Tactile Language for a Head-Mounted Sensory Augmentation Device

Hamideh Kerdegari[1(✉)], Yeongmi Kim[2], and Tony Prescott[1]

[1] Sheffield Robotics, University of Sheffield, Sheffield, UK
`{h.kerdegari,t.j.prescott}@sheffield.ac.uk`
[2] Department of Mechatronics, MCI, Innsbruck, Austria
`yeongmi.kim@mi.edu`

Abstract. Sensory augmentation is one of the most exciting domains for research in human-machine biohybridicity. The current paper presents the design of a 2nd generation vibrotactile helmet as a sensory augmentation prototype that is being developed to help users to navigate in low visibility environments. The paper outlines a study in which the user navigates along a virtual wall whilst the position and orientation of the user's head is tracked by a motion capture system. Vibrotactile feedback is presented according to the user's distance from the virtual wall and their head orientation. The research builds on our previous work by developing a simplified "tactile language" for communicating navigation commands. A key goal is to identify language tokens suitable to a head-mounted tactile interface that are maximally informative, minimize information overload, intuitive, and that have the potential to become 'experientially transparent'.

Keywords: Sensory augmentation · Vibrotactile feedback · Tactile language

1 Introduction

Sensory substitution (translating one sensory modality into another [1]) was one of the first domains for research in human-machine biohybrid systems [2]. The development of devices for both sensory substitution and sensory augmentation (synthesizing new information to an existing sensory channel) remains an exciting prospect for biohybrid technology. For example, whilst sensory substitution can help people with impaired sensing systems, the additional senses provided by sensory augmentation can be used to augment the spatial awareness of people operating in hazardous environments such as smoked-filled buildings, on construction sites, or on the battlefield [3, 4].

Research in this area has been strongly influenced by the enactive view of cognition (see e.g. [5, 6, 7, 8]). Here, a key design aim is to make the device 'experientially transparent' such that the goal-directed behavior of the user naturally incorporates properties of the artifact including its capacity to transform from one sensory modality to another. Another influential approach has been from research on active perception—the view that sensing in animals including humans is purposeful and information-seeking. That

S.P. Wilson et al. (Eds.): Living Machines 2015, LNAI 9222, pp. 359–365, 2015.
DOI: 10.1007/978-3-319-22979-9_36

approach, together with bio-inspiration from mammalian sensing systems, informed our earlier efforts to develop a sensory augmentation device that incorporated a haptic interface for remote touch [3]. In the current contribution we describe our research on a second generation device that seeks to overcome some of the limitations of the earlier system. Here we describe the motivation for the approach and the design of a new prototype. Pilot results from the experiment outlined below will be presented at the conference.

2 A Sensory Augmentation System Inspired by the Mammalian Vibrissal System

Many mammals have a sensitive tactile sensing capacity provided by their facial whiskers (or vibrissae) that allows them to acquire detailed information about local environment useful for local navigation and object detection and recognition. Similar information could be provided to humans using a sensory augmentation system that combines active distance sensing of nearby surfaces with a head-mounted tactile display [3, 9]. Two such devices have been investigated to date: the Haptic Radar [9] and the Tactile Helmet [3].

The *Haptic Radar* [9] linked infrared sensors to head-mounted vibrotactile displays allowing users to perceive and respond simultaneously to multiple spatial information sources. Here, several sense-act modules were mounted together 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 moving close to the head, indicating that the device could be useful for detecting and avoiding collisions.

The *Tactile Helmet* [3] was a prototype sensory augmentation device developed in Sheffield in collaboration with *South Yorkshire Fire and Rescue* (SYFR) services. We selected a head-based tactile display as this allows rapid reactions to unexpected obstacles, is intuitive for navigation, can easily fit inside the helmet, and leaves the fire fighter's hands free for tactile exploration of objects and surfaces [9]. The first generation device (see Figure 1) comprised a ring of eight ultrasound sensors on the outside of a fire-fighter's safety helmet with four 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. Thus, unlike Haptic Radar, the Tactile Helmet was non-modular, allowing direction signals from the array of sensing elements to be combined into an appropriate display pattern to be presented to the new user. 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. This is particularly important in the case of head-mounted tactile displays, as vibration against the forehead is also detected as a sound signal (buzzing) in the ears; too much vibrotactile information can therefore be confusing and irritating and could mask important auditory stimuli. Despite seeking to provide better control over the signal display, however, field tests with the Tactile Helmet, con ducted at SYFR's training facility, showed that tuning the device to suit the user needs and situation was problematic. Specifically, a design that directly converted local distance information into vibration on multiple actuators generated far too much vibrotactile stimuli in confined situations such as a narrow corridor.

Fig. 1. Ist generation Tactile Helmet design undergoing field testing. In right-hand picture the fire-fighter is in a confined smoke-filled space in the South Yorkshire Fire and Rescue training facility.

The above tests established the need to better regulate the tactile display of information to ensure clear signals and to minimize distracting or uninformative signals. Through a series of psychophysical studies (e.g. [10]) we are investigating how to best optimize signals to relay information to the user. For instance, we want quantify people's ability to localize tactile stimuli on the forehead and to understand, and make use of, sensory phenomena such as the "funneling illusion" whereby nearby concurrent tactile stimuli are experienced as a single stimulus at a central point. Based on the outcome of these studies, we are currently developing a "tactile language" for testing with a new Tactile Helmet prototype. Specifically, using our new device we are seeking to understand what are the minimal haptic signals—the tokens of the command language—that can be used to relay useful navigational information. In the current study we wished to have full control over the information provided to the user and therefore we imagine a virtual wall, and used a motion capture system, to directly calculate the user's distance and orientation to that wall. The actuators on the helmet are then used to relay navigation commands to help the user move in a trajectory parallel to the wall. We evaluate the effectiveness of the commands according to speed of movement and the smoothness of the user's trajectory. In future studies we will also examine how the language could be used to convey navigational signals calculated directly from active distance sensors for real-world obstacles. The eventual aim is to identify a tactile command language that can be used with a map of local surface positions, estimated with ultrasound or ladar, and that is maximally informative, minimizes information overload, and intuitive; hopefully with the potential to become experientially transparent. The remainder of the paper explains the design of our new prototype and the experiment we are conducting to evaluate some of the possible tokens of the tactile language.

3 System Overview

3.1 Vibrotactile Helmet

The second-generation Tactile Helmet (fig. 2) consists of an array of twelve ultrasound sensors mounted with approximately 30 degrees separation to the outside of a skiing helmet (2d), and a tactile display composed of 7 tactors (2b) [10].

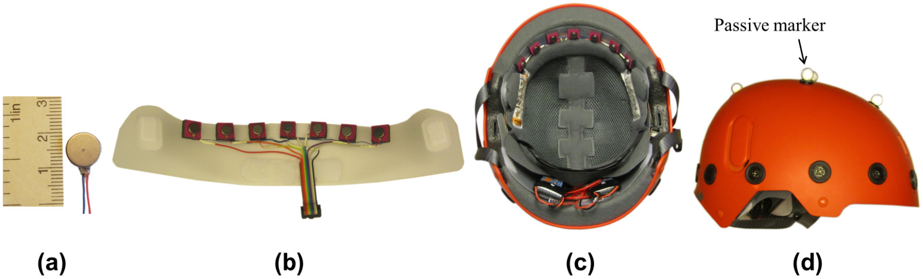

Fig. 2. (a): Eccentric rotating mass vibration motor (Model 310-113 by Precision Microdrives). (b): Tactile display interface. (c): Tactile display position inside the helmet. (d): Vibrotactile helmet.

The tactile display consists of seven eccentric rotating mass (ERM) vibration motors (2a) 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 (2b) with 2.5 cm inter-tactor spacing which can easily be adjusted inside the helmet. The helmet also incorporates an inertial measurement unit (IMU), a microcontroller unit and two small lithium polymer batteries (7.4 V) to provide the system power. As shown in Figure 3, the ultrasound sensors and IMU 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 generates commands for the tactile actuators sending them back to microcontroller wirelessly for onward transmission to the tactile display. For the experiment described below we disable the direct generation of actuator commands and substitute signals based on information from the motion-capture system.

3.2 Tracking System

We used Vicon motion capture system as a precise optical marker tracking system to track the user's position and orientation. It consists of 10 cameras and reflective markers. The vibrotactile helmet, whose motion is to be captured by cameras, has five reflective passive markers attached to its surface (Fig. 2.d). Data generated by the Vicon software is streamed in real time to a PC via TCP/IP. Finally, the proper tactile command is generated and sent wirelessly to the helmet to navigate the user in the capture room.

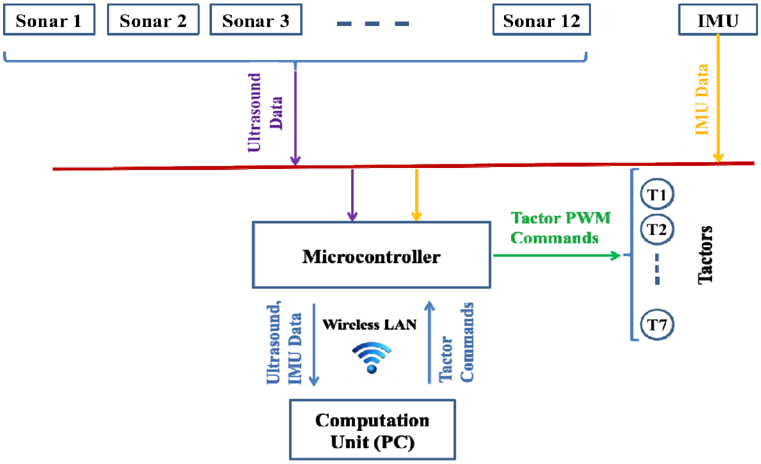

Fig. 3. Data flow diagram of vibrotactile helmet

4 Procedure

The aim of our experiment is to investigate the optimal vibrotactile commands and effectiveness of the proposed tactile commands for navigation along a virtual wall. The experiment is performed in the motion capture room (4 * 5m^2). The user's distance from the virtual wall is calculated continuously, based on this distance, and on the helmet orientation measured by motion capture system, the proper tactile command is produced. For our initial experiment we are evaluating different ways of communicating three simple tactile commands: *turn-right, turn-left* and *go-forward.* Turn right/left command induce a rotation around self (right/left rotation) which is used to control the human orientation; while go-forward command is intended to induce a motion toward forward direction. Fig. 4 illustrates the vibrotactile patterns for presenting turn left/turn right and go-forward commands in the tactile display.

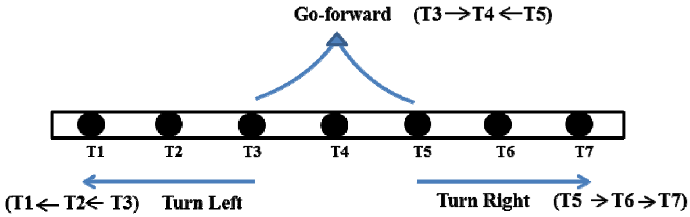

Fig. 4. Vibrotactile patterns for turn left, turn right and go-forward commands

We present these commands in four different modes: *recurring apparent motion*, *single apparent motion*, *recurring discrete* and *single discrete*. In *recurring* cues the tactile command is presented to user' forehead repeatedly until a new command is received, in the single cue case, the system presents the tactile command once and then waits until a new command is generated. *Apparent motion* commands exploit on the concept of vibrotactile apparent movement illusion [11] which creates an illusionary sensation that the stimulus is travelling continuously from one position to another. The feeling of apparent motion is controlled by two main parameters: duration of stimuli (DOS) and the stimulus onset asynchrony (SOA). The desired movement impression was obtained with a DOS of 400 ms and a SOA of 100 ms. Unlike apparent motion, discrete commands create a discrete motion across the forehead. We will evaluate these four types of vibrotactile patterns for turn left/right and go-forward commands to find out which one is better suited for indoor guidance.

5 Discussion

Whereas some approaches to sensory substitution/augmentation, that take an enactive view, have favoured using simple mappings between modalities, our research is moving in the direction of more complex mappings. One reason is that the sensorimotor contingencies [12] are often very different in the modalities we are mapping from (here ultrasound for distance sensing) and to (here cutaneous touch). In particular, our project aims to investigate the hypothesis that the transparency of the device depends primarily on having a clear and timely mapping between the environmental affordances (e.g. surfaces for navigational guidance) and the display presented on the sensory surface. We suggest that to achieve this may require significant processing of the primary sensory data to identify the relevant affordances before re-coding them for the new modality.

References

1. Bach-y-Rita, P., Tyler, M.E., Kaczmarek, K.A.: Seeing with the brain. International Journal Of Human-Computer Interaction **15**(2), 285–295 (2003)
2. Bach-Y-Rita, P., Collins, C.C., Saunders, F.A., White, B., Scadden, L.: Vision Substitution by Tactile Image Projection. Nature **221**(5184), 963–964 (1969)
3. Bertram, C., Evans, M.H., Javaid, M., Stafford, T., Prescott, T.: Sensory augmentation with distal touch: the tactile helmet project. In: Lepora, N.F., Mura, A., Krapp, H.G., Verschure, P.F., Prescott, T.J. (eds.) Living Machines 2013. LNCS, vol. 8064, pp. 24–35. Springer, Heidelberg (2013)
4. Gallo, S., Chapuis, D., Santos-Carreras, L., Kim, Y., Retornaz, P., Bleuler, H., Gassert, R.: Augmented white cane with multimodal haptic feedback. In: 2010 3rd IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), pp. 149–155 (2010)
5. Engel, A.K., Maye, A., Kurthen, M., König, P.: Where's the action? The pragmatic turn in cognitive science. Trends Cogn. Sci. **17**(5), 202–209 (2013)
6. Froese, T., McGann, M., Bigge, W., Spiers, A., Seth, A.K.: The Enactive Torch: A New Tool for the Science of Perception. IEEE Transactions on Haptics **5**(4), 363–375 (2012)
7. Nagel, S.K., Carl, C., Kringe, T., Märtin, R., König, P.: Beyond sensory substitution–learning the sixth sense. J. Neural Eng. **2**(4), R13–R26 (2005)

8. Auvray, M., Hanneton, S., Regan, J.K.O.: Learning to perceive with a visuo-auditory substitution system: Localisation and object recognition withThe vOICe. Perception-London-**36**(3), 416 (2007)
9. Cassinelli, A., Reynolds, C., Ishikawa, M.: Augmenting spatial awareness with haptic radar. In: 2006 10th IEEE International Symposium on Wearable Computers, pp. 61–64 (2006)
10. Kerdegari, H., Kim, Y., Stafford, T., Prescott, T.J.: Centralizing bias and the vibrotactile funneling illusion on the forehead. In: Auvray, M., Duriez, C. (eds.) EuroHaptics 2014, Part II. LNCS, vol. 8619, pp. 55–62. Springer, Heidelberg (2014)
11. Sherrick, C.E., Rogers, R.: Apparent haptic movement. Percept. Psychophys. **1**(6), 175–180 (1966)
12. O'Regan, J.K., Noë, A.: A sensorimotor account of vision and visual consciousness. Behav. Brain Sci. **24**(5), 939–973 (2001). discussion 973–1031