Using the OptiBand to Increase the Long-Range Spatial Perception of People with Vision Disabilities

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***Abstract*— Mobility aids such as the white cane provide close-range information to help people with vision disabilities navigate the world. However, this technology has a limited sensing range and does not provide long-distance scene awareness. This paper proposes a vibrotactile feedback device to fill this gap: the OptiBand, which was developed based on design criteria from a blind stakeholder. The presented user study (N = 27) compared the OptiBand to a proxy for existing shorter-range mobility aids, considered two potential sensed distance-to-vibration mapping strategies, and covered the use cases of locating and approaching objects of interest. Results of the object-locating trials showed that using the OptiBand led to faster and more successful performance, as well as lower task load and more satisfaction with the device, compared to using a proxy state-of-the-art device. A final trial with the original stakeholder demonstrated that the design criteria were met and supplied insights for the next iteration of participatory design for the OptiBand. Those who are interested in assistive devices for people with vision disabilities can benefit from this work.**

I. Introduction

As reported by the Centers for Disease Control and Prevention [1], approximately one million adults in the United States are legally blind. Most human abilities to avoid obstacles and make navigation decisions are heavily reliant on sight. As such, blind individuals depend on alternative ways to perceive the space around them and navigate the environment.

The white cane allows for partly independent travel by providing high-resolution haptic information about a one-meter arc around the user [2]. However, the white cane is limited by its reach, so users lack part of the spatial perception information needed to navigate without a preexisting mental map of the surroundings.

Over 50 years of research has sought to improve the independent space traversal of blind individuals. Wearable aids can deliver reliable and consistent information, improving the user's orientation and direction sense. Researchers have incorporated such functionality into belts [3]–[7], headwear [8], [9], wristbands [10], [11], handheld devices [12], and canes [3], [4], [13]–[16]. Commercial devices in this space include the Sunu Band [17] and Miniguide [18].

Most of these devices use tactile or aural signals to inform the wearer of obstacles within the immediate surroundings (i.e., within a 5m arc). At the start of our project, a stakeholder who is blind indicated a different need: to sense and seek distant objects (rather than avoiding them), as well as to sense large landmarks (such as buildings in city navigation scenarios) and build a mental map of new surroundings. Indeed, among current related devices, we observed that there was a cap on typical sensing abilities, with no ranges greater than 10m (e.g., [19]) and few ranges greater than 6m. Thus, our efforts build on past related work by equipping a haptic wearable device with longer-range sensing abilities than most past alternatives in this space.

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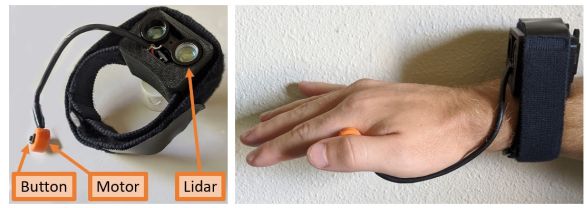

Fig. 1. *Left:* The OptiBand, the Lidar-based scene awareness device used in the study. *Right:* A mock user wearing the device.

Our proposed device (the OptiBand, shown in Fig. 1) is a wrist-mounted device that uses Lidar sensing and vibrotactile feedback to inform the user about physical objects in the surroundings. The presented work evaluates this device's ability to help the user locate nearby objects and seek landmarks in their nearby and distant surroundings, building on preliminary pilot results presented in a past short abstract [20]. One key contribution of this work is information about the benefits and use cases of a haptic spatial perception wearable device with a longer sensing range and updated purpose compared to similar research or commercial devices. Further, we offer design criteria for a particular use case from a stakeholder who is blind, present a systematic comparison of mapping strategies for converting distance to sensed objects into vibration signals, and return to evaluation by the stakeholder in a closing preliminary trial.

In this paper, we first explain design criteria collected from a representative stakeholder in Section II. Past work shows that sighted individuals wearing blindfolds are not suitable replacements for blind system users [2], but the population of individuals who are blind is relatively small. Our work aimed to balance these two factors. We pursued an in-lab study (Section III) to initially validate the OptiBand with a convenience population of sighted users. Our follow-up preliminary trials in Section IV built on the findings from the convenience population to return an improved device to our original stakeholder for in situ testing. We discuss the key findings, design implications, and strengths and limitations of the work in Section V.

II. Stakeholder Design Criteria

This project originated from a real-life need of a stakeholder who is in his 60s and has been blind most of his life. Through a mutual acquaintance of the stakeholder and the authors, this stakeholder approached us with an interest in a new navigation aid for locating distant objects on his large plot of land (e.g., a shed or a vehicle at the end of a driveway). This user had experience with a white cane, an e-cane, and experimental wearable devices similar to our eventual prototype device, but with a shorter range. He perceived a gap in the availability of spatial perception aids for detecting farther-away objects of interest.

A. Design Criteria

During the system design process, we were informed by a beginning hour-long call with the stakeholder, email conversations, and subsequent calls throughout the prototyping process which helped us to better understand his needs. Based on his input, we identified the four design criteria below.

Haptic Feedback Modality. The stakeholder had previously tried audio-based navigation aid systems and found these devices too distracting, stating that when you "want to pay attention to traffic, people, and extraneous noise, [sound-based devices] can be distracting." This opinion is seconded by related academic literature [21]. The stakeholder preferred that the designed system use haptic feedback.

Long Sensing Range. For the purpose of finding and seeking distant objects, the stakeholder found the sensing range of alternative aids too limited. He noted the desire for a "laser that can measure distances at least in the 50-100ft range" (i.e., 15-30m). This request related to this user's desire to better navigate the large and rural plot of land where he lived, but he was interested in similar functionality in urban settings (for example, for "feeling" cars that drove by). His experiences with a white cane ($\sim$1m reach) and experimental electronic aids (typically $<$4m reach) were unsuitable for seeking distant objects.

Suitable Mapping Method. The stakeholder had certain specific methods in mind for mapping sensed distance to outputted vibration. He articulated the need for different types of trends, such as "frequency being more rapid as distance increases [or alternatively, frequency being] more rapid as [an] object grows closer."

Ability to Find and Seek. As hinted at by some of the criteria above, the device should be appropriate for at least two phases of task: finding and seeking. An example use of the envisioned device was to "help me pick out if there's a building [...] there" when scanning the surroundings.

B. Resulting OptiBand Design

Our stakeholder's feedback led us to design our wearable device, the OptiBand, which is meant for use as a secondary aid in conjunction with a cane. The device design, software design, and use cases were guided closely by the presented design criteria, as detailed below.

1) System Design, Including Haptics and Long-Range Sensing: Following the first and second requirements, we selected the key components of the OptiBand. The OptiBand, as shown in Fig. 1, consists of a Garmin Lidar Lite v3, Adafruit vibrating mini motor disc, Teensy 3.2 microcontroller, custom PCB, push-button, 3D-printed PLA case, and portable power source. Ultrasonic sensors used in past systems like [17], [21], [22] were able to detect objects up to 4m away, which were not suitable for the use case of this device. We experimentally determined that the 1D Lidar used in the OptiBand can reliably sense up to 15m in representative use cases, although the nominal range listed on the Lidar datasheet is 40m. The button and vibrating motor are located at the end of the free-floating wire. The Lidar reads linear distance values from the device's front and the motor vibrates at a frequency related to the sensed distance, as computed in a custom Arduino IDE script. (More information on the mappings is provided later in this section.) The push-button activates the Lidar to both save power and reduce vibration fatigue. Aside from the Lidar sensor, system components were selected to be low-cost to maximize system affordability.

To investigate the impact of having a long-range Lidar sensor, compared to common alternatives like ultrasonic sensors, we later manipulate the maximum distance the OptiBand could sense to represent our device vs. similar ultrasonic sensing-based mobility aids.

2) Vibration Mapping Functions: Based on the stakeholder's recommendations in design criterion three, we considered two ways to map sensed distance to vibration output. Our previous pilot work in [20], we investigated two additional mappings as well as the stepped mapping explained further below; however, none of the mappings led to significant differences in performance. We selected the stepped mapping in the present work because it was the most popular among pilot participants.

The methods by which sensed distances (D) are related to vibrations (V) for the two mapping methods appear in the below functions. The maximum vibration frequency used in the study (V_{max}) was 183Hz and the maximum distance used in the study (D_{max}) was 15m. These maximum values were used to scale the functions to our specific system.

- *Stepped Mapping*: This mapping divides the total range of the device into eight equal ranges. Each range relates to one vibration frequency inversely proportional to sensed distance using the following function:

$$V = (\frac{-\lfloor D/D_{max} * 8.0 \rfloor}{8.0} + 1.0) * V_{max}$$

  Efforts in [22] used a similar mapping with eight distance ranges matching to the eight notes of an octave. [13] also used unique tactile and audible signals to relay measurement ranges of interest.

- *Inverted Stepped Mapping*: An inverted version of the stepped mapping using the following function (with the same variables as defined above):

$$V = (\frac{\lfloor D/D_{max} * 8.0 \rfloor}{8.0}) * V_{max}$$

  This exploratory mapping method arose from later discussions with the blind stakeholder.

3) Use Cases: In alignment with design criterion four, we envisioned the OptiBand as a device to help with locating and pursuing objects in different regions of one's surroundings. To help to simulate this, the study outlined in this paper focuses on locating and approaching objects that appear within closer and farther radii from the system user.

III. In-Lab Study

With the design criteria and system design in mind, we designed an in-lab study for initially validating the OptiBand.

A. Methods

This study included two *sensor ranges* to clarify the advantages of the OptiBand compared to similar but shorter-range alternatives, as well as two *mapping methods* brought about by conversations with our stakeholder. We studied the two tasks intended to be performed by the OptiBand with distinct study phases: *locating* and *approaching*. The study was approved by the OSU Institutional Review Board (IRB) under protocol #IRB-2019-0656.

1) Study Design: We investigated efficacy in the *"locate"* task using a 2×2×2 full factorial within-subjects design crossing *sensing ranges* (i.e., proposed and existing, as further detailed below), *mapping methods* (i.e., stepped and inverted stepped), and object *distances* (i.e., representative 1.1m×2m cardboard objects at 4m and 12m, as shown in Fig. 2), as further detailed below. This led to eight individual trials for the locate task (one per condition).

We investigated system use for the *"approach"* task using a 2×2 full factorial within-subjects design crossing the same *sensing ranges* and object *distances* as in the locate task; all of these trials used the stepped mapping to constrain the overall length of the study to a feasible duration. This yielded four trials for the approach task (one per condition).

For both investigated tasks, condition order was counterbalanced across users. Two objects were present at once for each locate trial, and one object was present for each approach trial; the objects were moved between trials. Each condition for each trial was presented to participants one time.

The sensor range conditions are further described below:

- The Proposed Long-Range Sensor *(Proposed)* used the Lidar to sense and relay information about objects up to 15m away from participants. The OptiBand Lidar functions well within this full range.
- The Existing Short-Range Sensor *(Existing)* simulated the experience of using current electronic mobility aids by only relaying information about objects up to 5m away, a similar range to previous mobility aids such as [3], [4], [17].

2) Hypotheses: Our hypotheses are grounded in the results of the past pilot study [20] and the logical reasoning that far-range information will be helpful for finding distant objects.

H1: While using the proposed long-range device, participants will be faster and more accurate at locating and approaching objects relative to when using the short-range device.

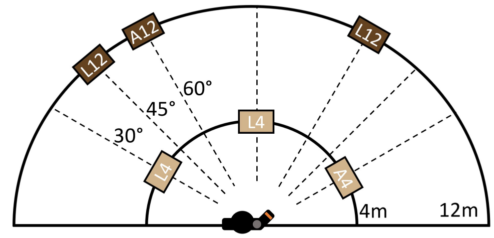

Fig. 2. A top-down view of the study space showing the 4m and 12m cardboard object locations. For the 4m locate trials, we placed objects at the positions labeled as L4. The object positions for the 12m locate trials are likewise labeled as L12. For approach trials, the object positions are labeled as A4 for the 4m trials and A12 for the 12m trials.

H2: Participants will rank the proposed long-range device to have a lower task load, to be less discomforting, to be more reliable, and to be more understandable than the existing short-range device.

Note that although the mapping method and distance manipulations do not appear in the hypotheses, each one played a key role. The exploratory mapping manipulation allowed us to study a later-proposed mapping from the stakeholder. We manipulated object distance to investigate device performance for short-range vs. long-range sensing.

3) Participants: A total of 27 people from the greater Corvallis community participated in the study. The 15 male, 10 female, and two non-binary participants were between 18 and 67 years old (M = 29.9, SD = 14.7). One participant reported past experience using a mobility aid, and another participant reported having exposure to high degrees of vibrations in their profession. Participants generally reported moderate experience with vibration technologies (M = 3.7, SD = 2.1), and 15 participants work in a technical field.

4) Procedure: Each participant came to an on-campus gymnasium space for one hour to complete the study. When participants arrived, we collected informed consent and administered a demographic survey.

The locate task began with a brief training that included using the OptiBand without a blindfold to feel how the device behavior changed when pointed at a nearby object compared to the distant walls of the study space. For the official trials, participants donned a blindfold to simulate a lack of vision and noise-cancelling headphones playing pink noise to limit potential hearing-based confounds. Each trial involved using the designated mapping to locate the two objects in the study space at the designated radius. Participants indicated their guess of where each object was located by pausing their movement and pointing with an outstretched index finger and nodding motion for emphasis. To conclude each trial, participants verbally indicated that they were done searching. (Note that sometimes this meant participants had located two objects, but other times they failed to locate enough objects or found extra/erroneous objects.) Fig. 3 shows a participant in a locate trial. Lastly, to ensure that participants could complete the study within the allotted time, we enforced a time limit of two minutes maximum per trial. After each set of two trials, participants completed a survey.

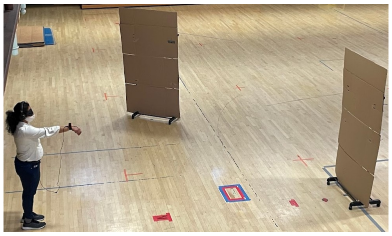

Fig. 3. A participant successfully locating an object in a 4m trial.

The approach task activity began with an approximately four-minute training exercise meant to orient participants to using the OptiBand while walking. First, participants watched an animation showing a person walking and the OptiBand field of view changing as the person moves. The participant then used the long-range device (without a blindfold) to "feel" three specific locations in the study space, the third of which included a cardboard object. Next, the participant donned a blindfold and noise-cancelling headphones. Each trial involved using the designated device mode to locate one object in the study space at the designated radius. Participants could search the space however they desired, but they received notice if they were about to walk into an obstacle. Participants had four minutes to try to touch the sought object with an outstretched hand. To prevent guessing the next object radius, we led the still-blindfolded participants back to the starting spot using a string. After each set of two trials, participants completed a survey.

At the end of the study, the participant completed a brief semi-structured interview about the OptiBand and experiences during the study. Participants received \$10 US upon completing the interview.

5) Measures: Measurement in this study entailed a mix of objective and self-reported information. The beginning-of-study demographic survey collected age, gender, experience with mobility aids, and experience with vibrations.

Overhead video was recorded from the study sessions to support post hoc extraction of two key objective measures:

- Time: the time taken during each trial. The start of the trial was defined as when the participant began searching, and the end was marked by either the participant's verbal indication of having completed their search or the elapsing of the two-minute time limit, whichever came first.
- Success Rate: the number of correctly located objects. Correctness was defined as a pointing angle within plus or minus 10 degrees from the true radial position of an object; pointing angle was extracted using a tool that asked the annotator to click the key points to compute this angle.

Both measures were manually extracted from the video recordings by a trained annotator. (Note that the video was recorded from directly overhead the participant, i.e., using a different angle than shown in Fig. 3.) Together, these objective measures helped us to assess the OptiBand's ability to satisfy the original stakeholder's need to locate objects with relative efficiency.

Survey questions helped us to capture further aspects of system use experience and usability, as detailed below:

- The Self-Assessment Manikin (SAM) [23] helped us to measure participant happiness, stimulation, and dominance feelings while using each particular device mode.
- The NASA Task Load Index (NASA TLX) [24] captured the effort required to use the system.
- The discomfort portion of the Robotic Social Attributes Scale (RoSAS) [25] evaluated participant comfort.
- The Measuring Human Computer Trust (HC Trust) survey [26] captured elements of how reliable and comprehensible each mode is to use.

Each assessment used Likert-type questions with seven anchor points. With these self-reports, we could evaluate participant experiences with each device mode.

The closing semi-structured interview supported our understanding of the overall study experience.

6) Analysis: Objective performance data and subjective survey responses for the locate task were analysed using three-way and two-way rANOVA tests, respectively. For the approach task, the main tests were two-way rANOVAs for objective data and one-way rANOVAs for subjective data. Tests used an $\alpha = 0.05$ significance level. We selected these tests based on previous work that supports the use of ANOVA tests even with small samples that may not satisfy normality assumptions [27], [28]. For significant main effects, we performed pairwise t-tests between the different factor levels using a Bonferroni correction.

B. Results

All 27 participants successfully completed the study. Corresponding objective and subjective results appear below.

1) Performance Data: Generally, participants successfully identified a mean of 9.2 (out of 16 total) objects (SD = 2.2) in the locate task and 2.8 (out of 4 total) objects (SD = 1.1) in the approach task. The objective results appear in Fig. 4.

In the locate task, participants were faster ($p < 0.001$, $F(1, 26) = 14.18$, $\eta^2 = 0.086$) and more accurate ($p < 0.001$, $F(1, 26) = 37.01$, $\eta^2 = 0.098$) when using the proposed long-range device. Likewise, participants completed tasks faster ($p < 0.001$, $F(1, 26) = 169.14$, $\eta^2 = 0.521$) and were more successful at locating objects ($p < 0.001$, $F(1, 26) = 51.88$, $\eta^2 = 0.278$) for closer objects. No other main effects were significant for the locate task (all $p \geq 0.076$).

We further observed significant interaction effects for the combination of device range and object distance for time spent locating objects ($p < 0.001$, $F(1, 26) = 24.84$, $\eta^2 = 0.094$) and success doing so ($p < 0.001$, $F(1, 26) = 39.00$, $\eta^2 = 0.176$). The proposed long-range Lidar setup led to significantly faster and more successful finding of 12m objects, compared to short-range trials involving 12m objects. The existing short-range Lidar led to significantly more success finding 4m objects than long-range trials with the 4m objects. Consistent with the main effects, participants were significantly faster and more successful at finding 4m objects (compared to 12m objects) within each individual Lidar range.

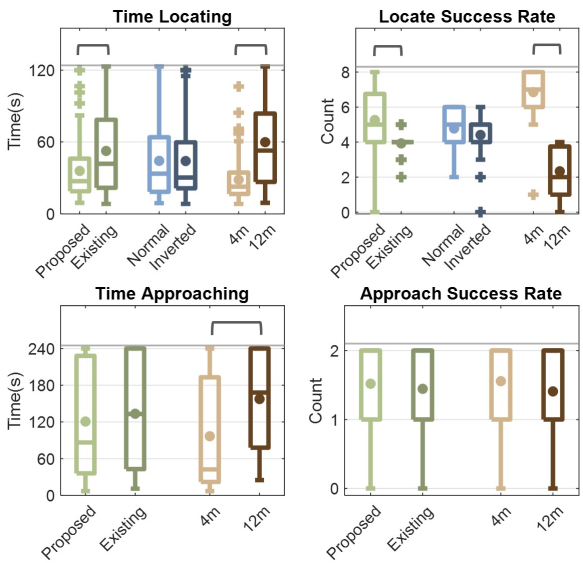

Fig. 4. Objective results from the in-lab study. Horizontal lines represent the median, dots represent the mean, pluses represent outliers, boxes represent the 25th and 75th percentiles, and whiskers cover up to 1.5 times the interquartile range. Brackets represent significant differences. Note that depicted times are trial-wise, while success rates are summed across each individual's results for a particular factor level.

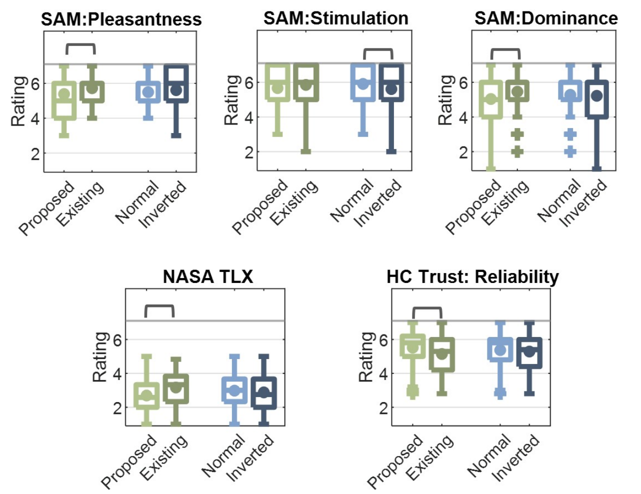

Fig. 5. Subjective results from the locate task.

Additionally, we saw a success rate interaction effect across device range, mapping method, and object distance together ($p = 0.020$, $F(1, 26) = 6.12$, $\eta^2 = 0.010$). One uncovered difference hinted at an influence of mapping method selection: participants using the normal stepped mapping method had a significantly higher success rate for 4m objects using the proposed long-range Lidar setup, as compared to the inverted stepped mapping. The other pairwise results were reminiscent of previously reported effects. Specifically, the long-range device led to higher success rates (compared to the short-range device) while participants used each individual mapping to find 12m objects. The short-range device also led to more success than the long-range device when participants were using the inverse stepped mapping method to find 4m objects. Finally, participants had a significantly higher success rate locating 4m objects (compared to 12m) across all four combinations of Lidar range and mapping methods.

For the approach study task, we found that participants were significantly faster at finding closer objects ($p = 0.003$, $F(1, 26) = 11.13$, $\eta^2 = 0.116$). No other main effects were significant for the approach task (all $p \geq 0.299$).

2) Survey Responses: Survey responses showed five significant differences in self-reported data for the locate task, but none in the approach task. Box plots for the locate task appear in Fig. 5. For brevity, we display only scales that yielded significant differences. We found that participants rated the proposed long-range Lidar setup to have a significantly lower task load ($p < 0.001$, $F(1, 26) = 20.10$, $\eta^2 = 0.053$) and to be significantly more reliable ($p = 0.010$, $F(1, 26) = 7.70$, $\eta^2 = 0.028$) than the short-range existing system condition. In contrast, participants were happier ($p = 0.005$, $F(1, 26) = 9.20$, $\eta^2 = 0.026$) and felt more in control ($p = 0.010$, $F(1, 26) = 7.90$, $\eta^2 = 0.022$) while using the existing short-range system. Participants reported to have significantly higher feelings of stimulation while using the stepped mapping method compared to the inverted stepped mapping ($p = 0.030$, $F(1, 26) = 5.30$, $\eta^2 = 0.016$). We did not observe any other significant differences in subjective ratings (all $p \geq 0.057$).

In the approach study task, we did not find any significant differences in the subjective ratings (all $p \geq 0.245$).

IV. Preliminary Trials with a Target User

Past related work like [2] shows that blindfolded system users are not representative of individuals who are blind, so it was also important to conduct testing with a blind prospective technology user. Thus, we decided to temper and extend the results of our empirical study with the results of in situ system testing performed with the original blind stakeholder.

Our original stakeholder received an OptiBand for use at home and tested the system for 10 days. (See Section II for more background information on this user.) We conducted a beginning orientation call and ending check-in call with him, and between these calls, he was free to use the device as he wished. He reported trying the system in an indoor workplace, around his home, and outdoors on his plot of land. A subset of these tasks (for example, finding distant objects indoors and seeking nearby objects outdoors) aligned well with the nature of the in-lab testing tasks. One way to qualitatively evaluate his system use experience is by returning to the original design criteria identified with his assistance:

Haptic Feedback Modality. The stakeholder was happy with the vibration feedback methods used in the OptiBand generally, stating "the hardware [and] the software I like. I think the engineering part was good. I have some suggestions on the human factors side of it." For example, he was interested in changing the length of the wire connecting the button-motor assemble to the rest of the OptiBand.

Long-Range System. The stakeholder shared that "the distance we have now is pretty much adequate" for his use case of finding and approaching objects. He expressed that, compared to a previous mobility aid he had used, "15-20ft...

that's not really adequate." Further, in his view, a device that could sense up to 150ft, "wouldn't be of much use anyways" as there would be too much information to interpret.

Mapping Methods. While testing the OptiBand, the stakeholder liked the ability to use different mappings for specific tasks. He mentioned "I can toggle back and forth between [the mappings], that way I [can] actually find something and get to it, which was more useful." Using the inverted mapping alone, he "could find things, but not get to them."

Usefulness for Finding and Seeking. Based on his experiences with the OptiBand, the stakeholder described how he was able to identify several objects at home (i.e., a pump, car, gate, shed, garbage can, and even dog) and approach locations of interest. Referring to his 8ft-wide (i.e., 2.4m-wide) shed, the stakeholder said "I was able to find [the shed] at a distance and guide myself up to the doorway." With regards to the device overall, the stakeholder concluded that "it is useful for what I specifically wanted it for, finding a distant object...and actually getting there."

As in any iterative participatory design process, the experience of working with the stakeholder also led to notes and critiques relevant to future prototypes. Notably, we had assumed that making the device hands-free by mounting it on the wrist would be desirable, but our stakeholder expressed a preference for the device to be "more like a digital camera." that he could store in his pocket. Further, to avoid vibration fatigue, we included a button to activate haptic feedback in the OptiBand, but the stakeholder was interested in having a mode option that supplies constant vibration feedback.

V. Discussion

Our efforts spanned three main phases (i.e., *design discussions*, *in-lab study*, and *preliminary in situ trials*) to ensure relevance to actual end users while also allowing us to validate basic device characteristics with a convenience population. Initial *design discussions* with a target stakeholder led to design criteria: namely, an assistive device that uses haptic feedback, has a long sensing range, maps sensed distance to objects to outputted vibration in different ways, and allows the user to find and seek objects in the distance.

Objective *in-lab study* results partially support **H1**. We found participants to be faster and more successful during the locate task with the long-range device. We did not see the same effect in the approach task, but we did observe high levels of success in approaching objects generally (i.e., most participants found all objects). Although the effect was not significant, the approach time also tended to be lower with the proposed long-range device. Interaction effect results hint that particular device modes are better for distinct tasks; a short-range device is better for locating nearby objects than a long-range device, but a long-range device leads to more success locating far-away objects. The difference here might imply a higher cognitive load associated with the long-range device, which is not needed in the case that a short-range device will suffice for a given task. Mappings also play a role in the specific case of finding nearby objects with a long-range device.

Subjective *in-lab study* results likewise partially support **H2**. We found the proposed long-range device to be rated as significantly more reliable with a lower task load for the locate task, but this mode was not found to be less discomforting or more understandable. Counter to our expectations, the short-range device was actually perceived as more pleasant to use. This may indicate that "extra" information is counterproductive; for detecting nearby objects, restricting sensing range to nearby is best, but for far-away objects, a longer range provides an advantage.

The *in-lab study* results suggest that the ability to toggle OptiBand range and mode would lead to the most valuable device. The *case study* results second this insight; our stakeholder preferred to toggle the device mode, for example, as he approached an object of interest. He also anecdotally found the OptiBand helpful for both locating and seeking objects of interest in his surroundings.

Strengths of this work include evidence (from our controlled empirical study and in situ evaluation) that the OptiBand is useful for scanning the horizon and noting objects of interest. Our stakeholder also found the device helpful for approaching objects. We further propose the methodology of this work, which balances larger-scale empirical investigation with the need to fit the needs of real stakeholders, to be a potential model for designing helpful devices for people with vision disabilities.

On the other hand, the study has key *limitations*. For example, we conducted the in-lab study with sighted individuals. The learning curve for device use also influenced the generalizability of these short-term experiences, and design decisions (such as setting criteria for what a "correct" pointing angle is) have implications on use contexts of this work. At the same time, the preliminary trials with our stakeholder reflect the needs and experiences of just one blind user. Thus, follow-up work is needed, particularly longer in situ investigations with a larger number of system users who are blind. In these future efforts, we should make sure to assess fatigue analysis, which may play a larger role in long-term use and lead to the need for additional form factor designs.

Overall, this paper establishes the need for the proposed OptiBand system: an assistive device for long-range spatial perception. The results, both from in-lab trials and in situ evaluation, indicate the promise of the OptiBand compared to existing shorter-range mobility aids, particularly for the intended tasks of locating and seeking distant objects. In next steps, we will pursue broader in situ studies and explore additional device form factors to further the potential of this work to advance the state of knowledge on assistive devices for individuals who are blind.

Acknowledgments

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