PneuFetch: Supporting Blind and Visually Impaired People to Fetch Nearby Objects via Light Haptic Cues

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Abstract
We present *PneuFetch*, a light haptic cue based wearable device that supports blind and visually impaired (BVI) people to fetch nearby objects in an unfamiliar environment. In our design, we generate friendly, non-intrusive, and gentle presses and drags to deliver direction and distance cues on BVI user's wrist and forearm. As a concept of proof, we discuss our *PneuFetch* wearable prototype, contrast it with past work, and describe a preliminary user study.

Author Keywords
Object fetching; touch; blind and visually impaired people; pneumatic system; fabrication; accessibility.

CSS Concepts
• **Human-centered computing~Human computer interaction (HCI)**; *Haptic devices*; Accessibility technologies.

Introduction
Blind and visually impaired (BVI) people can fetch objects in an acquainted environment by touching objects or relying on their memory. However, in a complex and less familiar situation, those strategies become less useful or even result in dangers (*e.g.,* touching hazardous obstacles). Auditory feedback is effective for BVI users to estimate and localize an

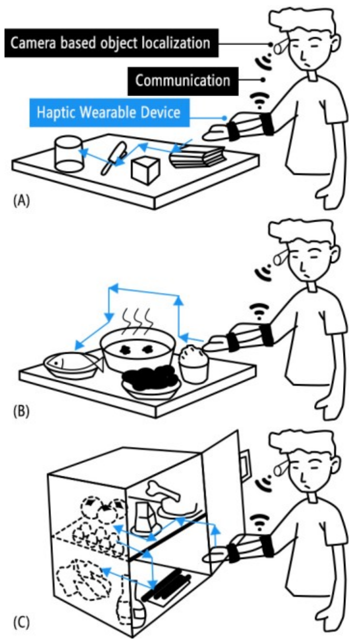

Figure 1: *PneuFetch* helps BVI people fetch nearby objects in three example scenarios: (A) a 2-dimensional exploration on a desk; (B) a 2.5dimensional searching on a dining table; and (C) a refrigerator that provides a 3-dimensional space in a refrigerator. (A) also shows how our envisioned object localization mechanism works with the haptic wearable device for object fetching.

object is in a 2D surface [1, 6, 7], but requires more verbal articulation and becomes error-prone in a complex environment. Recently, haptic feedback is used for indicating spatial information, including: vibro-motor feedback [9, 14, 28], mechanotactile mechanisms [5, 12], touch feedback [10], and air vortex [29]. However, they either provide navigation guidance on a simple flat surface or simulate directional cues for an immersive experience. In this paper, we explore light touch haptic guidance for nearby object fetching in complex or less familiar environment (Figure 1A-C).

Informed by an informative survey with 19 BVI respondents, we extend *PneuHaptic* [10] by creating a touch based wearable device for BVI people to fetch nearby objects. The prototype simulates presses around the wrist and drags on the forearm as direction and distance cues for the BVI user to explore the surrounding environment. The wearable prototype has three parts: a three-node pneumatically controlled wristband that generates *up*, *down*, *right*, *left* directional cues, a servo controlled forearm attachment mechanism that generates *forward* and *backward* drag cues, and a separate armband that hosts all the electronics and the circuit. We validate the potential of our approach through a preliminary user study.

To build an overall system, knowing "where to fetch" (*i.e.,* object localization) is also a critical part (Figure 1A) and it has been studied in previous research [2, 25], we see haptic guidance for BVI people to fetch objects as an important open research field. In our future work, we propose to incorporate computer vision-based method to enable the functionality of object localization for a complete system.

Our contributions include: (i) an informative survey to understand what haptic feedback is preferred by BVI people for fetching nearby objects; (ii) a wearable prototype to deliver on-body touch guidance; and (iii) a preliminary user study to validate the feasibility of our approach.

Related Work

Our work builds on research in the field of on-body haptic and tactile feedback and haptic assistive technology for BVI people.

On-body Haptic and Tactile Feedback

Researchers have explored a number of techniques that generate on-body interaction [8, 30, 31], as well as tactile and haptic feedback, such as physical and vibro-motor [14, 26], mechanical tactor [5, 13, 15,16], electrical muscle stimulation (EMS) [22, 23, 27], shape memory alloy (SMA) [12], pneumatic [3, 10, 32], 3D-printed tactile cues [18, 11], and thermal haptic [24]. *Tactile Brush* [14], for example, varied frequency, intensity, velocity and direction of tactile motion to simulate smooth moving strokes on human back. *Impacto* [22] rendered haptic sensation of hitting or being hit in virtual reality using EMS. These vibration/motion and EMS based haptic impulses produce high frequency movements, which could raise negative responses after lengthy exposure [19]. Compared with SMA and thermal property-based haptics, custom mechanical mechanisms offer a more reliable control and still work without the direct contact with the skin. For example, *Frictio* [13] supported custom program and control to generate expressive force feedback around the finger in a ring-like enclosure. Finally, unlike vibration-based designs, pneumatically controlled haptic feedback offers gentle and continuous force. For example, *PneuHaptic* [10], the closest to our work, stimulated soft touches around the forearm for notification, navigation, and motion. Our wearable prototype combines both pneumatically actuated designs and mechanically controlled tactors to simulate a circumstance where a sighted assistant pokes the BVI user's wrist or drags the forearm toward the target object.

Haptic Assistive Technology for BVI People
Haptic guidance, as an alternative to visual feedback, have been explored for people with visual impairment to understand directions [9, 10] and learn unfamiliar environment [17, 20, 21]. For example, in a comparison study that examined how motors vibrating around the wrist affected the haptics as a directional hand guide, Hong *et al.* found that it was easier for participants to identify the direction when fewer motors were distributed around the wrist and single motor vibrated [9]. We adapted the similar design in our pneumatic wristband with only three air actuators. Since we aim to assist BVI people to fetch objects in an unfamiliar environment, we learned that acquainting BVI users with the unknown environment is cognitively costly and provided haptics are easy to perceive from [17, 20, 21]. In our design, we provide direct haptic feedback that contains only direction and distance cues without enforcing the user to learn the environment.

Haptic Feedback for Nearby Object Fetching

To understand how BVI people fetch nearby objects and inform our prototype design, we developed a survey eliciting preferred haptic feedback to indicate direction and distance. The survey included 8 questions divided into: (1) demographics—gender, age, visual impairment, *etc.*, (2) haptic feedback type—vibration, touch, and electrical stimulus, (3) on-body positions to provide directional haptic feedback, and (4) haptic cues to indicate the proximity of the target object. The survey was distributed online and 19 volunteers from a school for the blind completed our survey. Further, we invited two participants to explain their answers orally. All the volunteers have experience with vibration haptics and 17 know other types of haptic feedback (*i.e.,* touch and EMS). Volunteers were compensated $2. Below, we characterize the participants and present our findings in detail.

Participants. Our survey resulted in the following demographic breakdown: (1) 6 female, 1 unknown, and 12 male; (2) 79% younger adults (30 yrs and below) and only one older adult (60 yrs and up); (3) 2 are left-handed; (4) 17 have college or higher degrees; (4) 16 blind and 3 have low vision.

Haptic Feedback and Design. Vibration and touch are the two most favored. While vibration is the most common haptic feedback used by BVI users (*e.g.,* on mobile phones), touch, explained and demonstrated during the interview, was reported more acceptable and less intrusive when applied directly to skin. As a result, we built our wearable prototype to deliver on-skin touch cues. For the best location to provide touch feedback, wrist was most favored, followed by forearm and finger. However, from our interview, we found that fingers might be interruptive as BVI people recognize objects by finger touching. We thus provide 6-axial directional touch cues around the wrist and on the forearm in our prototype design. In our device, we can also simulate proximity information by controlling both touch duration (how fast a repeating touch occurs) and power (how strong the touch is applied), which are suggested in the survey and interviews.

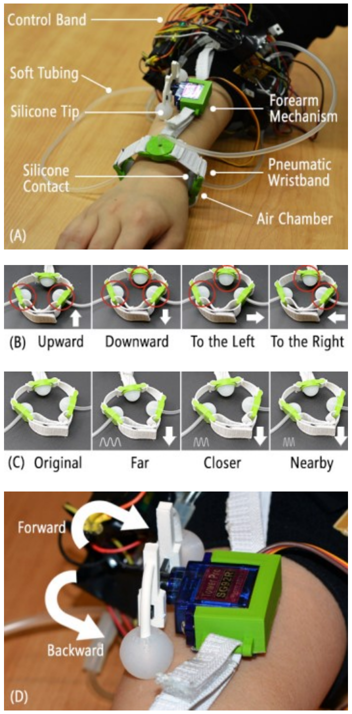

Figure 2: (A) *PneuFetch* wearable device overview; (B) four presses around the wrist indicate directions and the chambers in the red circles chambers swell; (C) three touch frequencies and strengths are used to indicate the proximity. Here, the *downward* cue is shown as an example; and (D) two drags on the forearm using the same frequency and strength pattern indicate the proximity.

PneuFetch Wearable Design

Informed by the survey and interviews, we created *PneuFetch*—a wearable device that delivers light haptic cues around the wrist and on the forearm for BVI people to fetch nearby objects (Figure 2A). By pressing on the wrist and dragging on the forearm, our device indicates the direction toward the target object. The user is also alerted with the proximity of the object via provided haptic touch frequency and strength.

Haptic Touch Cues Design

To enable BVI people to locate and fetch objects in complex environment (Figure 1), we create a set of haptic touch cues by pressing and dragging skin to indicate the direction toward and the proximity of the target object. For directional cues, we simulate presses around the wrist (Figure 2B) to indicate *upward*, *downward*, *to the left*, and *to the right*, and drags on the forearm to indicate *forward* and *backward* (Figure 2D). With these gentle presses and drags, the BVI user can explore the space in 6-axial directions. We use only three touch contacts around the wrist to provide equivalent four directional cues because attaching additional components beneath the arm might intrude in external surface and result in worse comfortability. For proximity estimates, we program the duration and power of presses and drags—shorter and lighter touch indicates a closer proximity of the target, and vice versa: see Figure 2C and our supplementary Video Figure. The current prototype provides three proximity levels: far (30cm and up), closer (between 5cm and 30cm), and nearby (5cm and below).

Hardware Implementation

The *PneuFetch* wearable prototype is composed of three parts (Figure 2A): a pneumatic wristband, a mechanical arm-dragging mechanism, and a control armband. The wristband and arm-dragging mechanism are dynamically controlled by the control armband to generate presses and drags. Using elastic bands to connect all these three parts, we can easily calibrate the positions of air nodes around the wrist and the servo tips on the forearm.

Pneumatic Wristband. Three pneumatically actuated nodes are distributed and fixed at the top, right, and left of the wrist through adjustable elastic bands (Figure 2A), which fits in the wrist of any size. Each node consists of an *air chamber* that is cast in silicone in a semi-sphere and encapsulates an air pocket with one hole for air inflation and deflation, and a *rigid 3D-printed socket* that holds the chamber in place and constrains the expansion of the silicone chamber.

Mechanical Forearm Attachment Mechanism. To create dragging cues on the forearm, we attach two 3D-printed shafts with soft silicone-made tips to a servo (Figure 2A&D). When the servo is programmed to rotate, the silicone tips touch the skin and slide in one direction, creating directional pulling force.

Control Armband. Three air chambers on the pneumatic wristband are connected to a miniature air pump (KOGE, KPV 14A) via soft plastic tubes and four normally open solenoid valves, which controls the air flow for chamber inflation and deflation. The pump, solenoid valves, the servo are controlled by an UNO Arduino board. In addition, we use a pair of nRF24L01 modules to establish a wireless communication between the wearable prototype and a laptop (Apple Mackbook Pro). Figure 2A shows all electronics (*e.g.,* transistors, batteries, *etc.*) installed on a black elastic band.

Software Control
The inflation and deflation of all the air actuators and the rotation of the servo are controlled through an Arduino program. Based on the three proximity levels, the air chambers swell and restore for 450ms (far), 300ms (closer), and 150ms (nearby) or the servo rotates by clockwise 20° or counter-clockwise 20° three times at an interval of 480ms (far), 240ms (closer), and 160ms (nearby). Obviously, when the object is closer, the presses and drags act faster and less strong. While capturing the object location is not included in our current system, we manually send direction and distance commands from the Arduino Serial Monitor on the laptop to the microcontroller on the control armband via wireless communication.

Preliminary User Study

To examine how BVI people respond to our wearable prototype, we conducted a preliminary user study with a congenitally blind massage therapist (age 41; female). We investigated how BVI people reacted to our wearable device, the thoughts on the light touch feedback, and how the wearable device assists them with object fetching tasks.

Methods
The study began with a semi-structured interview on the experience of fetching objects in a familiar and unfamiliar environment. Then, the participant was asked to complete three object fetching tasks: (1) fetching a book next to a cutter on a desk (2D); (2) fetching a dish over a bowl of soup on a dining table (2.5D); and (3) fetching a frozen meat in the bottom cubby of a refrigerator without touching exposed jelly and meat (3D). All tasks were set up in a room with which the participant was not familiar. An experimenter performed a Wizard of Oz [4] by manually sending direction and distance commands on a laptop at an interval of 5 seconds. Finally, the participant was also asked to share their personal feelings and thoughts regarding usability with us in a post-study interview. We analyzed our data based on the participant's answers and notes.

Results
The participant completed all three tasks without sighted assistance. Longer completion time was recorded as the situation became more complex: 7.6s for task1, 12.4s for task2, and 20s for task3. From the analysis, we summarize the results in the following three themes.

Direction and Distance Cues. Based on the responses of the participant, the presses and drags could deliver clear directional hints throughout all three tasks. She stated: *"It feels like someone holds my arm and tells me where to go".* However, she expressed confusion about the transient impulse caused by the deflation of the air flow in the air chambers: *"at beginning I feel the press from the top and the right [for 'to the left' command], but why there is a slight tap on the left after those three presses".* The drags on the forearm worked thoroughly. As for the distance cues, the participant preferred the press and drag frequency: *"Oh I don't feel any difference of how hard it touches me, but I know I am almost there when it touches me faster".* She also suggested the user could potentially benefit from more proximity ranges because she stayed in one range for most of the time in the tasks.

Touching Objects. From the pre-study interview and all the tasks, we found that the participant touched objects very often regardless of the haptic feedback. She could not help touching objects because she had developed a habit of learning the surrounding environment by touching for years: *"I can find what I want by touching the objects on the table if I am sure it is on the table"*. Nevertheless, in the first desk task, the participant was faced with potential dangers when she touched the exposed cutter.

Physical Comfort. The participant agreed that the wristband and the forearm mechanism were comfortable to wear. However, she reported that the control armband was too heavy and the most uncomfortable part of the prototype. When the participant moves her arm and body, she acted very slow and stated: *"I am worried that the wires and the electronics may fall off. They are exposed and bulky on the [control] band"*.

Discussion and Conclusion

We introduced *PneuFetch*, a touch-based wearable device that provides direction and distance haptic cues for BVI people to fetch nearby objects in an unfamiliar environment. In this paper, we described the design and implementation of three main parts in our wearable prototype: a pneumatically actuated wristband, a mechanical forearm mechanism, and a control armband. Our preliminary study demonstrated the feasibility of our approach and revealed problems that our future design should address. Below, we enumerate limitations and describe future work.

Limitations. Our exploratory wearable approach showed the potential of using light touch cues for BVI people to fetch objects; however, more touch haptic feedback is necessary to extend existing touch vocabulary for other needs from BVI people, for example, identifying a potential danger. In addition, our preliminary study included only one participant, who provided valuable feedback on the usability of our prototype but underrepresented the whole BVI population. A thorough comparison test that investigates how BVI users fetch objects without our device is necessary. Finally, the uncovered circuitry and electronics in the current prototype may frustrate the wearer in the object fetching task.

Future Work. As early work, we have identified many opportunities to explore, including: (i) optimizing the wearable device by developing lighter and miniatured mechanisms that provide robust haptic feedback and can be easily and firmly attached to body; (ii) exploring other touch haptic cues that can be used for conveying richer information such as potential danger notifications; and (iii) developing a 360 camera-based mechanism that identifies and locates the target object using computer vision and speech recognition algorithms and communicates with the wearable device in real time. In the longer term, we hope to deploy the system and run formal studies with a larger set of BVI participants.

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