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Head-mounted Sensory Augmentation Device: Comparing Haptic and Audio Modality

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Abstract. This paper investigates and compares the effectiveness of haptic and audio modality for navigation in low visibility environment using a sensory augmentation device. A second generation head-mounted vibrotactile interface as a sensory augmentation prototype was developed to help users to navigate in such environments. In our experiment, a subject navigates along a wall relying on the haptic or audio feedbacks as navigation commands. Haptic/audio feedback is presented to the subjects according to the information measured from the walls to a set of 12 ultrasound sensors placed around a helmet and a classification algorithm by using multilayer perceptron neural network. Results showed the haptic modality leads to significantly lower route deviation in navigation compared to auditory feedback. Furthermore, the NASA TLX questionnaire showed that subjects reported lower cognitive workload with haptic modality although both modalities were able to navigate the users along the wall.

Keywords: Sensory augmentation, haptic feedback, audio feedback, classification algorithm

1 Introduction

Sensory augmentation is an exciting domain in human-machine biohybridicity that adds new synthesized information to an existing sensory channel. The additional senses provided by sensory augmentation can be used to augment the spatial awareness of people with impaired vision [1, 2, 3, 4, 5] or for people operating in environments where visual sensing is compromised such as smoked-filled buildings [6, 7, 8].

The sensitive tactile sensing capabilities supported by facial whiskers provide many mammals with detailed information about local environment that is useful for navigation and object recognition. Similar information could be provided to humans using a sensory augmentation device that combines active distance sensing of nearby surfaces with a head-mounted tactile display [6, 7]. One of the attempts to design such a device was the ‘Haptic Radar’ [7] that linked infrared sensors to head-mounted vibrotactile displays allowing users to perceive and respond simultaneously to multiple spatial information sources. In this device, several sense-act modules were mounted together

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on a band wrapped around the head. Each module measured distance from the user to nearby surfaces, in the direction of the sensor, and transduced this information into a vibrotactile signal presented to the skin directly beneath the module. Users intuitively responded to nearby objects, for example, by tilting away from the direction of an object that was moving close to the head, indicating that the device could be useful for detecting and avoiding collisions. Marsalia [9] has evaluated the effectiveness of a head-mounted display in improving hazard recognition for distracted pedestrians using a driving simulator. Results showed that response hit rates improved and response times were faster when participants had a display present.

The above studies indicate the value of head-mounted haptic display for alerting wearers to possible threats. The ‘Tactile Helmet’ [6] was a prototype sensory augmentation device developed by the current authors that aimed to be something more than a hazard detector—a device for guiding users within unsafe, low-visibility environments such as burning buildings. We selected a head-mounted tactile display as this facilitates rapid reactions, can easily fit inside a modified fire-fighter helmet, and leaves the hands of the firefighters free for tactile exploration of objects and surfaces. Our first generation device (see Fig.1) comprised a ring of eight ultrasound sensors on the outside of a firefighter’s safety helmet with four voice coil-type vibrotactile actuators fitted to the inside headband. Ultrasound distance signals from the sensors were converted into a pattern of vibrotactile stimulation across all four actuators. One of the goals of this approach was to have greater control over the information displayed to the user, and, in particular, to avoid overloading tactile sensory channels by displaying too much information at once.

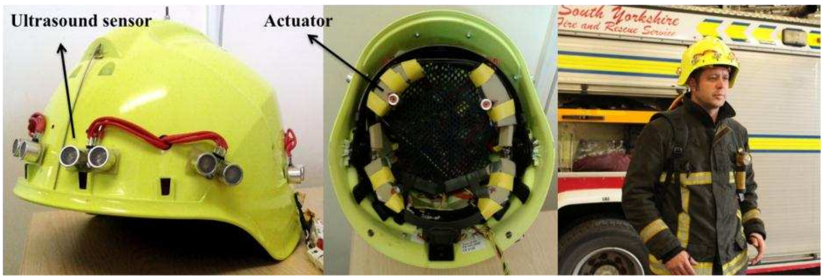

Fig. 1. The first generation ‘Tactile Helmet’ [6] was composed of a ring of ultrasound sensors and four actuators inside the helmet and was designed to help firefighter’s navigate inside smoked-filled buildings.

Auditory guidance in the form of non-verbal acoustic sound or synthetic speech is another means for providing augmented navigation information for people with visually impairments or for rescue workers [3, 4, 5].

The effectiveness of haptic and audio modalities have been compared in a number of augmented navigation tasks with mixed results. For example, in [3], audio and haptic interfaces were compared for way finding by blind pedestrians and it was found that haptic guidance resulted in closer path-following compared to audio feedback. Marston et al. [10] also evaluated nonvisual route-following with guidance from audio and haptic display. Their results showed that haptic feedback produced slightly faster path completion time and shorter distance, however, there was no significant difference between audio and haptic modality. In [11], multimodal feedback strategies (haptic, audio and combined) were compared. Whilst there were no significant differences between modalities in navigation performance, subjects reported that the audio guidance was less comfortable than others. Kaul et al. [12] have evaluated audio and haptic guidance in a 3D virtual object acquisition task using HapticHead (a cap consisting of vibration motors) as a head-mounted display. User study indicated that haptic feedback is faster and more precise than auditory feedback for virtual object finding in 3D space around the user. Finally, in [13] haptic and audio modalities were compared in terms of cognitive workload, in a short-range navigation task, finding that workload was lower in haptic feedback compared to audio for blind participants.

The aim of the current paper is to evaluate and compare audio and haptic guidance for navigation using a head-mounted sensory augmentation device. We designed a second-generation vibrotactile helmet as a sensory augmentation device for fire fighters' navigation that sought to overcome some of the limitations of our first prototype (Fig. 1) [6] such as low-resolution tactile display. We previously investigated how to design our tactile interface worn on the forehead [14] to present useful navigational information as a tactile language [15]. Here, we use this tactile language to generate haptic guidance signals and compare this to audio guidance in the form of synthetic speech. In order to simulate a wall-following task similar to that faced by fire-fighters exploring a burning building, we constructed temporary walls made of cardboard in the experimental room and asked subjects to follow these walls using the two alternative guidance systems. The vibrotactile helmet uses ultrasound sensors to detect the user's distance to the walls and then a neural network algorithm to determine appropriate guidance commands (Go-forward/Turn right/Turn left). We evaluated the effectiveness of haptic and audio guidance according to the objective measures of task completion time, distance of travel and route deviation, and subjective measure of workload measurement using NASA TLX questionnaires.

2 Method

2.1 Subjects

Ten participants - 4 men and 6 women, average age 25 - voluntarily took part in this experiment. All subjects were university students or staff. The study was approved by the University of Sheffield ethics committee, and participants signed the informed consent form before the experiment. They did not report any known abnormalities with haptic perception.

2.2 Vibrotactile helmet

The second generation vibrotactile helmet (Fig. 2) consists of an array of twelve ultrasound sensors (I2CXL-MaxSonar-EZ2 by MaxBotic), a tactile display composed of 7 tactors (Fig. 2 (b)) [14], a sound card, a microcontroller unit and two small lithium polymer batteries (7.4 V) to provide the system power. Furthermore, five reflective passive markers were attached to the vibrotactile helmet surface (Fig. 2 (d)) to enable us to track the user's position and orientation using Vicon motion capture system.

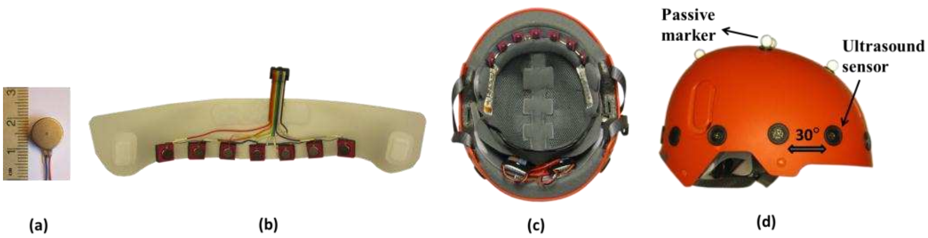

Fig. 2. (a) Eccentric rotating mass vibration motor (Model 310-113 by Precision Microdrives). (b) Tactile display interface. (c) Tactile display position inside the helmet. (d) Vibrotactile helmet.

Twelve ultrasound sensors were mounted with approximately 30 degrees separation to the outside of a skiing helmet (Fig. 2 (d)). The ultrasound sensors are employed sequentially one at a time. A minimum pulse-pause time of 50ms is maintained between consecutive readings to make measurements more stable against ultrasound reflections. Using a 50 ms pulse-pause time, a complete environmental scan is accomplished every 0.6 s. The practical measuring range by this ultrasound sensor is between 20 cm and 765 cm with 1 cm resolution. The tactile display consists of seven eccentric rotating mass (ERM) vibration motors (Fig. 2 (a)) with 3V operating voltage and 220Hz operating frequency at 3V. These vibration motors are mounted on a neoprene fabric and attached on a plastic sheet (Fig. 2 (b)) with 2.5 cm inter-tactor spacing which can easily be adjusted inside the helmet. Furthermore, a sound card was connected to the microcontroller to produce the synthetic speech for audio modality. The ultrasound sensors data are sent to the microcontroller through I2C BUS. The microcontroller in the helmet reads the sensors values and sends them to the PC wirelessly using its built-in WiFi support. The PC receives the sensor values and performs the required processing then generates commands, sending them back to the microcontroller wirelessly for onward transmission to the tactile display/sound card.

2.3 Haptic and audio guidance

In low visibility environments, firefighters navigate using the existing infrastructure such as walls and doors. These reference points help them to stay oriented and make a mental model of the environment [16]. To facilitate this form of navigation behavior we used a wall-following approach inspired by algorithms developed in mobile robotics that maintain a trajectory close to walls by combining steering-in, steering-out and moving forward commands [17]. Specifically, to navigate the user along the wall, we utilized three commands: turn-left, turn-right, and go-forward. The turn-left/right commands are intended to induce a rotation around the user (left/right rotation) in order to control the orientation of the user; the go-forward command is intended to induce forward motion. These three commands are presented to users in the form of haptic and audio feedback.

Haptic feedback in the form of vibrotactile patterns is used to present the commands to the user through the vibrotactile display. Fig. 3 illustrates the positions of tactors in the vibrotactile display and vibrotactile patterns for presenting different commands. Note that tactor 4 is placed in the center of forehead. The turn-left command starts from tactor 3 and ends with tactor 1 while turn-right starts from tactor 5 and finishes with tactor 7. Go-forward command starts from tactor 3 and tactor 5 simultaneously and ends with tactor 4. We already investigated the utility and user experience of these commands as our tactile language using the combination of two command presentation modes— continuous and discrete and two command types— recurring and single [18]. Results showed that "recurring continuous (RC)" tactile language improved the performance better than other commands.

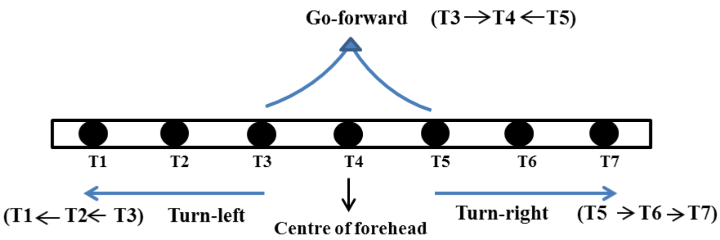

Fig. 3. Vibrotactile patterns for presenting turn-left, turn-right and go-forward commands in the tactile display.

The continuous presentation mode takes advantage of the phenomena of tactile apparent movement [19]. Specifically when two or more tactors are activated sequentially within a certain time interval, subjects experience the illusionary sensation of a stimulus travelling continuously from the first stimulation site to the second. The two main parameters that control the feeling of apparent motion are the duration of stimulus (DoS) and the stimulus onset asynchrony (SOA) [20]. In the current study, a DoS of 400ms and a SOA of 100ms were utilized respectively. This results in a total rendering time of 600ms for turn right/left commands and 500ms for go-forward command. However, in the discrete presentation mode the tactors are activated sequentially with no stimulus overlap that creates the experience of discrete motion across the forehead for all three commands. As command type, recurring condition presents the tactile command to the user's forehead repeatedly with interval between patterns of 500ms until a new command is received; while for the single condition the tactile command is presented just once when there is a change in the command. A schematic representation of continuous command presentation and recurring command type for the turn-left command is presented in Fig. 4.

An alternative modality to haptic is audio modality through spoken direction [3]. Similar to the haptic modality, our audio modality also uses three commands to navig-

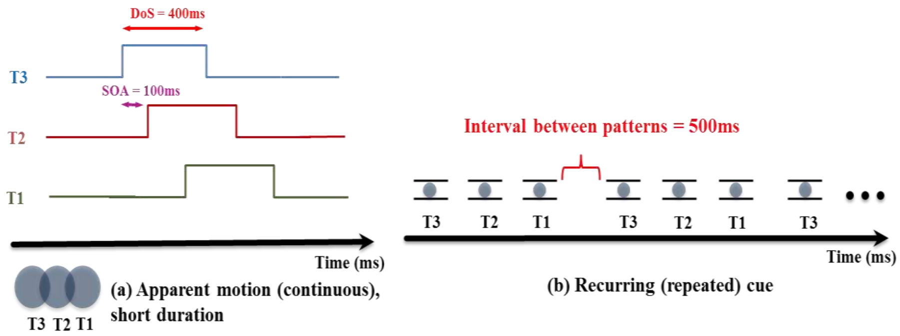

Fig. 4. Schematic representation of the tactile language employed in this study. (a) Tactile apparent motion (continuous) presentation, (b) recurring cue.

ate the user along the wall. However, rather than using tactile language for presenting these commands, the following synthetic speech is applied: Go-forward, Turn-right and Turn-left. The duration of each synthetic speech is equal to its similar haptic one and the interval between patterns is 500ms like the recurring condition in haptic commands.

2.4 Procedure

We made a path consisting of several cardboard walls in the experiment room to navigate the subjects along it (Fig. 5 (a)). In order to track the subject's position and orientation during the navigation, we used a Vicon motion capture system in the experiment room. At the beginning of the experiment, each subject was invited into the experiment room and asked to wear the tactile helmet and a blindfold. They were not be able to see the experiment set-up and cardboard walls before starting the experiment. Participants were told that haptic/audio feedback would assist them to follow the walls either by turning to the left or right or by maintaining a forward path. Subje-

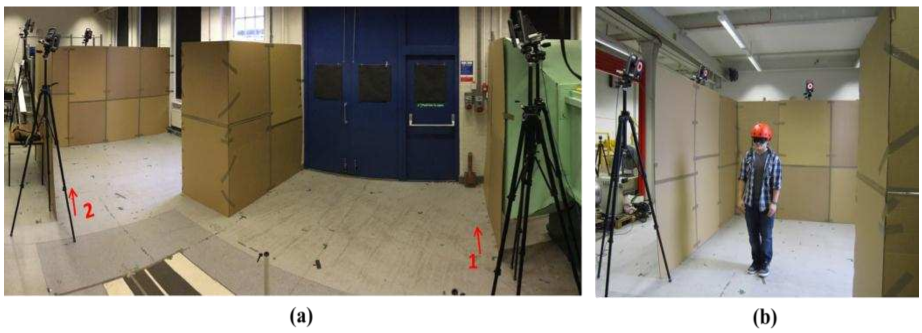

Fig. 5. (a) Overhead view of the experimental set-up consisting of cardboard walls and motion capture cameras, position 1 and 2 show the trial stating points. The length of the walls from the start point to the end is 20m. (b) Subject is navigating along the wall.

cts were also asked to put on headphone playing white noise to mask any sounds from tactors during navigation with haptic feedback. Furthermore, subjects were asked to keep their head oriented in the direction of travel and to avoid making unnecessary sideways head movements. A short training session was then provided to familiarize subjects with the tactile language, audio feedback and with the experimental set-up. Once the participant felt comfortable, the trial phase was started. We considered two starting points (1 and 2 as shown in Fig. 5 (a)) to not let the subjects to memorize the paths. Blind-folded subjects (Fig. 5 (b)) started the first trial from position 1 and the second trial from position 2 and repeated it for the third and fourth trial. When each trial finished, subjects were stopped by the experimenter. Subjects were allowed to rest after each trial and started the next trial whenever they were ready. The maximum duration of the experiment was approximately 20 minutes. In total, each subject performed 4 trials including 2 feedback types (haptic and audio), each for two times in a pseudo-random order. Task completion time, travel distance and route deviation as objective measures for each trial were measured.

After finishing the experiment, subjects were asked to complete a paper and pencil version of the NASA task load index (TLX) [21] to measure subjective workload. It consists of six dimensions including mental demand, physical demand, temporal demand, performance, effort and frustration with 21 graduations. Additionally, subjects were asked to rate their preference for completing the task with audio and haptic modality.

3 Classification algorithm

The wall-following task as a pattern classification problem is nonlinearly separable which is in favor of multilayer perceptron neural network [22]. In this work, multilayer perceptron neural network algorithm was utilized to guide the user along the wall as one of common methods used for robot navigation using ultrasound sensors [23]. As a classification algorithm, it associates the ultrasound data to the navigation commands (go-forward and turn right/left) in the form of haptic or audio modality. In order to collect data for training the classification algorithm, the experimenter wore the helmet and kept the laptop in her hands and followed the cardboard walls in the experiment room without wearing a blindfold (Fig. 5 (a)). The datasets are the collection of ultrasound readings when the experimenter follows the walls in a clockwise and anti-clockwise direction, each for 8 rounds. The data collection was performed at a rate of 1 sample (from 12 ultrasound sensors) per 0.6 second and generated a database with 4051 samples. Data were labeled during data collection by pressing the arrow key on the laptop keyboard when turning or going forward is intended (pressing left/right arrow key button for turn left/right and up arrow key button for go-forward). Ultrasound data in every scan were saved with a related label in a file. Three classes were considered in all the files: 1) Go-forward 2) Turn-right and 3) Turn-left and were used to train the classifier. We used Multilayer Perceptron (MLP) neural network to classify ultrasound data into three navigation commands. Our MLP (as shown in Fig. 6) consists of 12 input nodes (distance measurement form 12 ultrasound sensors), 1 hidden layer with 15 nodes and 3 nodes in output layer (three navigation commands). Back propagation algorithm was used to train the data and evaluation was done using 10 times 10-Folds cross-validation. Sensitivity and specificity of the MLP algorithm for recognizing go-forward (G), turn-right (R) and turn-left (L) commands are defined as:

$$\text{Sensitivity} = \frac{TP_{G,R,L}}{TP_{G,R,L}+FN_{G,R,L}} \quad (1)$$

$$\text{Specificity (G)} = \frac{TP_R + TP_L}{TP_R + TP_L + FP_G},\ \text{Specificity (R)} = \frac{TP_L + TP_G}{TP_L + TP_G + FP_R},\ \text{Specificity (L)} = \frac{TP_R + TP_G}{TP_R + TP_G + FP_L} \quad (2)$$

where $TP_{G,R,L}$ (True Positive) corresponds to successfully classified Go-forward, Turn-right and Turn-left commands, $FP_{G,R,L}$ (False Positive) corresponds to erroneously classified Go-forward, Turn-right and Turn-left commands and $FN_{G,R,L}$ (False Negative) corresponds to missed Go-forward, Turn-right and Turn-left commands [24].

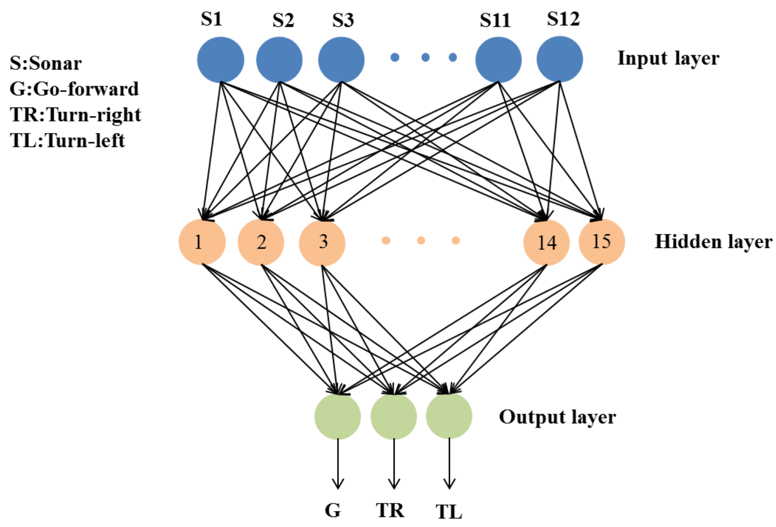

Fig. 6. The structure of the proposed MLP. It consists of 12 input nodes, 15 hidden nodes and 3 outputs.

The overall accuracy of the MLP is 94.9%. Table I presents the results of sensitivity and specificity of the MLP algorithm for recognizing the go-forward and turning commands. Finally, the proposed trained MLP algorithm was used to navigate the subjects along the walls.

Table 1. Sensitivity and specificity for recognizing go-forward and turning commands.

	Go-forward	Turn-right	Turn-left
Sensitivity (%)	95.9	95.3	90.6
Specificity (%)	92.7	98.6	98

4 Results

An alpha value of 0.05 was chosen as the threshold for statistical significance, all reported p-values are two-tailed. Shapiro-Wilk test showed that data are normally distributed. We measured task completion time (minute), travel distance (meter) and route deviation (meter) for audio and haptic modality as our objective measures. Task completion time was recorded as the time that subject took to navigate along the wall from start point to the end point. Task completion time for audio and haptic modality in Fig. 7 (a) shows that subjects navigated faster with haptic modality than audio modality. However, paired t-test showed no significant difference between audio and haptic modality in task completion time ($t = -1.287$, $p = 0.33$). Travel distance as a di-

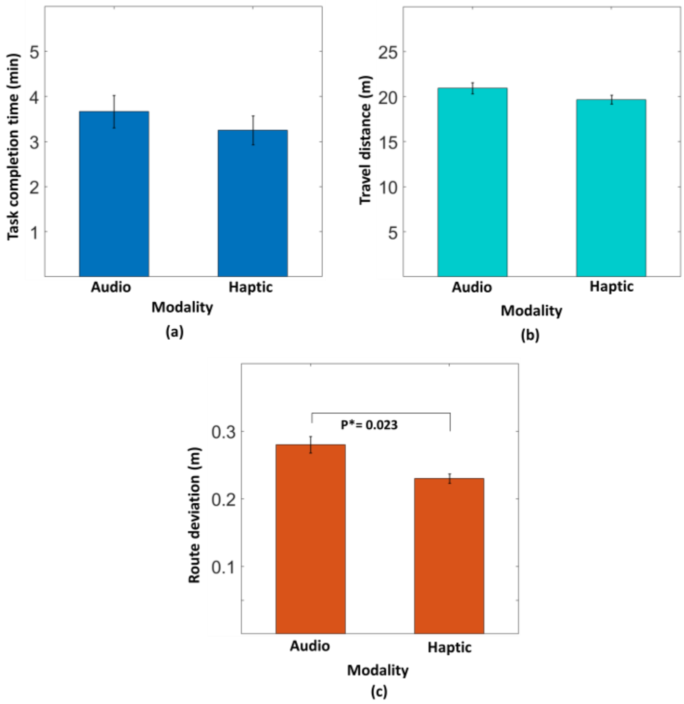

Fig. 7. Objective measures. (a) Task completion time, (b) Travel distance, (c) Route deviation. The unit of task completion time is in minute and unit of travel distance and route deviation is in meter. Error bars show standard error.

stance that subjects have walked along the wall was measured using motion capture system. As shown in Fig. 7 (b), subjects traveled shorter distance with haptic modality. A paired t-test revealed no significant difference between audio and haptic modality in travel distance ($t = 2.024$, $p = 0.074$). We further measured route deviation using motion capture system when navigating with audio and haptic modality. It shows subjects' position deviation relative to the walls during the navigation. Subjects had lower route deviation (Fig. 7 (c)) when navigating with haptic modality. A paired t-test showed a significant difference in route deviation between audio and haptic modality ($t = 2.736$, $p = 0.023$).

After completing the experiment, we subjectively measured workload for each modality by asking subjects answer the NASA TLX questionnaire. As shown in Fig. 8, physical and temporal demand did not vary much between two modalities which shows both of them were able to navigate the subjects. However, subjects rated that mental demand and effort are higher when navigating with audio feedback. These higher mental workload and effort are because subjects had to concentrate more to process audio feedback to navigate successfully along the wall. Subjects also rated better performance and lower frustration with haptic modality, which shows the capability of haptic modality for navigation along the wall consistent with our objective measure. Furthermore, subjects were asked to rate their preference for navigation with audio and haptic modality. This preference was rated on a scale of 1-21 to keep continuity with our NASA TLX, where (1) represents a strong preference for navigation with haptic feedback and (21) represents strong preference for navigation with audio feedback. The average preference rate of 3.4 as illustrated in Fig. 8 indicated subjects' preference for navigating with haptic modality.

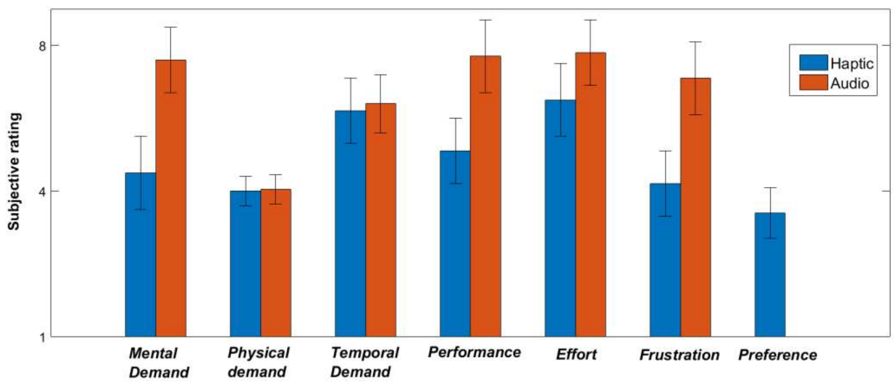

Fig. 8. Questionnaire feedback. The first six bar plots represent the NASA TLX score for audio and haptic modality. The rating scale is 1-21, where 1 represents no mental, physical and temporal demand, best performance, no effort required to complete the task and, no frustration. The last bar plot shows subjects' preference for navigation with haptic modality. The error bars indicate standard error.

5 Conclusion

This paper compares and investigates haptic and audio modalities as non-visual interfaces for navigation in low visibility environment using the vibrotactile helmet as a sensory augmentation device. The haptic modality utilizes our tactile language in the form of vibrotactile feedback while audio modality applies synthetic speech to present navigation commands. The objective measure showed that haptic feedback leads to lower route deviation significantly. We also measured task completion time and travel distance. Although subjects had faster task completion time and lower travel distance with haptic feedback, no significant difference was found between these two modalities. Unlike [13] which blindfolded users had higher cognitive workload in navigation with haptic modality than with audio modality, our analysis using NASA TLX questionnaire indicated that haptic modality had lower workload on the subjects. The results of this study show the effectiveness of haptic modality for guided navigation without vision. Future work will use a local map of the environment estimated with the ultrasound sensors to generate the navigation commands in place of the MLP algorithm. Furthermore, it would be interesting to conduct this experiment with visually impaired people to investigate the potential of haptic and audio modality as a communication channel for assisted navigation devices.

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References

1. S. M. Kärcher, S. Fenzlaff, D. Hartmann, S. K. Nagel, and P. König, "Sensory augmentation for the blind," Front. Hum. Neurosci., vol. 6, 2012.
2. Kim, Y., Harders, M., & Gassert, R. "Identification of vibrotactile patterns encoding obstacle distance information," IEEE Transactions on Haptics, vol. 8 no. 3, pp.298–305, 2015.
3. G. Flores, S. Kurniawan, R. Manduchi, E. Martinson, L. M. Morales, and E. A. Sisbot, "Vibrotactile Guidance for Wayfinding of Blind Walkers," IEEE Trans. Haptics, vol. 8, no. 3, pp. 306–317, 2015.
4. S. Shoval, J. Borenstein, and Y. Koren, "Auditory guidance with the NavBelt-a computerized travel aid for the blind," IEEE Trans. Syst. Man, Cybern. C, Appl. Rev., vol. 28, no. 3, pp. 459–467, Aug. 1998.
5. S. Holland, D. R. Morse, and H. Gedenryd, "AudioGPS: Spatial audio navigation with a minimal attention interface," Pers. Ubiquitous Comput., vol. 6, no. 4, pp. 253–259, 2002.
6. C. Bertram, M. H. Evans, M. Javaid, T. Stafford, and T. Prescott, "Sensory augmentation with distal touch: The tactile helmet project," Lect. Notes Comput. Sci., vol. 8064, pp. 24–35, 2013.
7. A. Cassinelli, C. Reynolds, and M. Ishikawa, "Augmenting spatial awareness with haptic radar," in Wearable Computers, 10th IEEE International Symposium on, 2006, pp. 61–64.

8. A. Carton and L. E. Dunne, “Tactile distance feedback for fire-fighters: design and preliminary evaluation of a sensory augmentation glove,” in Proceedings of the 4th Augmented Human International Conference, 2013, pp. 58–64.
9. A. C. Marsalia, “Evaluation of Vibrotactile Alert Systems for Supporting Hazard Awareness and Safety of Distracted Pedestrians,” Master Thesis at Texas A&M University, 2013.
10. J. R. Marston, J. M. Loomis, R. L. Klatzky, and R. G. Golledge, “Nonvisual route following with guidance from a simple haptic or auditory display,” J. Vis. Impair. Blind., vol. 101, no. 4, pp. 203–211, 2007.
11. M. Hara, S. Shokur, A. Yamamoto, T. Higuchi, R. Gassert, and H. Bleuler. “Virtual environment to evaluate multimodal feedback strategies for augmented navigation of the visually impaired,” IEEE Engineering in Medicine and Biology Society, pp. 975–978, 2010.
12. O. B. Kaul and M. Rohs, “HapticHead: 3D Guidance and Target Acquisition through a Vibrotactile Grid,” in Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, 2016, pp. 2533–2539.
13. M. Martinez, A. Constantinescu, B. Schauerte, D. Koester, and R. Stiefelhagen, “Cognitive evaluation of haptic and audio feedback in short range navigation tasks,” Lect. Notes Comput. Sci, vol. 8548, pp. 128–135, 2014.
14. H. Kerdegari, Y. Kim, T. Stafford, and T. J. Prescott, “Centralizing Bias and the Vibrotactile Funneling Illusion on the Forehead,” in Haptics: Neuroscience, Devices, Modeling, and Applications, Springer, 2014, pp. 55–62.
15. H. Kerdegari, Y. Kim and T.J. Prescott, “Tactile Language for a Head-mounted Sensory Augmentation Device,” in Biomimetic and Biohybrid Systems, Springer, 2015, pp. 359-365.
16. S. Denef, L. Ramirez, T. Dyrks, and G. Stevens, “Handy navigation in ever-changing spaces: an ethnographic study of firefighting practices,” In Proceedings of the 7th ACM conference on Designing interactive systems, pp. 184-192, 2008.
17. Y. Ando and S. Yuta, “Following a wall by an autonomous mobile robot with a sonar-ring,” Proc. 1995 IEEE Int. Conf. Robot. Autom., vol. 3, pp. 2599–2606, 1995.
18. H. Kerdegari, Y. Kim, and T. Prescott, “Head-mounted Sensory Augmentation Device: Designing a Tactile Language,” IEEE Trans on Haptics, vol. PP, no. 99, 2016.
19. C. E. Sherrick and R. Rogers, “Apparent haptic movement,” Percept. Psychophys., vol. 1, no. 6, pp. 175–180, 1966.
20. J. H. Kirman, “Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration,” Percept. Psychophys., vol. 15, no. 1, pp. 1–6, 1974.
21. S. G. Hart and L. E. Staveland, “Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research,” in Human Mental Workload, Elsevier, Amsterdam: North Holland Press, 1988, pp.239-250.
22. A. L. Freire, G. a. Barreto, M. Veloso, and a. T. Varela, “Short-term memory mechanisms in neural network learning of robot navigation tasks: A case study,” Robot. Symp. (LARS), 2009 6th Lat. Am., no. 4, 2009.
23. A. Zou, Z. Hou, S. Fu, and M. Tan, “Neural Networks for Mobile Robot Navigation : A Survey,” Adv. Neural Networks - ISNN 2006, vol. II, pp. 1218–1226, 2006.
24. B. Ando, S. Baglio, V. Marletta, and A. Valastro, “A Haptic Solution to Assist Visually Impaired in Mobility Tasks,” IEEE Transactions on Human-Machine Systems, pp. 1-6, 2015.