Investigating Haptics-Supported Spatial Perception with the OptiBand: A Wearable Haptic Feedback Device

Ryan Quick[1], Anisha Bontula[1], Karina Puente[1], Naomi T. Fitter[1]

***Abstract*— Mobility aids such as the white cane provide close-range information to help people who are blind 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. The presented pilot (N = 10) study focuses on validating this new device's efficacy to inform the user of near and far objects in their surroundings with three different distance-to-vibration mappings. Stakeholders who are interested in wearable robotic systems and assistive devices for the blind can benefit from this work.**

I. Introduction

While most human abilities to avoid obstacles and navigate are heavily reliant on sight, approximately one million adults in the United States are blind [1]. People who are blind depend on alternative ways to perceive the space around them, such as the white cane (which provide information about a 1-m arc around the user [2]) and existing wearable electronic devices (which tend to only provide information for up to 5 m from the user, e.g., [3], [4]). At the start of our project, a stakeholder who is blind indicated a need to sense and seek objects beyond a 5-m reach. Thus, our efforts in this paper include equipping a haptic wearable device with longer-range sensing abilities than most past related alternatives. The presented pilot work with the resulting wearable robotic device (Fig. 1) evaluates this system's ability to help a user locate nearby and distant objects.

II. Pilot Study

As will be explained more completely in a future full paper on this work, early discussion with a project stakeholder led us to design our OptiBand device with haptic feedback, a long sensing range, varying mapping methods for connecting sensed distance to user-facing information display, and the ability to support finding and seeking objects. Thus, in our pilot study, we sought to begin to evaluate whether we had fulfilled a subset of these design criteria, specifically focusing on: 1) if a user can locate an object in their environment using different OptiBand mappings and 2) if the system appears easy-to-use and reliable to the user.

A. Device Design

We designed the OptiBand, as shown in Fig. 1, with 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. We experimentally determined that the Lidar used in the OptiBand can reliably sense up to a distance of 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.

[1] Collaborative Robotics and Intelligent Systems (CoRIS) Institute, Oregon State University, Corvallis, OR 97331, USA.
{quickr, bontulaa, puentek, fittern}@oregonstate.edu

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

We considered three ways to map sensed distance to vibration output. The methods by which distances (D) are related to vibrations (V) for the 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.

- *Curved Mapping*: Vibration feedback are inversely exponential to measured distance using this function:

$$V = \frac{1.0}{((3 * D/D_{max}) + 0.8) - 0.265} * V_{max}$$

- *Linear Mapping*: Vibration frequencies are inversely proportional to distance measured:

$$V = (-D/D_{max} + 1) * V_{max}$$

- *Stepped Mapping*: This mapping divides the total range of the device into eight equal ranges, relating one vibration frequency to each range:

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

These mappings mirrored approaches in past related work, particularly [5] (for linear) and [6], [7] (for stepped).

B. Methods

We were uncertain of which mapping method would work best for locating objects in one's environment. Our exploratory pilot investigation focused on answering this question while assessing initial usability and perceived characteristics of the OptiBand. All study procedures were approved by the Oregon State University (OSU) Institutional Review Board (IRB) under protocol #IRB-2019-0656.

1) Study Design: We manipulated mapping strategy and object distance in a 3×3 full factorial within-subjects design with nine individual trials. We tested all three *mapping methods*: *curved*, *linear*, and *stepped*. We also manipulated the *distance* between participants and cardboard objects in the study environment (1.1m×2m in size) as shown in Fig. 2.

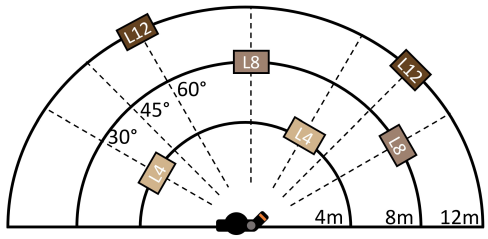

Fig. 2. Sketch of the study space. Object locations (consistent across participants) for 4m, 8m, and 12m trials are labeled L4, L8, and L12, respectively. Only two objects were present per trial.

The selected distances were *4m*, *8m*, and *12m*. The shortest distance is similar to the reach of current wearable electronic devices, and the farther lengths represent new longer ranges for this type of wearable assistive device.

2) Participants: 10 robotics graduate students (six male, four female) participated in the pilot. Participants were between 20 and 30 years old (M = 25.6, SD = 3.6). No participants had used a mobility aid previously. Participants had moderate experience with vibration technologies.

3) Procedure: Participants came to an on-campus gymnasium space for the hour-long study session. First, participants provided informed consent and completed a demographics survey. Participants completed a one-minute training on how to use the OptiBand (without a blindfold) to "feel" the floor, ceiling, and one illustrative cardboard object.

The study trials occurred in sets of three; the mapping method order was partially counterbalanced across participants using a Latin squares method, and the order of distance trials was partially counterbalanced within each mapping.

During each trial, the participant used the designated mapping to locate two objects in the study space. Participants indicated object locations by pausing their movement and pointing with an index finger. To conclude each trial (regardless of success finding the two objects), participants verbally indicated that they were done searching. During each trial, participants donned a blindfold to simulate (albeit imperfectly) a lack of vision and noise-cancelling headphones playing pink noise to limit potential hearing-based confounds.

After each set of three trials (i.e., experience set using a particular mapping method), participants completed a survey. At the study's close, participants selected a favorite mapping.

4) Measures: Measurement entailed a mix of objective and self-reported information. The beginning-of-study survey collected basic demographic information (i.e., age, gender, and experience with mobility aids and vibrations).

We recorded overhead video to support post hoc extraction of the following objective measures by a trained annotator:

- The time to complete each trial.
- The success rate, i.e., number of correctly located objects, as defined by a pointing angle within 10 degrees from the true radial position of an object.

Together, these objective measures help us to assess the OptiBand's helpfulness for locating objects efficiently.

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

- The Self-Assessment Manikin (SAM) [8] helped us to measure affect while using each particular mapping.
- The NASA Task Load Index (NASA TLX) [9] captured the effort required to use the system.
- The discomfort portion of the Robot Social Attributes Scale (RoSAS) [10] evaluated participant comfort.
- The Measuring Human Computer Trust (HC Trust) survey [11] captured mapping reliability and clarity.

Each assessment used seven-point Likert scales. With these self-reports, we could assess experiences with each mapping.

5) Analysis: We performed repeated measures analysis of variance (rANOVA) tests with an $\alpha = 0.05$ significance level. We report effect size with η^2. For significant main effects, we performed pairwise t-tests with a Bonferroni correction.

C. *Results*

All 10 pilot participants successfully completed the study. In this exploratory pilot, we focused on addressing two main research questions: 1) can users locate objects during trials? and 2) is the OptiBand generally usable and reliable?

Participants successfully located an average of 11 (of 18 total) objects (SD = 4.1) across the study. There was no significant difference in time spent searching for objects or success rate of locating objects across mapping methods (both $p \geq 0.486$). Search speed significantly varied across object distance ($p = 0.042$, $F(2, 4) = 3.80$, $\eta^2 = 0.103$). Search time was faster for 4m objects compared to 8m and 12m. Participants tended to be better at locating closer objects, but this trend was not statistically significant ($p = 0.279$).

In the survey, there was no significant difference between mapping method ratings on any scale (all $p \geq 0.118$). Related descriptive statistics can help us understand the general system use experience. Participants felt pleasant (M = 5.3, SD = 0.92), energetic (M = 6.1, SD = 0.7), and in control (M = 5.2, SD = 1.3) while using the system. The task load of using the system was moderate (M = 3.5, SD = 1.7). For all device setups, participants reported low discomfort (M = 1.8, SD = 1.4) and felt the device was reliable (M = 5.1, SD = 1.3) and understandable (M = 6.0, SD = 1.2).

For favorite mapping methods, three users chose curved, one chose linear, four chose stepped, one preferred stepped and linear equally, and one had no preference.

III. Discussion

Outcomes of the pilot study did not support one mapping over any other, but results indicate that the OptiBand is useful for locating objects. Survey results demonstrated general positive opinions of the OptiBand and a lack of universal differences between investigated mapping methods, perhaps because different mappings are better for distinct tasks.

Strengths of this work include evidence that the Optiband is useful for scanning the horizon and noting objects of interest. *Limitations* include our approach using in-lab studies with sighted individuals. In situ follow-up work is needed with blind system users. In next steps, we will pursue such studies to advance the state of knowledge on wearable robotics and assistive devices for individuals who are blind.

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