the room were configured prior to trials. The rest of our participants had never been to the room and no information regarding the room size and what objects and features it contained was shared during the pre-test briefing. The briefing sheet used to introduce participants to the HIPI and haptic feedback is presented in Annex B. Before starting the trials, the participants were introduced to the different haptic signals. Vibration speed and intensity were adjusted to ensure user comfort during the test.

Set-up and Stimuli

Experiment Setup

The lab room was reconfigured to create a treasure hunt game scenario. The room is about 8.5x6.5 meters. A few static obstacles (e.g., tables, chairs, etc) were placed in the room at specific locations to limit accessible areas. Figure 2 shows an outline of the room with the door at the far-right end of the room. The room was divided into 4 equal areas (quadrants). Quadrants are further divided into smaller quadrants. In this example we have a grid of 16 cells addressed using global and local quadrant (e.g., G3L1: 1st local quadrant in the 3rd global quadrant). The entrance of the room is used to establish the relative location of each global and local quadrant. In this scenario, G1, G2, G3, and G4 corresponds to bottom right, top right, top left, bottom left positions, respectively. Local quadrants follow the same convention.

To assess the navigation performance, we needed to add to the experimental setup explicit measurements of user position and heading, so, we developed and implemented a wireless localization system inside the room based on Ultra-Wide-Band (UWB) technology. UWB enables us to log the relative position of the HIPI user inside the room. An IMU sensor was utilized to log change of heading data. Navigation inputs were sent wirelessly to the HIPI by the experiment conductor using a Bluetooth joystick. The joystick axes and buttons are mapped to trigger various initialisation and navigation messages listed in Table 1.

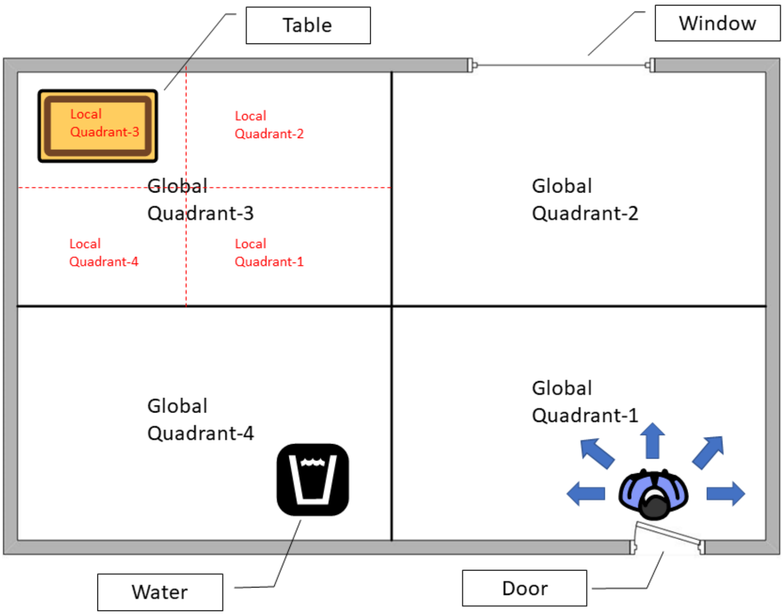


Figure 2: Room outline where trials took place, University of Leeds. In this specific case, the user stands at G1L1 (entrance) and the water bottle is located at G4L1. Shortest path from G1L1 to G4L1 depends on obstacles distribution in the room.

System Set-up

The system developed for the navigation trials consists of the prototype HIPI tactile vest, developed in D4.3, sensors to localize the user inside the room, a wireless joystick to send control signals, and a monitoring station connected wirelessly to the HIPI computer using a local wireless network, shown in figure 3. HIPI is equipped with a total of 23 vibrating motors distributed to cover three areas; 5 motors are organized in a pentagon shape around the waist, 16 motors are mounted on the back area in a 4x4 grid to display haptograms, and two vibrators around the shoulder area. The HIPI diagram and motor configuration are shown in figure 4. The onboard computer used in the HIPI is Raspberry Pi 4 running ROS (Robot Operating System) running on top of Linux Ubuntu 20.04. The monitoring/control station communicate with Raspberry Pi and monitor the experiment data over a local wireless network. The Ultra-Wide Band (UWB) system established in the room is based on DWM1001 UWB modules by Decawave. A UWB tag is connected to the HIPI and its relative distance from four anchors placed inside the room is measured to compute the relative position of the participant. The data form the RealSense camera embedded IMU (Inertial Measurement Unit) is fused to estimate the attitude and heading of the HIPI. A wireless joystick is used in the experiment to calibrate the system and send the action signals to the HIPI computer.

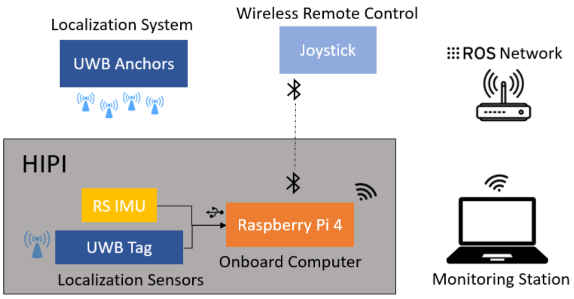


Figure 3: Experimental Setup for Navigation Trials

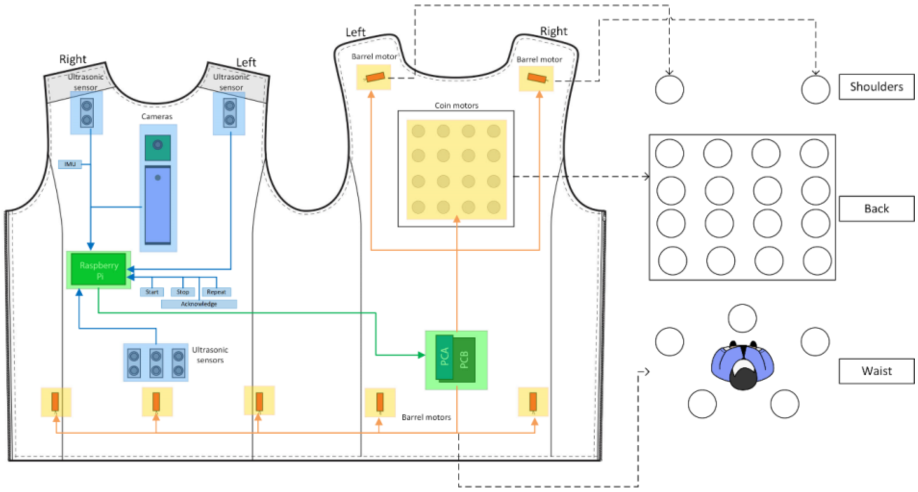


Figure 4: HIPI System with 23 embedded actuators

It is important to note that all software modules were running onboard on the Raspberry Pi computer embedded in the HIPI. The laptop shown in figure 3 is used only for monitoring purposes. The software modules include sensor management and filtering, wireless networking, motor control interface, joystick interface, action to haptic signal mapping, and logging experimental data.

Stimuli and Haptic Sequence

Two categories of haptic signals are developed to convey directions and relative positions. We list below the haptic signals for the belt and back grid (haptograms). Each one of these signals was validated with multiple users before the start of trials. Rather than replicate the patterns found in the few back array studies in the literature, we opted to base ours on existing haptic signals, drawing them from the 103 Haptic Signals provided by the Danish Association for the Deafblind[1]. Vibration switching speed and intensity can be adjusted to the preference of the participant. The first category of direction signals is relevant to the turn-by-turn navigation experiment and the second category consists of position signals which are used in the quadrant experiment. An initialization signal was sent before the main message to get the user's attention for a change in direction or position.

[1] http://www.wasli.org/wp-content/uploads/2013/07/103-Haptic-Signals-English.pdf

A. Turn-by-turn navigation – Direction Messages.

Messages: Ahead – Left – Right – Diagonal Left – Diagonal Right – Stop – Arrived.

Initialization: A single vibration on the right shoulder.

<u>Belt Direction Signals</u>

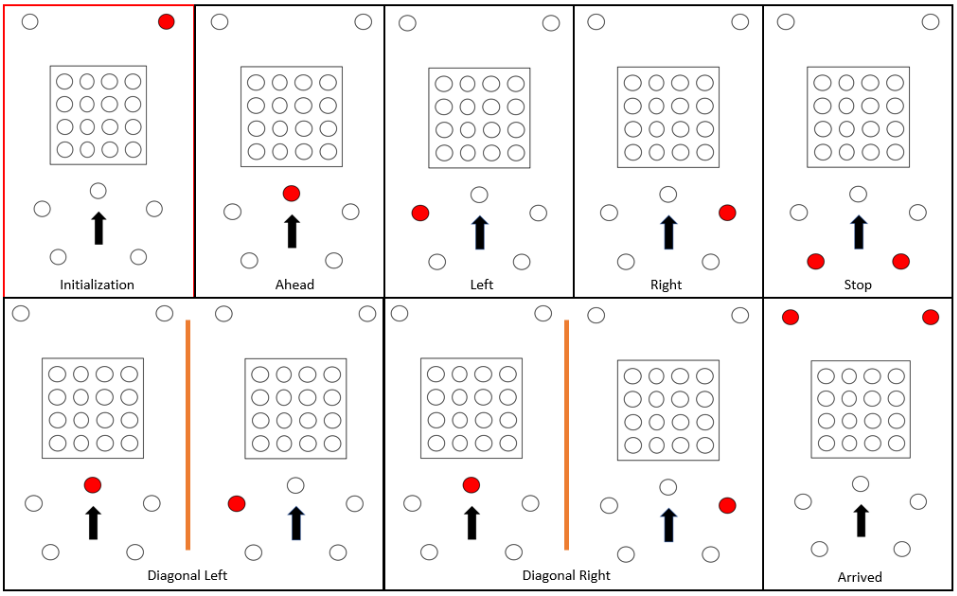


Figure 5: Direction Messages (Belt)

<u>Grid Direction Signals</u>

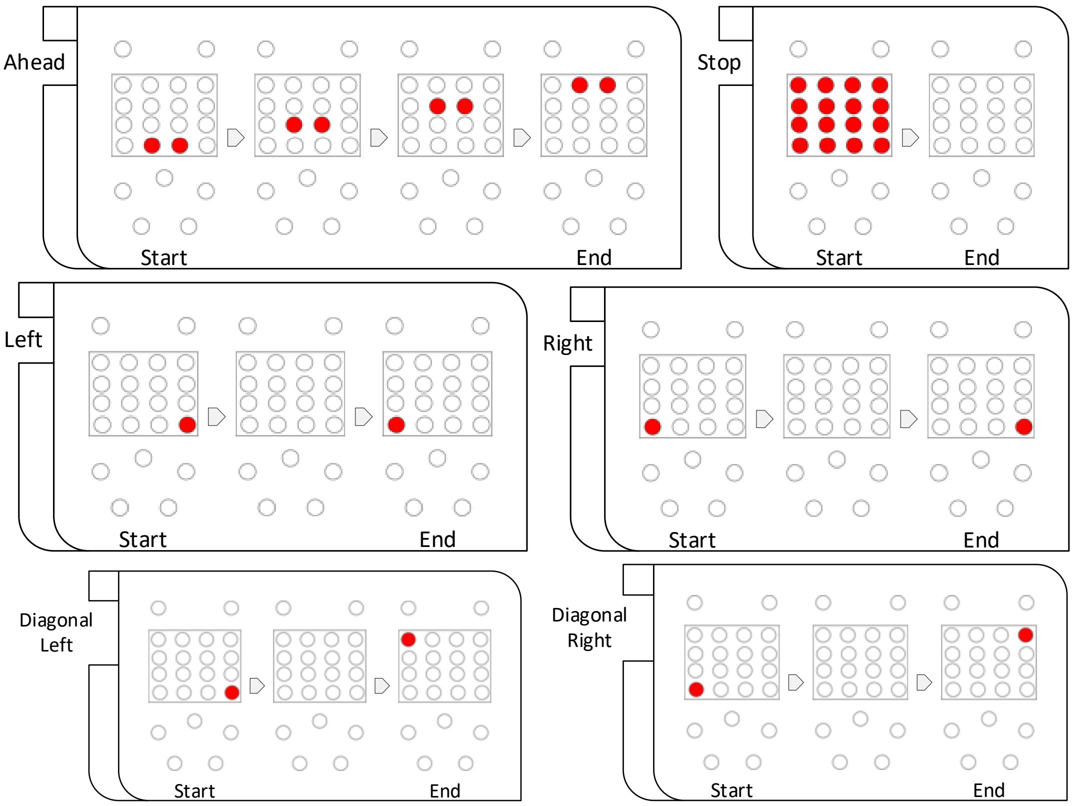


Figure 6: Direction Messages (Back Grid)

B. Quadrant-based Navigation - Relative Position Messages

Messages: Bottom Left, Bottom Right, Top Right, Top Left.

Initialization: Global Frame, Local Frame.

<u>Belt Position Signals</u>

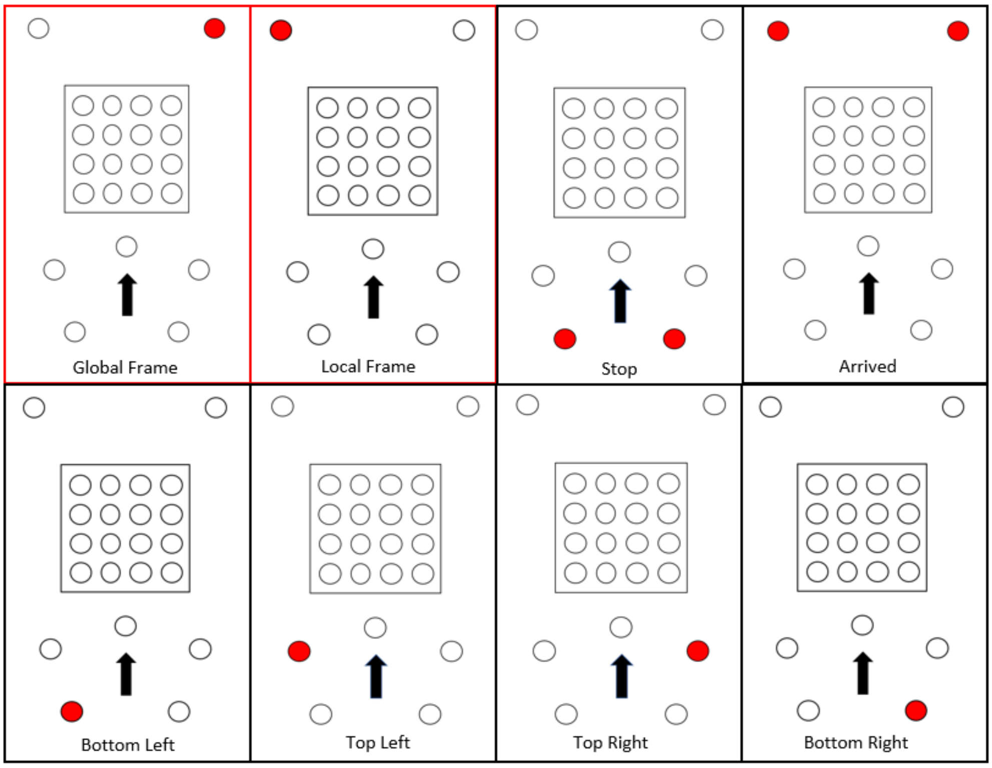


Figure 7: Position Messages (Belt)

Grid Position Signals

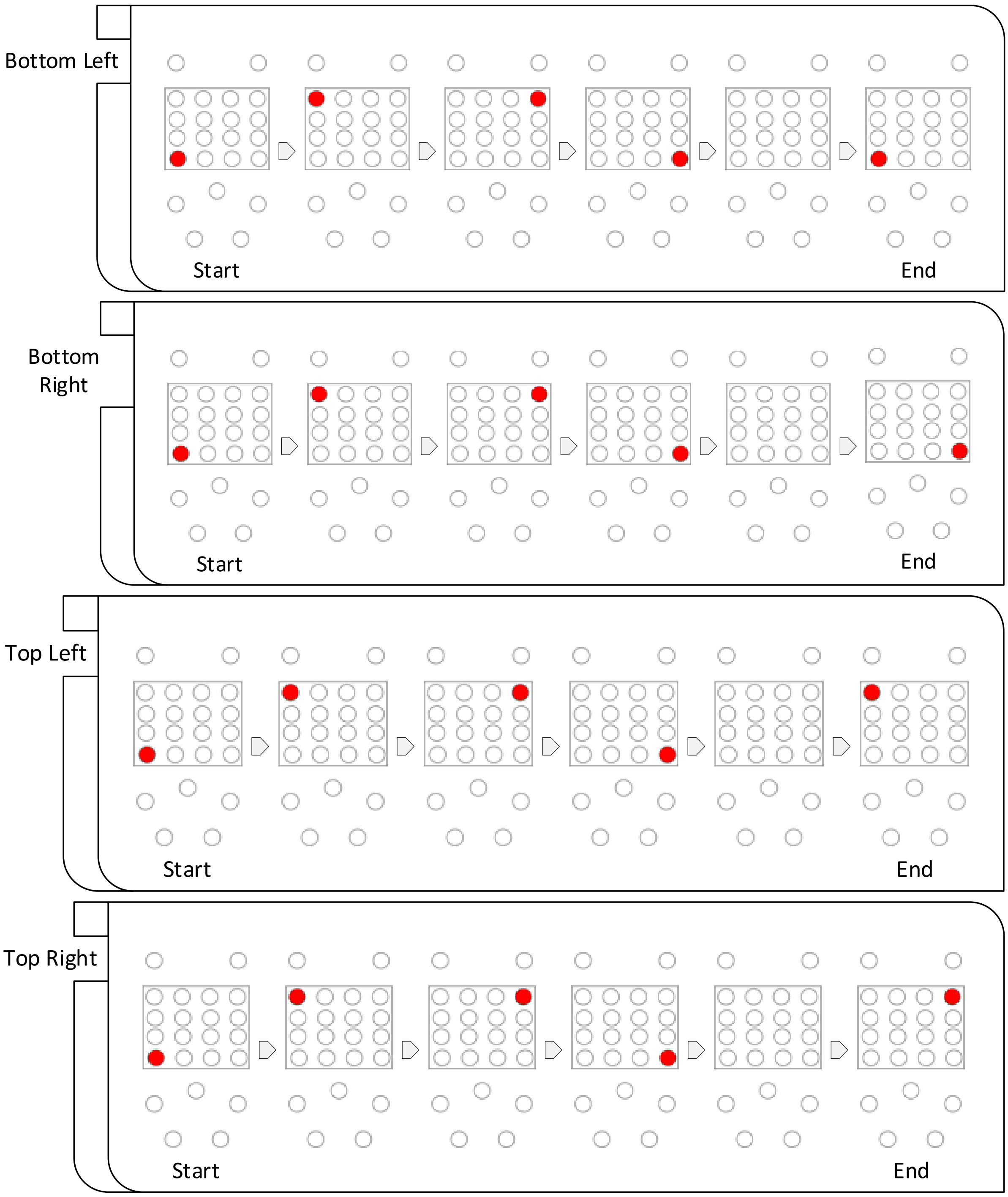


Figure 8: Position Messages (Back Grid)

Haptic Signals Flow

Haptic signals were originated by the experiment conductor and ends by executing the vibration patterns to be felt by the user. Figure 9 illustrates the flow of a signal used in these trials to communicate haptically with participants.

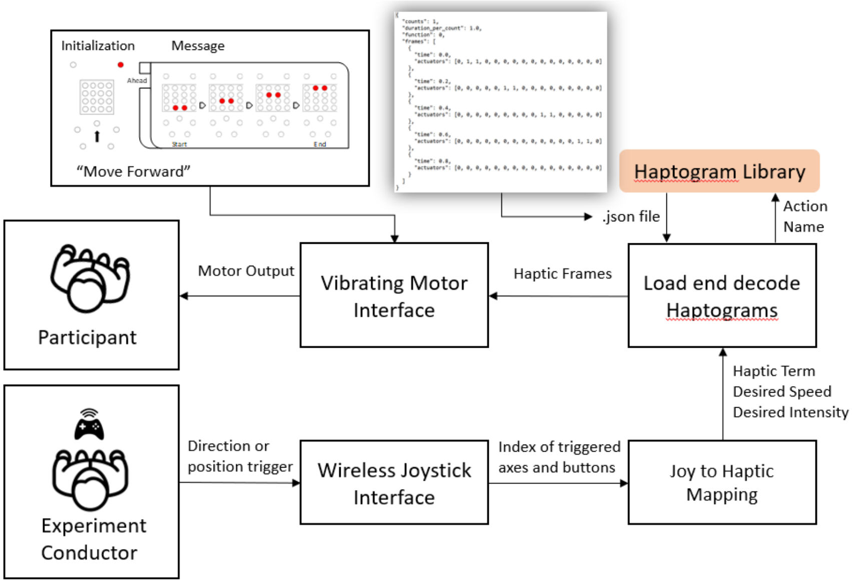


Figure 9: Haptic Signal Flow

Results

A total of 64 trials (on average ~13 trials per participants) were conducted at Leeds University using the experimental setup presented in figure 3. The trials covered both navigation modes (Turn by turn and Quadrant-based) and both haptic interfaces (belt around the waist and vibrating grid on the back). Each trial started where the participant wearing the HIPI and with eyes and ears covered stood at the door outside the room until an agreed haptic signal was sent. The door opened, the participant entered the room, and the trial commenced. The Experiment conductor was not allowed to talk to participants or move in the area but participants were allowed to ask the defined queries as often as they wished. Position and orientation data was filtered and logged for all trials using the integrated UWB tag and IMU. No timing constraints were imposed on the trials, but all participants were given the choice of terminating the trial if they give up. The target which is a standard size 1L water bottle was successfully found in all 64 trials. Once the object was found, the trial ends, and the participant was escorted outside the room to prepare for the next trial. Before discussing our findings and drawing some comparisons between modes and interfaces, we will start by presenting a sample result for each navigation mode.

Turn-by-Turn Navigation

A sample result for the turn-by-turn (TBT) navigation is shown in Figure 10. The starting position is (4.85, 5.9) and the target object is placed at ~ (0.75, 1.75). Note that coordinates are with respect to the UWB system reference frame. The origin is located at the opposite corner to where the room entrance is located. In TBT mode, the only allowed query is the request to repeat the signal. In figure 10, queries (orange circles) and feedback (green circles) times are logged during the trial and reflected on the 2D path and change of heading (black triangles) to assess performance and analyse the participant response to haptic inputs.

Haptic signals are sent to the participants to communicate only change in direction as he/she moves. In this trial, a total of 11 haptic updates are sent to the user. The initial assumption of the turn signals was based on 45 and 90 degrees turn angles, respectively. It is not the case, hence we had to send correction signals to compensate for that. The user is asked to do a smooth left turn but since it was not sufficient to head toward the target, a sharp 'left' signal is sent and then a second 'left' signal is sent to get the user on track. As the user was drifting to the left more than required, a 'right' direction signal is sent. To prevent pumping into an obstacle, the user receives a stop signal followed by a 'right' signal. This was slightly a point of confusion, the user overturned and headed almost opposite toward and opposite direction. The user stopped and asked two times to repeat the signal. The user was on track again toward the object. When the target is within hand reach and within a maximum of 45 degrees offset from the user heading, an 'arrived signal is sent to the user to prompt him/her to extend hands to grab the object. We noticed that this final phase (object grasp) is not as quick as we anticipated because small adjustments in direction overshoot. This phase (time between arrival and grasping the object) represent on average 25-40% of the total time.

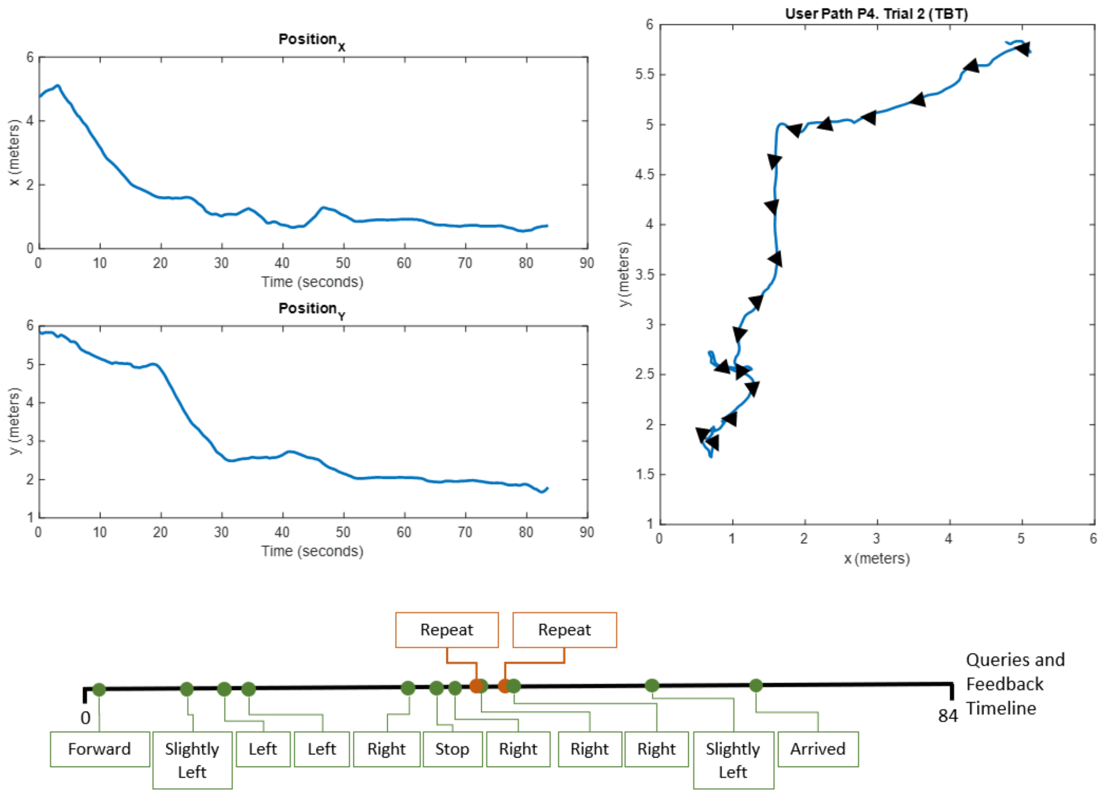


Figure 10: Turn by Turn Navigation Experiment

Quadrant-Based Navigation

This mode is slightly more challenging compared to the TBT mode because of the nature of the haptic signals sent to the user. The relative room mapping (quadrants and convention) is communicated to the user before starting the trials. The user needs to mentally connect the map with the current relative position to navigate toward the target. This mode is based on interactions between the system and the user. Haptic signals are sent when the user ask one of three allowed questions and when the user move from one global quadrant to another (G1-G4). When the user is in the same global quadrant as the target. The relative frame while moving or answering queries becomes local. Global frame reference is used again if the user exits the target's global quadrant.

Figure 11 presents one of the conducted quadrant-based navigation trials. The participant starts at (4.8, 5) and the target is placed at (3, 0.75). No direct passage from G1 to G4; it is blocked with obstacles. Typically, the first question to ask is 'Where am I?' and while participants are told the entrance lies in G1 before the trial, the question is still important because it will give the initial relative position mapping. The haptic feedback received by the user is associated with G1. In this specific configuration, it will be 'position- bottom right' haptic signal. This association and the knowing that a counterclockwise convention is assumed here for the quadrants order (G1: bottom right, G2: top right, G3: top left, and G4: bottom left). Local quadrants follow the same convention. The target is in 'G4L3' (L3 local frame in G3 global frame).

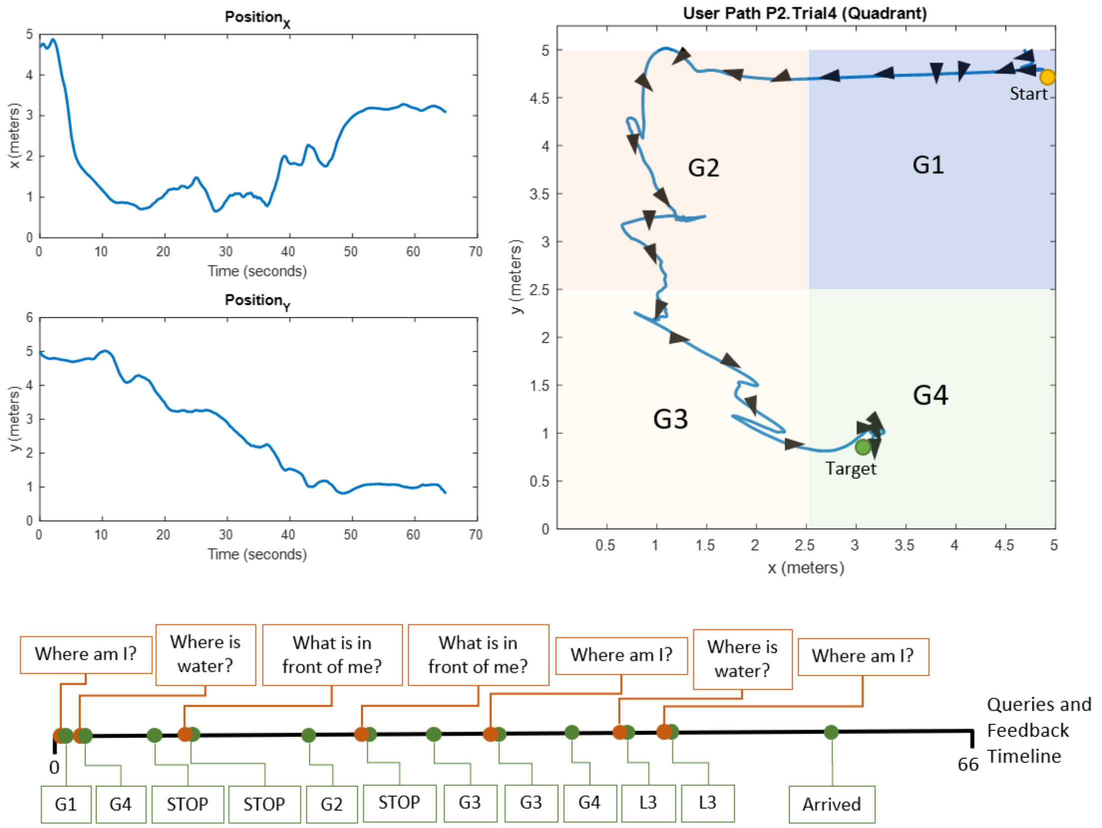


Figure 11: Quadrant-based Navigation Experiment

Before starting the search, the user should also ask about the location of the target, the haptic answer at this stage will return only the global quadrant, which is 'G4'. The user first guess after establishing the map mentally is to take the shortest path. Knowing that 'G4' is adjacent to 'G1' toward the left means that, 90 degrees left turn and moving forward is the way to get there. Since the path from 'G1' to 'G4' is blocked, the user will receive a 'stop' signal. The user chose to confirm by asking 'What is in front of me?' and received a 'stop' feedback signal again. The participant decided to walk straight as it seemed to be obstacle free. When the user walked from ‘G1’ to enter ‘G2’, an updated location ‘G2’ (position - top right) signal is received. The user wondered in ‘G2’ then entered ‘G4’ via ‘G3’. When ‘G4’ is reached, the user receives subsequent locations using the local frames ‘G4(L1-L4)’. When the target object is within reach, an ‘arrived’ signal is triggered to hint the user to proceed with grasping the target object. The user may need to rotate slightly within the local quadrant and use hands to find the object as shown in the timeline in Figure 11.

As previously mentioned, the relative position (quadrant-based) navigation mode depends heavily on queries asked by the user to continuously build a localization perception using prior information or experience. In this trial, seven queries are asked by the and 12 haptic signals are sent back to user. As trials are repeated, users tended to ask less and rely slightly more on experience. Note that repeated trials do not mean the target object is placed at the exact same location. It is moved randomly between 4 spots selected while designing the experiment. We have experienced two approaches used by participant; 1) those who ask more to reach faster, and 2) those who ask less for the favour of building better experience (do it the hard way for a potential future reward). As the number of queries increase, the quadrant navigation mode becomes very similar to the Turn-by-Turn approach.

<u>Navigation Modes and Interfaces Comparison</u>

Given the limited number of participants and trials we carried out so far due to ongoing COVID-19 lockdown restrictions, we are not here claiming a comparison that is based on deep analysis. It is still worthwhile to share our findings of running the HIPI navigation system. The comparison consists of a quantitative part and qualitative part. The quantitative part focuses on time and improvement. The quantitative part is based on direct user feedback collected during a short discussion at the end of each testing session. Table 2 presents a comparison between the four combinations of the conducted trials (TBT-Belt, TBT-Matrix, QB-Belt, QB-Matrix). Since we noticed a large time variability between participants (some tends to walk slower and some are faster in general), we will use relative timing to compare different navigation modes and haptic interfaces.

It is not surprising to know that the average quadrant-based navigation time is 2-3 times the average time of turn-by-turn navigation. However, trial time reduce rapidly as we did more trials in the case of the quadrant-based navigation while the time improvement of turn-by-turn navigation was very small. The average improvement in time for quadrant-based navigation was around 70%. This parameter indicates that QB approach motivates learning and adapting and, in some cases, surpasses the TBT performance after a few trials. The final approach, which is the time between arrival and actual object grasp forms a large portion of the total navigation time where it is exceeding 20% of the time for all trial categories. Therefore, an explicit relative heading sensing can greatly improve performance.

In line with observations from the literature, participants were more likely to confuse or miss incoming signals using the back matrix haptic interface; they were also more likely to request a ‘repeat’ of a signal with the back matrix than with the belt. It is specifically a problem with participants with wide shoulders, suggesting that greater adaptability of the motor positions within the HIPI are required. In terms of game experience, all participants found the quadrant-based navigation more enjoyable mostly because it is slightly more challenging triggering independence and learning. The level of stress is higher in the quadrant-based navigation compared to the TBT navigation. Users felt more assured and relaxed in the turn-by-turn mode because they were under continuous supervision.

Category	# Trials	Avg. Time	Avg. Grasp Time/Trial Time	Avg. # Queries	Avg. # haptic signals	Avg. Time Improv. 1st to last
TBT-Belt	14	T	34%	0	13	8%
TBT-Matrix	14	1.1 T	29%	2	15	5%
QB-Belt	17	2.3 T	24%	9	12	68%
QB-Matrix	19	2.9 T	22%	14	18	71%

Category	Confusion	Dependency	Intrusion	Joy	Room Mapping
TBT-Belt	Low	High	Intermediate	Low	Poor
TBT-Matrix	Intermediate	High	Low	Low	Poor
QB-Belt	Intermediate	Low	Intermediate	High	Good
QB-Matrix	High	Low	Low	High	Good

Table 2: Comparison Between the Four Trials Categories

Summary

This report has detailed a pilot experiment exploring the use of the prototype HIPI for navigation. COVID-19 restrictions mean that laboratory and participant access has been severely limited, so the experiments are necessarily small scale. Nevertheless, they do highlight some interesting areas. As identified in the literature review, and demonstrated in this study, tactile belts are well-established as an intuitive and effective means of giving direction signals. While our experiment has demonstrated that simple haptograms based on existing social haptic signals for direction can be delivered on the back using an array of vibration motors, the belt provides a more robust signal.

A far more interesting issue is the question of building a mental map of an area, and working out where things are, rather than just being directed through an environment with no knowledge about it. We know from our advisory board and user interviews that this is something important to people a significant number of people with deafblindness, but it is something that none of the identified literature has addressed. This represents a significant gap that warrants further investigation. In this report, we have taken the first step towards addressing this, by trying to adapt an existing method from social haptic communication for describing the position of objects to the haptic capabilities of the HIPI. The pilot study here suggests that the approach is promising. Future work will need to focus on testing this approach with persons with deafblindness, and on linking this to haptograms for objects in order to assess the ability to use it to convey information about features of interest within an environment.

Annexes

Annex A: Wearable Haptic Navigation Devices for Walking

In this text an overview is presented of existing haptic navigation devices that have been proposed, tested and published in peer reviewed papers, book chapters or conference contributions. As this overview is meant as background information for research and development of the HIPI (Haptic Intelligent Personalised Interface), only devices for the torso (back, belly, waist and chest) were taken into account. An additional requirement was that the device was intended for and actually tested during walking.

Introduction

The HIPI (Haptic Intelligent Personalised Interface) that is being developed in the SUITCEYES project is currently aimed at indoor use for both navigation and subsequent object retrieval. Users of the HIPI should be guided towards an object or location via navigation directions given by means of vibratory patterns presented to back, shoulder and/or waist. There exist studies that introduce devices that also use these specific body parts. There are also devices that are explicitly meant for indoor navigation. Here we describe the results of a literature search that has been conducted to have an overview of all relevant studies.

This research started with collecting peer-reviewed papers, book chapters and conference contributions that on the basis of their title and/or keywords seemed relevant for navigation while walking. Thus all devices meant for use in a car, aircraft or similar were excluded if possible on the basis of the title. For all papers that were included at this first stage, the references and citations were checked for relevance. And subsequently, references and citations of the so added studies were also checked. This iterative process eventually converged to a set of 536 publications.

These 536 publications were looked at in more detail by reading the abstract, looking at the method and/or checking the results and conclusions sections. Hard inclusion criteria were the following:

1. the study indeed tested navigating from one location to another location;
2. participants had to actually walk;
3. the experimental setting with several participants was well described (reproduceable);
4. not just obstacle detection;

In addition, one or both of the following criteria had to apply:

5a. body parts were waist, back, belly, chest and/or shoulder;
5b. the experimental setting was explicitly indoors.

The reason not to enforce both 5a and 5b at the same time is that these requirements focus on quite different aspects that are both relevant for the development of the HIPI. Based on these criteria 45 publications were included. Several of the 536 studies were excluded because they tested navigation in a virtual environment where participants were seated behind a console. Several other studies were excluded because they tested the recognition and suitability of several vibration patterns. And finally, many studies proposed devices for head, hand, arm, wrist or legs. Although these could be relevant for future developments of the HIPI, they were excluded at this time if they were not explicitly intended for indoor use. In total, 40 papers were identified as being relevant to this research: details of these papers are reported in Table 3, on the following pages.

Table 3: *Literature identified on Haptic Navigation Aids for Walking*

Reference	Location	Participants	Stimuli	Task	Outcome
Adame et al. [1]	Waist	(5f, 17m)	Vibration motors (various configurations around waist)	Navigate an obstacle course while blindfold.	Found to be feasible for navigation; Easy to use without training.
Aggravi et al. [2]	Left and Right Forearms	19-65 (2f, 5m)	Vibration Motors, one on each arm.	Following a predefined path	Found to be feasible for navigation; Easy to use without training.
Barontini et al . [3]	Right arm	26 (mean) (4f, 6m) VI: 51 (mean) (3f, 3m)	2 DC Motors attached to a band, worn on the upper arm. Can tighten and loosen and provide clockwise/anticlockwise tangential force.	Follow a path and avoid obstacles while blindfold.	Found to be feasible for navigation; Comfortable and easy to use; Motor returning to original position sometimes mistaken for a turn instruction; Valuable as supplement to white cane, not a replacement.
Bosman et al. [4]	Wrists	(7f, 9m)	1 vibration motor on each wrist.	Follow a pre-defined route; comparison of signage vs haptic signals. No blindfold used.	Found to be feasible for navigation; Participants found it easy to interpret turn instructions; Easier to interpret when signals were given in advance, rather than as corrective.
Cosgun et al. [5],[6]	Waist	(2f, 13m)	8 Vibration Motors arranged along belt: compared use of a single motor "tap" to indicate direction of motion or rotation and a "wave" pattern using all motors to indicate direction of rotation; also compared intermittent vs continuous signals.	Recognize patterns while walking, and follow direction signals from robot.	Participants generally able to recognize patterns; "wave" signals had higher confusion rate than "taps"; Intermittent signals preferred over continuous signals; Continuous signals had lower error rate.
Dim and Ren [7]	Ears, Wrists, Fingers, Feet, Neck.	22-37 (7f,8m)	Vibration motors (vibration on left or right side to indicate turn; vibration at neck to indicate start/stop).	Follow a pre-defined route	Found to be feasible for navigation. Walking resulted in reduced vibration perception when compared with static performance; Signals sent to feet were less well perceived than those in other locations.

Table 3, cont.

Reference	Location	Participants	Stimuli	Task	Outcome
Dura-Gil et al. [8]	Waist	(2f, 2m) VI: (1f, 3m)	Vibration (8 motors distributed around waist)	Follow a pre-defined track	Found to be feasible for navigation. Single tactors more effective for conveying turning direction than a sequence
Elliott et al [9,10]	Torso	23-40 (8m)	2 rows of 8 vibrotactor transducers, distributed evenly around belt.	Recognize defined instructions	Importance of being able to customize speed and length of signals to each individual; Participants trained to proficiency in 5 minutes. Recognition of signals and directions very good.
Ertan et al [11]	Back	19-30 (12)	4 x 4 array of vibration motors. Left, Right, Forward and Stop signals defined	Follow a pre-defined route.	Found to be feasible for navigation.
Flores et al [12]	Waist	VI: 18+ (10)	8 vibration motors, distributed evenly around belt	Follow a pre-defined path.	Found to be feasible for navigation. Tactile feedback preferred to audio feedback by participants.
Ghiani et al [13]	Finger and Thumb	27-66 (7f, 4m)	Vibration motors attached to forefinger and thumb. Vibration indicates the direction of travel.	Navigate between specified waypoints.	Found to be feasible for navigation.
Gkonos et al [14]	Waist	Mean 26.6 (2f, 8m)	8 vibration motors equally spaced around belt.	Follow a pre-defined route.	Found to be feasible for navigation.
Grierson et al [15]	Waist	(10f, 8m)	4 vibration motors, distributed evenly around the belt	Follow a pre-defined path	Found to be feasible for navigation; Reduced navigation errors in older participants, compared to relying on memory.
Heuton et al [16]	Waist	28-70 (4f, 9m)	6 vibration motors, distributed evenly around the belt.	Follow a pre-defined path.	Found to be feasible for navigation.
Johnson et al. [17]	Waist	Not Specified	14 vibration motors, distributed evenly around belt.	None	Preliminary study only: description of hardware.
Jones et al [18]	Back	22 to 26 (2f, 3m)	4 x 4 grid of vibration motors	Follow pre-defined path and instructions.	Found to be feasible for navigation.

Table 3, cont.

Reference	Location	Participants	Stimuli	Task	Outcome
Lobo et al [20,21]	Abdomen	27.6 mean (7f,4m) VI: 54.3 mean (6)	24 x 3 grid of vibration motors; intensity denotes distance, column vibrating angle to turn.	Walk to target.	Found to be feasible for navigation.
Machida et al. [22]	Ears, Wrists, Hands, Feet, Neck, Ankle	20-26 (3f, 7m)	Single vibration motor in given location	Recognize vibration pattern while walking at different speeds.	Chest and Waist perception most reduced by increased walking speed.
Ouyang et al. [23]	Waist and Chest	20-30 (5f, 15m)	6 vibration motors distributed equally around waist, 4 vibration motors distributed around chest.	Recognise displayed direction while static.	Found spatial resolution of 7.5 degrees feasible.
Pielot and Boll [24]	Waist	20-30 (7f, 7m)	12 vibration motors equally spaced around belt.	Follow pre-defined route.	Found to be feasible for navigation; Tactile information can reduce cognitive load in navigation; Orientation knowledge is important in reducing navigation errors.
Prasad et al [25]	Shoulders	20-30 (12)	5 vibration motors (one on front of each shoulder for obstacle alerts; one on back each shoulder for turning instructions; two on central back for straight forward instructions).	Follow a pre-defined route.	Found to be feasible for navigation; Lower cognitive load than audio instructions.
Ross and Blasch [26,27]	Shoulders	VI: 62-80 (15)	3 "Contact Speakers"positioned on either shoulder, and between the shoulders.	Follow straight path over road using pedestrian crossing.	Found to be feasible for navigation; enabled a straighter line than without haptic assistance.

Table 3, cont.

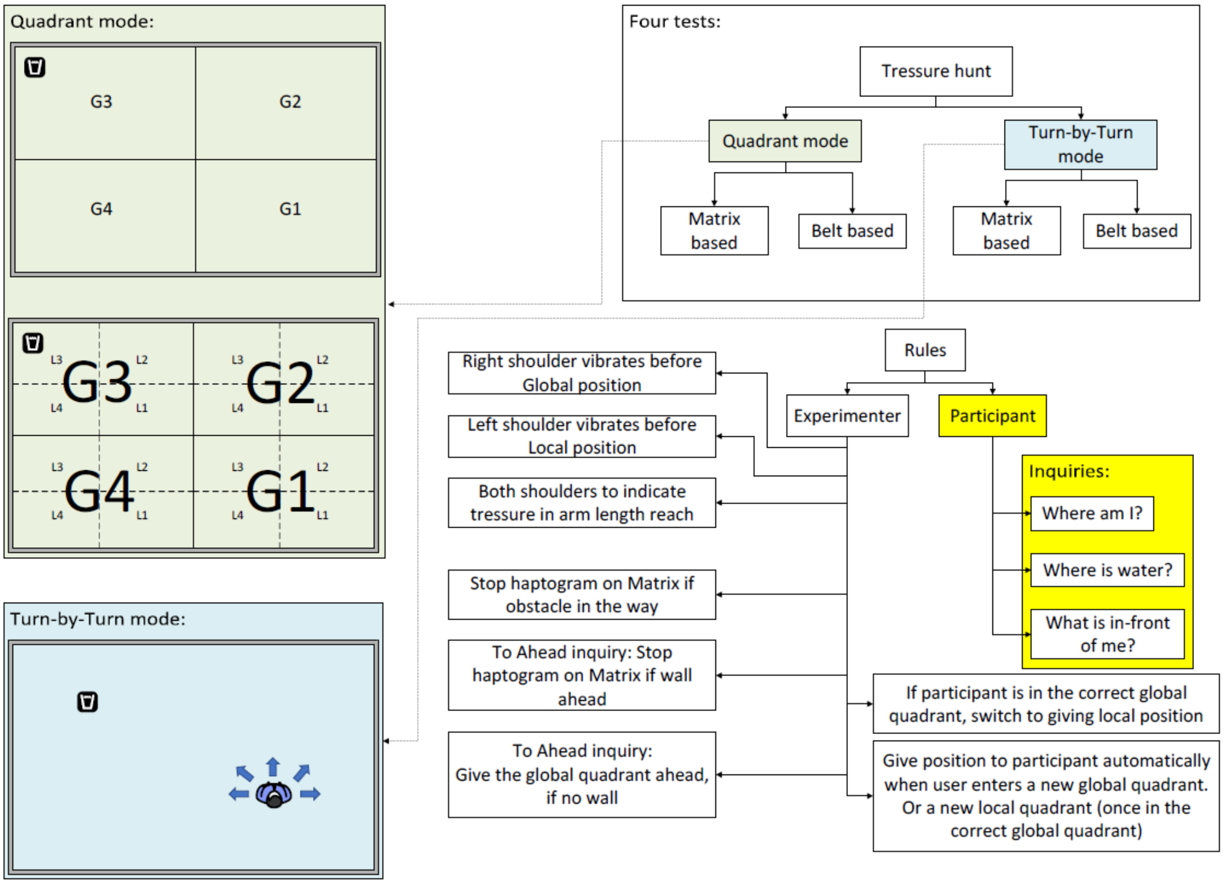
Reference	Location	Participants	Stimuli	Task	Outcome
Scheggi et al. [29]	Wrist	VI: 26-65 (4f, 6m)	2 vibration motors equally spaced around a bracelet, vibrations indicate turning direction.	Follow a defined route through a building.	Found to be feasible for navigation.
Spiers et al [30]	Hand	(77) VI: (14)	Shape-changing device where physical arrow rotated to point in required direction.	Navigate between specified waypoints.	Found to be feasible for navigation.
Srikulwong and O'Neill [31]	Back, Waist	Lab Test: 25 average (4f, 12m) Field test: 29 average (13f, 11m)	Lab test: 9 vibration motors in 3x3 array on back Lab and Field Test: 8 vibration motors equally spaced around belt	Lab test: identify displayed direction. Field test: Follow defined route through streets	Belt implementation found to be more effective at indicating direction. Belt found to be more effective than visual guidance in field test.
Steltenpohl and Bouwer [32]	Waist	26 average (4f, 16m)	8 vibration motors equally spaced around belt	Cycle along defined route.	Found to be feasible for navigation; Less distracting than visual guidance, but slower overall movement.
Strasnick et al [33]	Wrist	18-26 (4f, 6m)	6 DC motors with foam brushes spaced evenly around a bracelet. 6 Vibration motors spaced evenly around a bracelet.	Follow pre-defined route	Found to be feasible for navigation; Brushing and vibrotactile feedback equivalent in performance; Vibrotactile feedback more comfortable than brushing.
Stratmann et al. [34]	Shoulders	26-37 (3f, 9m)	Pneumatic airbags on each shoulder: increased pressure indicates direction to turn.	Follow pre-defined route.	Found to be feasible for navigation; Pneumatic and vibration systems found equally usable; Vibration rated as more "urgent".
Tsukada and Yasumura [35]	Waist	21-30 (6)	8 vibration motors equally spaced around belt.	Recognise direction of signal while stationary and walking.	Found to be feasible for navigation.
Van Erp [36]	Torso	(10m)	15 vibration motors equally spaced around torso	Identify displayed direction while stationary.	Found a systematic bias in estimated direction towards the midsaggital plane.

Table 3 concluded.

Reference	Location	Participants	Stimuli	Task	Outcome
Velázquez et al [38]	Feet	18-24 (10f, 10m) VI: 13-32 (1f, 4m)	4 x 4 grid of vibration motors on base of foot. Direction indicated through a dynamic line moving across the grid; other shapes and patterns presented.	Recognize presented patterns.	Found to be feasible for navigation
Wang et al [39]	Waist	(60)	6 x 2 array of vibration motors at front of waist; 2x2 at back of waist. Columns indicate direction to travel.	Follow a pre-defined path.	Found to be feasible for navigation.
Wang et al. [40]	Waist	VI: (11)	5 vibration motors arranged around belt. Vibration denotes direction of obstacles.	Navigate pre-defined routes.	Found to be feasible navigation; Fewer collisions than with cane.

For participants, first the age range is given in years (if known) and between brackets the number of participants (f indicates females, m indicates males, where this information is available). “VI” denotes visually impaired participants.

Annex B: Navigation Tests Briefing Sheet



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