Thumb-Based Tactile Feedback for Navigational Guidance

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This paper introduces a tactile feedback device designed to guide users to a destination via directional cues delivered to the peripheral thumb pad. The device provides five possible directions (left, diagonal left, forward, diagonal right, right) by moving along the peripheral thumb pad. To evaluate its performance, we compared it to audio instructions for the same directions. Results showed an accuracy of 90% for the haptic feedback device, compared to 99% for audio instructions. While less accurate, the tactile feedback demonstrates promising potential, indicating that further refinement of the prototype is necessary to make this approach a viable alternative.

Introduction

Navigation systems have transformed how individuals interact with their environment, particularly through auditory and visual feedback. Early systems relied on traditional maps, but through technological advancement have made dynamic GPS-based solutions widely prevalent. Despite their widespread adoption, these systems are not without limitations. Auditory feedback can be challenging to perceive in noisy environments, while visual instructions require users to focus on the device itself rather than their surroundings, which can limit situational awareness [4]. Moreover, certain navigation systems may not be fully accessible to individuals with sensory impairments, suggesting the potential value of alternative feedback modalities. To address these challenges, researchers have explored tactile feedback as an alternative modality. By leveraging the sense of touch, tactile systems can deliver intuitive navigational cues without overwhelming auditory or visual channels. This paper focuses on a thumb-based tactile feedback device, utilizing the peripheral thumb pad as a novel approach to providing navigational information.

Related work

In their 2023 paper, Adam Spiers and colleagues present the S-BAN[2], a shape-changing haptic interface offering two degrees of freedom (2-DOF) spatial feedback via a parallel kinematic structure. The device provides continuous, intuitive navigation aid and was effective in guiding users to virtual targets during spatial orientation tasks. However, its design, requiring users to bend their arm with the palm facing upward, may cause fatigue over prolonged use.

Ramiro Velázquez and colleagues's system integrates GPS-based localization with tactile-foot feedback, delivering four navigational directions via shoe-embedded vibrations [5]. Their device provides four direction, forward, left, right, backward. While effective in providing guidance, the limitation to four directions restricts its applicability in complex real-world environments. Additionally, the reliance on shoe-based vibration feedback raises questions about user comfort and long-term practicality in varied outdoor environments.

Alix Goguey and colleagues (2019) explored the use of the finger pad periphery for subtle haptic feedback, employing a ferromagnetic marble to provide localized stimulation [3]. Their findings highlighted the potential of finger-periphery feedback for nuanced interactions. However, they did not investigate whether this feedback could be used effectively for navigational cues.

Prototype developpement

This paper explores the potential of peripheral, thumb-based haptic feedback to deliver navigational cues to users. The device utilizes a Feetech FS90 servo motor [6], which is mounted securely in place using a custom 3D-printed holder. Part of the 3D model for the mount was created by Arnaud S on the platform www.printables.com [7]. The motor is controlled via an Arduino Uno Rev3 [1], and the software developed to command the motor was written in Python 3, using the PyFarma library to facilitates communication between the software and the hardware.

Experiment

This study explores the potential of delivering navigational cues to users via the peripheral pad of the thumb, using haptic feedback as an alternative to traditional auditory instructions. To evaluate the effectiveness of this modality, a comparative analysis is conducted between the haptic and auditory feedback systems. The haptic feedback provides

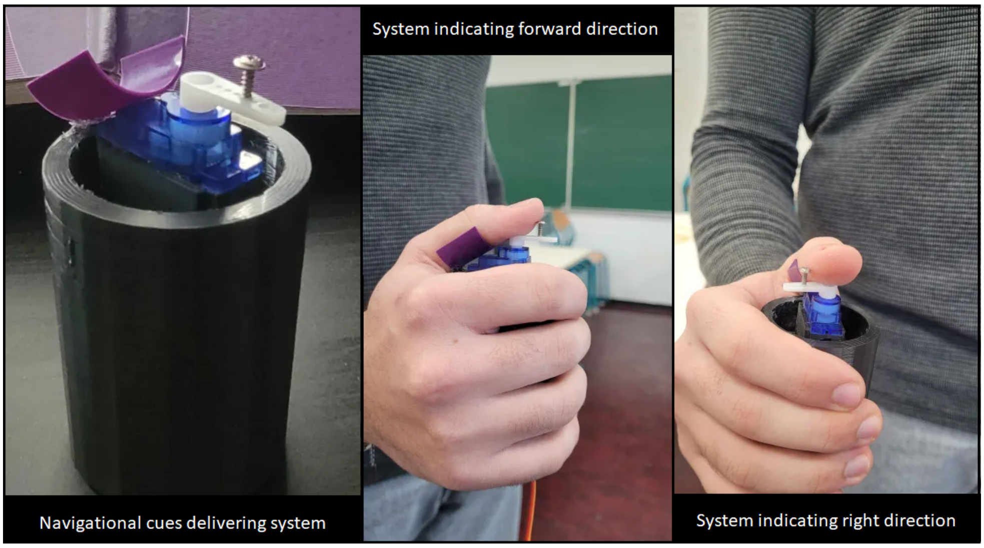

Figure 1: The navigational cues delivering system created for this experiment (left), a participant holding the device indicating the forward direction (middle), the same participant holding the device indicating the right direction (right).

five directional cues, with the motor angle changing to correspond to specific directions: left (-90°), diagonal left (-45°), forward (0°), diagonal right (45°), and right (90°). In the auditory condition, participants hear verbal instructions such as "move left", "move diagonal left", "move forward", "move diagonal right", and "move right" .

To simulate a real-world environment, background noise resembling the bustling soundscape of a busy street, including indistinguishable dialogues, is introduced to replicate potential distractions during navigation. Additionally, this ambient noise ensures that the participant is unable to perceive the sound of the servo motor during the haptic feedback phase, thereby isolating the sensory input to solely the haptic cues.

For both conditions (haptic and auditory) five distinct directions are delivered to each participant, with each direction presented three times in a random order to account for intra-participant variability. To ensure diversity, the current direction is always different from the previous one. All participants experience both the auditory instruction and haptic feedback modalities. To mitigate order effects, half of the participants begin with the auditory modality, while the other half start with the haptic feedback modality.

Participant

Twelve participants were recruited for this study, all of whom are students or PhD candidates in the field of computer science. Five participants were self reported female and seven self reported male. Their ages range from 21 to 29, with a mean and median age of 25. All participants have normal hearing. Ten participants exhibit normal sensitivity in the thumb of their dominant hand, as assessed using the Semmes-Weinstein monofilament test. Two participants demonstrate reduced sensitivity below J 4.31 filament (2.0g).

Procedure

At the start of the experiment, participants' thumb sensitivity is assessed using a Semmes-Weinstein test. The top, left, and right sides of the dominant thumb are tested sequentially with five filaments: D 4.56 (300g), K 4.56 (4g), J 4.31 (2g), F 3.61 (0.4g), and D 2.83 (0.07g). With their eyes closed, participants indicate aloud the side of the thumb where they feel pressure.

After the sensitivity test, participants proceed to the training phase. While most individuals are familiar with auditory instructions from an early age, however participants are trained to recieve auditory navigational instruction while listening to the ambient noise. On the other hand, receiving navigational cues through the peripheral pad of the thumb is a novel experience that requires specific training. Participants who begin with the haptic condition undergo haptic training first, while those starting with the auditory condition receive auditory training first.

Haptic Training

Participants hold the device with their dominant hand, placing their thumb on the purple section shown in Figure 1, and face the directions depicted in Figure 2. The top of their thumb lightly rests on the metallic part of the device without applying pressure. The experimenter verifies that each direction makes proper contact with the peripheral pad of the thumb, after which participants rest their arm and hand in a comfortable, natural position. During training, participants remain stationary and verbally indicate the perceived direction based on the haptic cues while ambient noise

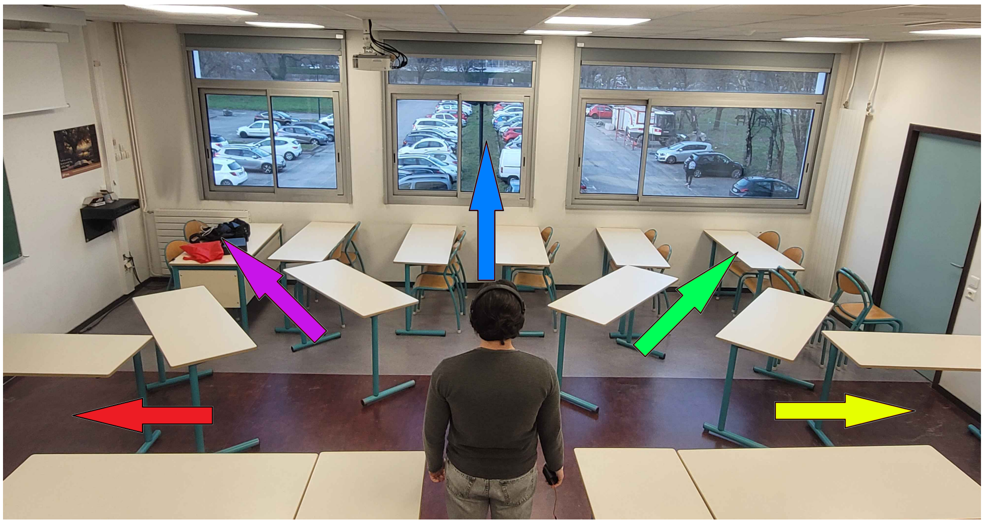

Figure 2: The experimental setup with a participant holding the haptic device while facing the five directions. Left = red arrow, diagonal left = purple arrow, forward = blue arrow, diagonal right = green arrow, right = yellow arrow

plays through a headset. The training phase concludes once participants correctly identify ten consecutive randomized directions.

Auditory training

Participants are asked to face the direction as in Figure 2. They wear a headset displaying ambient noise and recieve auditory instructions. In this phase participants are instructed to repeat oraly the instruction. Training concludes once they correctly identify ten consecutive randomized directions.

Once both training phases are complete, the experiment begins with two tested conditions: the haptic condition and the auditory condition.

Haptic and Auditory Conditions

In both the haptic and auditory conditions, participants perform the same task as in their respective training phases. Instead of verbally indicating the perceived direction, they physically move toward one of the five directions based on the feedback modality and then return to their initial position. In the haptic condition, movement is guided by the perceived position of the device on the peripheral pad of the thumb, while in the auditory condition, movement is guided by verbal instructions. Additionally, in the auditory condition, participants are asked to hold their phones near their ear. Each direction is tested three times in a randomized order, and the condition concludes once all trials are completed.

Result

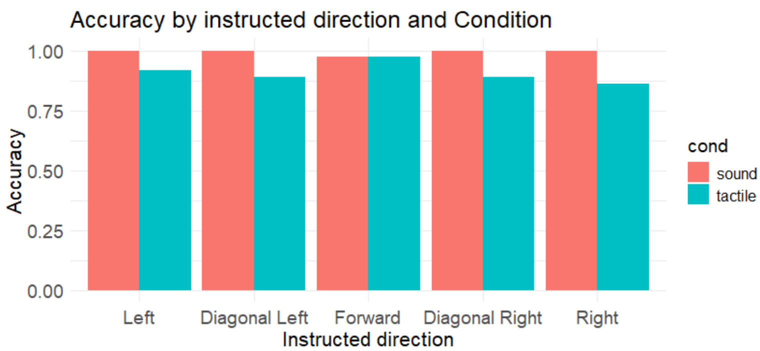

Figure 3: Accuracy for the haptic and auditory condition

With twelve participants, each performing the task for five directions repeated three times in both conditions, a total of 360 observations were recorded, 36 per participant. The data collected includes the condition (haptic or auditory), the instructed direction, the direction taken by the participants (referred to as their "response"), and a binary "result" variable indicating whether the response was correct (success) or incorrect (failure).

Figure 3 illustrates the accuracy of participants' responses. In the haptic condition, the accuracy for each direction is as follows: left = 0.917, diagonal left = 0.889, forward = 0.972, diagonal right = 0.889, and right = 0.861, resulting in an overall accuracy of 0.905. In the auditory condition, only one error was made across all participants. Consequently, the accuracy for left, diagonal left, diagonal right, and right is 1.0, with forward achieving an accuracy of 0.972, yielding an overall accuracy of 0.994.

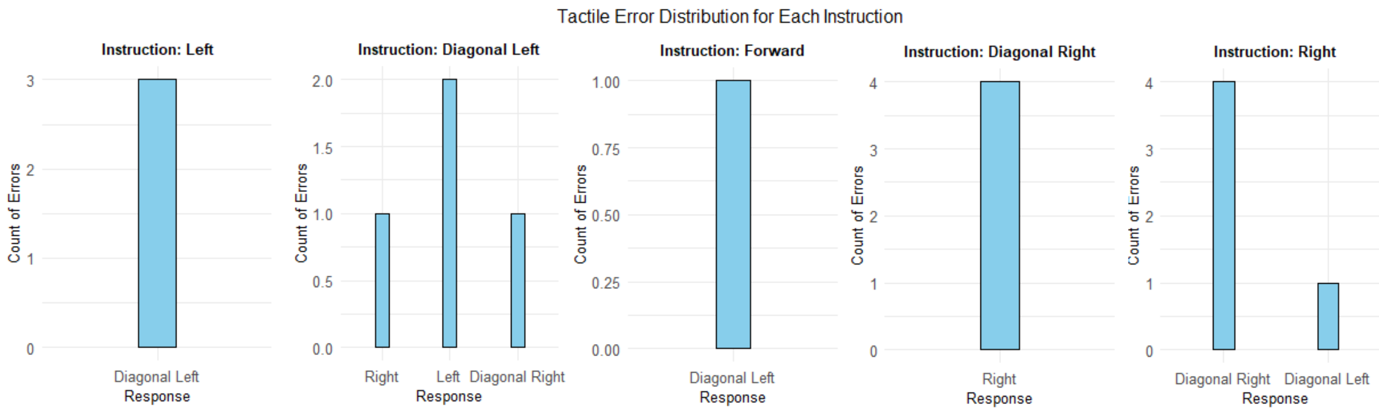

Figure 4: Accuracy for the haptic and auditory condition

Figure 4 depicts a closer examination of the errors made during the haptic condition. When given the left instruction, participants mistakenly chose the diagonal left direction three times out of thirty-six trials. For the diagonal left instruction, participants went to the right direction once, the left direction twice, and the diagonal right direction once out of thirty-six trials. For the forward instruction, one participant went to the diagonal left path once. Regarding the diagonal right instruction, participants incorrectly chose the right direction four times. For the diagonal right instruction, they went to the diagonal right path four times and the diagonal left path once.

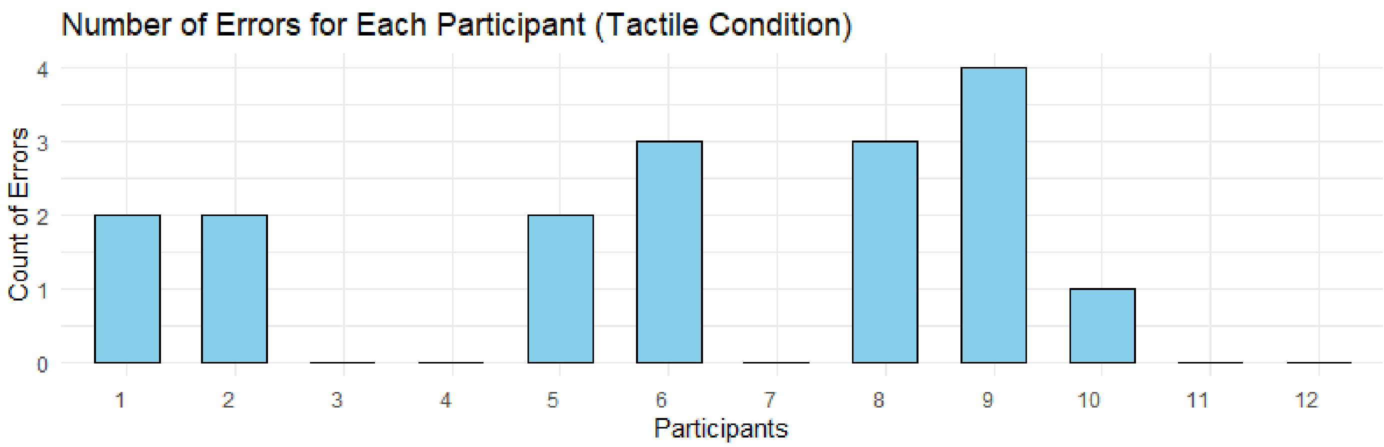

Figure 5: Number of error for each participants during the haptic condition

No outliers were identified in this study. Figure 5 shows that across all participant the minimum number of error was minimum of 0 with a maximum of 4. the mean number of errors was 1.41, with a median of 1.5.

Interview

To gain deeper insights into the user interaction during the experiment, participants were interviewed post-study. The findings from these interviews are summarized as follows:

Regarding the haptic condition, most participants reported difficulty distinguishing between "left" and "diagonal left," as well as "right" and "diagonal right." This challenge often led them to guess which path to take. Despite this, half of the participants stated that they would prefer using the haptic feedback device over auditory instructions in a noisy, busy street scenario. They explained that, although they could filter out ambient noise to focus on the auditory commands, doing so required significant concentration. Some participants even developed strategies, such as focusing on the last word of the instruction and determine whether it was a diagonal direction based on the length of the instruction. Two of them added that a GPS equipped with haptic feedback would be beneficial, as it would allow them to remain more engaged with their environment rather than being distracted by looking at a screen. Additionally, three participants mentioned experiencing arm discomfort during the auditory condition, as they had to hold their phone near their ear throughout the task.

Participants who preferred the auditory condition expressed concerns about the reliability of the haptic device in delivering precise directions, particularly in distinguishing diagonals from sides. Additionally, three of them noted that they found it easier to focus on voice commands compared to interpreting haptic feedback and stated they would still choose auditory instructions even if they were able to accurately identify haptic cues.

Discussion

The results of this study indicate that the auditory condition was significantly more accurate than the haptic condition, achieving an overall accuracy of 0.99 compared to 0.90. While this demonstrates the reliability of auditory instructions, the findings highlight the potential of haptic feedback as a viable alternative in specific contexts.

Although the auditory condition demonstrated superior performance, the haptic device offers unique advantages. Participants also highlighted the utility of haptic feedback to deliver navigational cues in busy environments where auditory instructions might be less effective due to ambient noise or where maintaining awareness of surroundings is important. Addtionally, a few participants noted discomfort in their arm during the auditory condition, as they had to hold the phone near their ear for the entire duration. It is important to note that this discomfort was reported by only a few participants, likely because the experiment was relatively short (arround 5 minutes for each conditions), and most participants did not have sufficient time to experience significant discomfort.

Several insights emerged from this study that can inform future improvements to the haptic device. The results revealed that accuracy for diagonal directions was 88%, while left and right directions achieved 91% and 86% accuracy, respectively. Participants reported difficulty distinguishing diagonals from sides, highlighting the need for refining tactile cues. We found that the angle difference between the diagonals and their respective side directions is too narrow, making them difficult to distinguish reliably.

Adjustments such as varying vibration intensity and duration could improve the differentiation between directions. Furthermore, integrating a GPS system within the device to provide real-time directional feedback could enhance both usability and precision. Dynamic vibrations guiding users until they align with the forward direction could simplify navigation and further reduce errors. This approach would also enable a continuous range of directions, as opposed to the current device, which discretizes directions into five distinct options. By addressing the limitations identified in this study, future iterations of the haptic device could rival auditory instructions, providing a robust alternative for navigation in diverse contexts.

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