Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness

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ABSTRACT

Deafblindness, a form of dual sensory impairment, significantly impacts communication, access to information and mobility. Independent navigation and wayfinding are main challenges faced by individuals living with combined hearing and visual impairments. We developed a haptic wearable that provides sensory substitution and navigational cues for users with deafblindness by conveying vibrotactile signals onto the body. Vibrotactile signals on the waist area convey directional and proximity information collected via a fisheye camera attached to the garment, while semantic information is provided with a tapping system on the shoulders. A playful scenario called "Keep Your Distance" was designed to test the navigation system: individuals with deafblindness were "secret agents" that needed to follow a "suspect", but they should keep an optimal distance of 1.5 meters from the other person to win the game. Preliminary findings suggest that individuals with deafblindness enjoyed the experience and were generally able to follow the directional cues.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interactive systems and tools; Accessibility; • **Social and professional topics** → User characteristics; People with disabilities.

KEYWORDS

Assistive Technology, Sensory Substitution, Visual Impairments, E-textiles

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1 INTRODUCTION AND BACKGROUND

Deafblindness, also known as dual sensory impairment, is the combination of sight and hearing impairments of such extent that it becomes difficult for one sense to compensate for each other [16]. Due to the combination of sensory impairments, individuals living with deafblindness often face challenges in fully participating in society, including issues with communication, access to information, and independent navigation [22, 23]. These limitations may lead to a high risk of social isolation, sedentarism and depression [20, 21]. Research has indicated that independent navigation is considered a key issue for the deafblind community [28]. An individual with deafblindness may experience a lack of confidence to move independently due to many accessibility barriers related to indoors and outdoors navigation [14, 17]. Extensive work has focused on supporting navigation for blind individuals [1, 2, 7, 11, 18, 26], however the majority of these approaches rely on voice commands and auditory feedback that make these assistive tools unsuitable for individuals with deafblindness. Furthermore, most systems use handheld devices and often require some sort of smartphone interaction [4, 8–10, 13, 27, 30, 31]. Mobile interaction can be useful, however, if users walk with a cane or guiding dog, it might be appropriate to move the interaction to other parts of the body and

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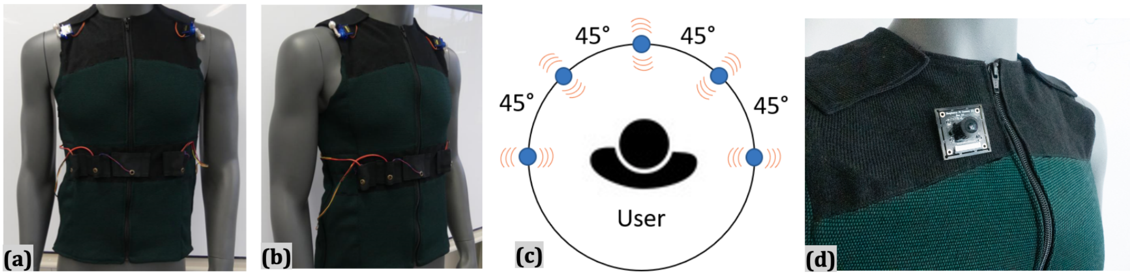

Figure 1: The *Keep Your Distance* vest provides distance and directional information to users with deafblindness by conveying haptic feedback around the waist and shoulder areas. Frontal (a) and Side (b) views of the haptic vest (wiring exposed for visualization purposes only); (c) Configuration of directional feedback consisting of five vibration motors placed around the waist area; (d) Position of the fisheye camera attached to the garment.

keep their hands free for other tasks [3, 6, 29]. Haptic wearables have the potential to compensate for dual sensory impairments since individuals living with deafblindness often rely on diverse modes of tactile communication [24]. Wearables have been used for displaying information and allowing a diverse range of interactions as an alternative to carrying and interacting with additional devices other than the one being worn [12, 22, 23, 29]. Early work by [15, 19, 32] attempted to design haptic wearables for sensory augmentation in non-impaired users, however, its suitability for providing navigational cues and independent mobility for users with deafblindness remain unclear.

Therefore, we developed a haptic vest that provides navigational cues to users with deafblindness by conveying vibrotactile feedback around the waist and shoulder areas (Figure 1). The wearable system translates proximity and directional cues related to objects or other people near the user with a fisheye camera and vibration motors attached to the textile. We aimed to explore intuitive vibration patterns that users could easily learn without the need of extensive training. Additionally, we evaluated the suitability of the haptic vest with a playful interaction scenario called *Keep Your Distance*, where individuals with deafblindness tested and learned how to be guided through haptic feedback in a non-intimidating environment.

2 PROTOTYPE DESIGN

We designed a haptic wearable that supports independent navigation to users with deafblindness by providing navigational guidance through vibrotactile signals on the upper body of the user. The haptic wearable was initially designed to foster playful experiences involving sensory substitution and wayfinding for the deafblind community. The haptic vest includes a fisheye camera that collects environmental data and vibration motors around the waist and shoulder areas to convey continuous (1) directional information via the activation of different vibration motors around the waist, so users know to which direction they should walk and shift their orientation; (2) proximity information in relation to a person or object through different vibration frequencies, where lower frequencies mean that users are getting far from the desired position and higher frequencies mean that users are too close to a desired point; and (3) semantic information by using tapping signals on the shoulder area to communicate "walk" and "stop walking" commands.

These navigational cues aim to support intuitive and unobtrusive sensory substitution of such manner that individuals with deafblindness do not need to hold or interact with additional devices other than the garment itself. The body-worn system consists of a vest made of a flexible fabric to fit several body sizes. Furthermore, the textile design allows actuators to be detached and reconfigured as desired. The five vibration motors are distributed across 180 degrees around the waist on the frontal side of the person wearing the vest, each motor being separated by 45 degrees from the next (Figure 1). Four additional actuators are attached to the vest, being two placed on the top front, near the clavicles, and two are placed on the top back, near the shoulder blades. Additionally, a small pouch located on the back side of the vest carries the microcontroller (RedBear Duo board) and the battery back that powers all the components.

2.1 Implementation

The navigational guidance system presents a fisheye camera connected to a Raspberry Pi 4 Model B. The camera is used to navigate the user by providing vibrotactile feedback based on the user's distance to an ArUco Marker [25] that can be attached to objects or another person walking in front or near the user. The detection of these markers is made possible through the OpenCV framework for Python. The software side includes commands related to the frequency at which the actuators vibrate and are transmitted to the RedBear Duo board via either Serial (USB) or BLE communication. On the hardware side, the haptic wearable comprises of (a) microcontroller (RedBear Duo board) connected to Raspberry Pi, (b) five vibration motors around the waist, (c) four micro-servo motors on the shoulder area, (d) fisheye camera attached to the torso area, and (f) a battery pack to power the components.

2.2 Haptic feedback

The haptic feedback modality consists of continuous vibrotactile signals provided by five vibration motors around the waist area (Figure 1). These vibrotactile signals use cylindrical shaped Precision Microdrives vibration motors (307-103, 25mm) on voltage of 3V, delivering vibrational amplitudes of 7G when attached to the vest. For the *Keep Your Distance* user evaluation, we used vibration frequencies of (a) 100ms when the user was too close to the other person (up to 0.5 meters), (b) 500ms when the user was within the optimal distance of 0.5 to 1.5 meters to the other person, and (c) 1000ms when the user was getting too far from the other person (more than 1.5 meters apart).

Furthermore, two micro-servo motors are placed on the front of the body near the clavicles (left and right), and two micro-servo motors are placed on the back of the body near the left and right shoulder blades (Figure 1). These servo motors provide feedback in the form of tapping sensation based on social haptic gestures [20, 21] and indicate "start walking/go" (back) and "stop walking/stop" (front). The tapping sensation is achieved by rotating the motors in a swift back and forth motion onto the body.

3 PRELIMINARY EVALUATION AND POTENTIAL APPLICATIONS

Five individuals with deafblindness participated in the *Keep Your Distance* gamified study (2 female; mean age = 46 years old). All five participants were fully deaf, however, three participants communicated verbally with the help of cochlear implants (CIs). Participants who used Sign Language were accompanied by professional interpreters, who assisted with communication throughout the study. Furthermore, participants presented varying eyesight characteristics: one participant was fully blind; one participant had a field of view of 100 degrees and a visual acuity of 2% to 5%; while the other three participants had tunnel vision with fields of view between 3 to 7 degrees and a visual acuity of up to 70%. Either written or verbal informed consent was given by all participants and their interpreters.

We intended to evaluate the haptic wearable system in a safe, non-intimidating study setting [5]. In the playful interaction scenario, participants wearing the haptic vest were "secret agents", and the researcher holding an ArUco Marker was a "suspect" that needed to be followed around a pre-defined route. Participants were asked to follow the vibrotactile signals being provided onto the body during the interaction. In order to win and "catch the suspect", participants were asked to keep within an optimal distance between 0.5 a d 1.5 meters from the "suspect" (i.e. the ArUco Marker being detected by the fisheye camera on the vest). Participants would not win if they were too close (less than 0.5 meters) or too far away (more than 1.5 meters) from the ArUco Marker at the end of the route.

Our preliminary findings suggest that haptic feedback can support sensory substitution and independent navigation for individuals with deafblindness. All participants were able to follow directional cues and complete the pre-defined route without assistance of others. The directional and continuous vibrotactile signals around the waist area were reported as being useful for wayfinding among participants who were legally blind and those who presented residual vision. Furthermore, participants enjoyed taking part in the *Keep Your Distance* playful scenario and wearing the haptic vest was generally a well-received experience.

During the study, participants stated that they felt comfortable and were not afraid of being misguided or bumping into things. A participant shared that *"as a person living with deafblindness, you always need one hand free to touch your intervener"* and by wearing the haptic vest the participant *"was able to navigate confidently in a new environment for the first time without the direct support of another person"*. Similarly, another participant shared that *"being provided with feedback regarding distance calmed me down. . . I knew that everything was ok"*.

Additionally, a participant suggested replacing the tapping sensation on the shoulder area with pressure because *"it was too weak and difficult to be perceived"*. For future work, we suggest looking at alternative methods for providing stronger haptic signals such as force-based actuators or localized vibration motors that can deliver efficient haptic feedback but still feel gentle on the skin.

Although the *Keep Your Distance* scenario was envisaged to explore the use of haptic feedback for providing proximity and directional information in a "game", the vibrotactile signals present in the wearable could be applied in real-world situations where individuals with deafblindness cannot touch the person guiding them (e.g. intervener) or need their hands free for other tasks (e.g. carrying a walking cane, guiding dog). These scenarios coincidently align with the current social distancing guidelines in place in many parts of the world due to the COVID-19 pandemic. Despite not being one of the initial motivations for this research, we assume that being able to perceive whether individuals with deafblindness are in safe distance from other people in proximity without the need of physical contact would be a relevant application of our haptic wearable in current days.

4 CONCLUSION AND FUTURE WORK

We presented the design of a haptic wearable prototype for supporting sensory substitution and independent navigation for individuals with deafblindness in a playful interaction scenario called *Keep Your Distance*. Users wearing the haptic vest were asked to follow a pre-defined route and keep within an optimal distance from another person. Wayfinding was supported by vibrotactile feedback being provided on the frontal waist area and additional haptic cues were provided on the shoulder area. Five individuals with combined sight-and-hearing impairments participated in a preliminary evaluation of the vest. As the *Keep Your Distance* playful scenario was conducted indoors, future work can explore the reliability of the fisheye camera and suitability of haptic cues for independent navigation in different contexts such as outdoors or complex environments with obstacles. Our preliminary findings indicate that on-body haptic feedback was able to support independent navigation and sensory substitution. Furthermore, users with deafblindness enjoyed the playful experience with the haptic vest and were able to follow all directional cues with the vibrotactile signals conveyed around the waist area.

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