Vi-Bros: Tactile Feedback for Indoor Navigation with a Smartphone and a Smartwatch

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Figure 1. Vi-Bros is a new interface that simultaneously utilizes two mobile devices, a smartphone and a smartwatch, to provide users with intuitive guidance during indoor navigation. A smartphone vibrates when users have to turn right at an intersection. A smartwatch vibrates when users have to turn left at an intersection.

CHI'15 Extended Abstracts, Apr 18-23, 2015, Seoul, Republic of Korea
ACM 978-1-4503-3146-3/15/04.
http://dx.doi.org/10.1145/2702613.2732811

Abstract
Vi-Bros is a new interface that simultaneously utilizes two mobile devices, a smartphone and a smartwatch, to provide users with intuitive guidance during indoor navigation. We evaluate the validity of the dual device interaction with the tactile feedback and provide insights for user experience via two experiments; one from a controlled environment and the other from the field. We present the core insights and potential design space for developing multi-device interaction.

Author Keywords
Indoor navigation, tactile feedback, dual-devices, smartwatch, smartphone.

ACM Classification Keywords
H.5.2. User Interfaces: Haptic I/O.

Introduction
There are growing demands for the indoor navigation as people encounter more difficulty on finding their ways in complex and large public buildings such as shopping malls or underground stations. With the development of accurate indoor position systems using multiple localization techniques e.g., Bluetooth beacons [3], more facilities are considering implementation of indoor navigation services for their visitors.

Figure 2. Four types of device holding positions: while a smartwatch is always on the left hand (assumed), a smartphone can be on the right hand (**RH**), on the left hand (**RP**), on the right pocket of the pants (**LH**), and on the left pocket of the pants (**LP**).

Often newer forms of interaction have been explored for indoor navigation systems, compared to visual/auditory systems, because of the limitations of indoor navigation systems found in the previous studies e.g., less situational awareness or less robustness in noisy environments [3]. The effectiveness and validity of tactile feedback for pedestrian navigation have been assessed and proved to be useful in the previous studies. Navigation with tactile feedback could significantly reduce the user's distraction. Some researches used a smartphone to convey the navigation information with vibration patterns [6]. Others designed additional hardware with multi-actuators to provide more intuitive navigation information [1, 9]. However, there are still limitations to be resolved in the past systems. For example, users have to learn specific patterns for systems with a single actuator such as a smartphone. In addition, although systems with multiple actuators could provide more intuitive navigation information, it might need additional hardware that is not readily available for most devices. On the other hand, indoor navigation has its own requirements. Although the main purpose of indoor navigation system is to provide proper way-finding, it is also important to facilitate eyes-free interaction for contextual awareness [4]. Thus, tactile feedback, more intuitive interaction, can be a viable solution for indoor navigation in the places such as a shopping mall.

To address these challenges, we introduce Vi-Bros, a tactile feedback for an indoor navigation system that utilizes existing devices. With this research prototype, we explore interaction opportunities with dual-devices. Vi-Bros can provide users with tactile signals on different locations of the body to signal directions when navigating. We are motivated by the fact that the proliferation of smart devices like smartphones and smartwatches open up a new horizon for re-exploring the modality of interaction [2]. Recent phenomena show that increasingly more people carry more than one devices. Hence, limitations of previous navigation with tactile feedback could be resolved by utilizing existing devices that are worn and carried simultaneously such as smartphone and smartwatch. Here, we are presenting the insights discovered from the design iteration and experiments. We also provide potential design space when developing multi-device interaction.

Motivation and Design iteration

Bosman et al. [1] proposed GentleGuide, a wearable wrist-band system composed of two vibrotactile devices with a single actuator mounted on each wrist. Their experiment showed that the system was helpful for providing an intuitive means to deliver directional information to indoor pedestrians. The solution, however, employs additional devices that users have to wear in order to utilize the system. In this study, inspired by the Bosman' research [1], we extend the concept of GentleGuide to two existing smart devices; a smartwatch and a smartphone as shown in Figure 1.

During our initial design iteration, three participants evaluated the perceptibility of four potential tactile patterns (Figure 3)- a smartwatch feedback for left signal(**L**), a smartphone signal for right signal(**R**) regardless of its holding positions, simultaneous signal from both devices for "Simultaneous"(**S**), and alternating signal between a smartphone and a smartwatch for "Alternating"(**A**). Decision on the patterns and the duration of each note had been

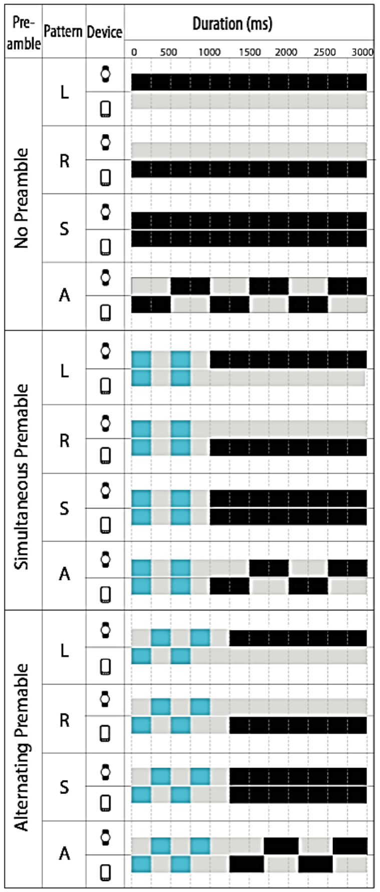

Figure 4. Twelve different patterns (3 preambles x 4 signals): device is activated when marked with black and preamble is on when marked with blue (: smartwatch, : smartphone). A smartwatch is always on the left hand (assumed). Four signals indicate left (**L**), right (**R**), simultaneous (**S**) and alternating (**A**).

inspired by the design in Srikulwong et al. [7] and Ternes et al. [8].

After the initial design, two modifications were made. We observed that the participants appeared to be confused when both devices were on the left hand (LH position in Figure 2). Also, they were likely to hesitate confirming the source of the tactile feedback when both devices were activated simultaneously. To resolve these issues, three types of preambles have been designed and added to the next design iteration (Figure 4); no-preamble (**NP**), simultaneous preamble (**SP**), and alternating preamble (**AP**) as an introductory notification. In addition, we decided the length of each note in alternating signal to be a 250ms to offer clear distinction between the two devices.

Design Challenge

The original concept for the Vi-Bros is not to modify or add any extra physical devices. Instead, with existing smartphone and smartwatch technologies, the design of Vi-Bros aims to facilitate users to perceive and distinguish patterns of incoming tactile stimuli better.

Vi-Bros was developed iteratively with a number of prototypes and pilot tests and focused on the following hypotheses.

- Participants will be able to perceive and distinguish directional signals (**L**) and (**R**) from dual-devices regardless of the devices' casual holding position. [***H1***]
- Providing preamble will help users distinguish the patterns better. [***H2***]

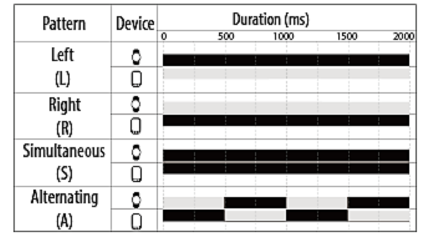

Figure 3. Initial design of directional patterns: device is activated when marked with black (: smart watch, : smartphone). A smartwatch is always on the left hand (assumed)

To test the hypothesis one, we identified four of the most common device-holding-positions where devices stayed in direct contact with the body as shown in Figure 2. The hypothesis two aims to determine whether the preamble helps participants perceive patterns better by adding a signal to alert haptic senses.

Experiment Design

To test the effectiveness of our approach, we performed a controlled user study with 16 participants: 8 males and 8 females with an average age of 28 (SD = 3.20, range 24-36 years). All participants were right handed who wore watches, if any, on the left wrist. Participants didn't possess smartwatches.

The experiment was conducted after a short training session to inform participants different types of signals in different holding positions as shown in Figure 4 (3 preambles x 4 directional signals x 4 holding positions; 48 times total). For each holding position, participants experienced twelve directional patterns once, which took about three minutes per participant.

	Holding Position			
Direc-tion	RH	LH	RP	LP
Left	144	142	144	143
Right	144	143	143	141
Simul-taneous	140	126	137	127
Alter-nating	140	142	141	143

Table 1. The number of correct responses (out of total 144 signals) for directional signals in each holding position (Shaded cells indicate least accurate conditions).

	Holding Position			
Pre-amble Type	RH	LH	RP	LP
NP	188	184	185	188
SP	189	178	189	187
AP	191	191	191	179

Table 2. The number of correct responses (out of total 192 signals) for preamble types in holding positions (Shaded cells indicate most accurate conditions); no-preamble (**NP**), simultaneous preamble (**SP**), and alternating preamble (**AP**).

We asked participants to stand up and listen to music with earphones for the experiment sessions to block unknown distractions. The order of four holding positions was counterbalanced for each holding position, and participant experienced 36 signals that were shuffled (i.e. 3 preambles x 4 directional signals x 3 repetitions). The total of 144 signals was tested for each participant. We discussed their experience of the experiment. The entire session took approximately 30 minutes per participant.

Result

Overall accuracy was high. Participants were able to recognize 4 patterns with the accuracy of 97.22% (SD=4.29). The total of 2,304 signals was tested over 16 participants and only 64 errors occurred.

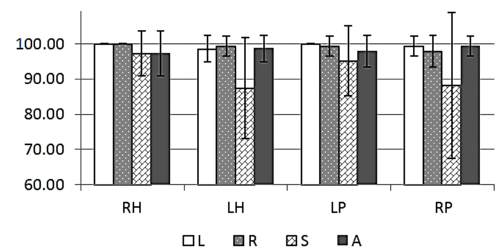

Figure 5. Accuracy (SD in error bar) of directional patterns in each holding position; left (**L**), right (**R**), simultaneous (**S**) and alternating (**A**).

To verify the hypothesis that participants can perceive and distinguish directional signals regardless of holding positions, chi-square test was performed (Table 1). There was no significant difference between directional patterns and holding positions ($\chi^2 = 0.9011$; df = 9; p = 0.9996)[***H1***]. Thus, the result supports H1.

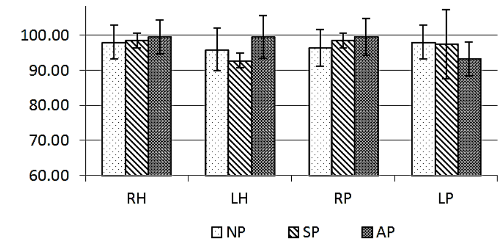

Figure 6. Accuracy (SD in error bar) for preamble types in each holding position; no-preamble (**NP**), simultaneous preamble (**SP**) and alternating preamble (**AP**).

On the other hand, H2 is not supported because there was no significant difference between preamble types and holding positions (Table 2)($\chi^2 = 0.7852$; df = 6; p = 0.9925)[***H2***]. The results might be because of ceiling effect that the accuracy cannot go over 100%. We were able to find interesting patterns which will be discussed later in the paper.

Field Test

To evaluate the practical applicability of Vi-Bros, a field test was conducted in a shopping center where *Bluetooth low technology* for indoor positioning system was installed. We compared Vi-Bros with a commercial visual navigation application provided as a courtesy by the shopping mall (Figure 7). Three participants (2 males and 1 female, Mean = 30.12, SD = 3.11), first-time visitors in the mall, and who were not involved in the previous experiment, were asked to navigate two 100m-long routes consisting of four turns, once with Vi-Bros and the next time with the visual navigation. The order was counter-balanced. After two trials, we asked their opinions of our prototype in the field.

Figure 7. Application for indoor navigation provided by a shopping mall as a courtesy [5].

Figure 8. Visual feedback (left) for indoor navigation induced head down interaction, while tactile feedback from Vi-Bros (right) provided more natural interaction with the environment during navigating indoor.

Participants held both smartphone and watch in the left hand (**LH**) and two directional patterns (**L**) and (**R**) and alternating preamble (**AP**) were tested because it was the best performing set and reported the highest accuracy in our previous experiment (Table 2). We wanted to explore user experience that provided additional insights from the experiment in GentleGuide [1]. Before the test, participants were provided with a brief introduction of Vi-Bros followed by a training session to experience directional patterns for three times, which took approximately three minutes.

A wizard of Oz technique was used in this field test. A wizard sent directional tactile signal to participants when they were at the intersection. The whole session was recorded for further analysis. We found that Vi-Bros was successful at guiding all participants to their destination in the shopping mall. Participants responded to the signals properly during the entire experiment. We interviewed the participants at the end of the test, and the interview was also recorded for the further analysis. In general, all participants liked Vi-Bros because it was intuitive, (P1, P3) and easier than reading the visual map (P2). Also participants reported that they would use Vi-Bros especially when they were walking with companions or care-needer because Vi-Bros facilitated eyes-free interaction (P1, P2, P3). As a matter of fact, we observed that participants didn't look at the device at all during the entire session with Vi-Bros. On the down side, participants were less confident in their routing compared to the visual navigation. Participants indicated that they became unsure of the remaining distance to the destination (P2). Another user reported that he was not sure whether he was on the right way because Vi-Bros interaction was only for himself and could not be shared with others (P3).

The result suggests that the strength of Vi-Bros lies in its intuitive operation as well as enhanced contextual awareness due to eyes-free interaction.

Discussion

Overall accuracy of Vi-Bros was high with 97.22% of accuracy, and there was no significant difference in accuracy between four different holding positions. The result implies that Vi-Bros could be a viable solution for indoor navigation without any special device.

In spite of statistical insignificance, we were able to find interesting patterns in errors by users. Out of the total of 64 errors, 46 errors (71%) occurred when "simultaneous" signals were tested (Table1). Participants answered either left (**L**) or right (**R**) for most of these errors (41 out of 46, 89.13%) which implies that sometimes they found it difficult to distinguish whether the signal was from a single device or both. During the interview after the experiment, six participants (P4, P6, P7, P8, P9, P10) pointed out that they might have "missed the watch's vibration because the vibration from the phone was too strong". Simultaneous signals might not be the best choice when implementing more patterns as signals using dual devices.

Although we could not conclude if preamble performed a significant role in distinguishing directional signals, we were able to identify interesting patterns as highlighted in Table 2. Participants performed the best with the alternating preamble except position LP. It is observed that alternating preamble helped users distinguish incoming patterns even when holding both devices in one hand. Some participants mentioned they preferred alternating preamble in position LH because it helped them distinguish unrelated tactile feedback from the smartwatch and that from the smartphone. (P4, P8, P10, P11, P15). However, alternating preamble didn't appear to help distinguish signals in position LP. Further research is needed to assess the effectiveness of various preambles.

There are still limitations to be considered for designing dual-device interaction for indoor navigation. In this study, we only tested four of the most casual holding positions. Our approach can be problematic if a user carries a smartphone in non-tactile position such as in bags or back-pockets. Also, more patterns using intensity, interval, or rhythm of vibration might be necessary for more cues (e.g., "Stop", "keep going", or "turn 45degrees"). Vi-Bros could be improved to provide a signal at ambiguous junctions or during a longer distance travel for indoor as well as outdoor navigation. Vi-Bros could be developed with a combination of visual and tactile feedback to prevent reduction of a subjective confidence (e.g., the minimal display on a smartwatch).

Conclusion

This paper introduces Vi-Bros, a new interface with tactile feedback that utilizes a smartphone and a smartwatch simultaneously. We designed and evaluated Vi-Bros to explore the effectiveness of the two-device approach for indoor navigation. The results provide useful insights on the design of future pedestrian navigation solutions.

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