Information Push and Pull in Tactile Pedestrian Navigation Support

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Abstract
For pedestrian navigation support, we report on how the feeling of being in control about receiving updates impacts navigation efficiency and user experience. In an exploratory field study, 24 participants navigated to previously unknown targets using a wristband which conveyed tactile information about targets' bearing. Information was either pulled by the user at times of her choosing via a simple arm gesture, or was pushed by the armband at a regular, preset interval. While the push mode resulted in higher efficiency, more users preferred actively pulling information, possibly as this afforded feeling more in control. Interestingly, mode preference was independent of individual navigation ability. Results suggest that properties of the specific navigation context should be used to determine whether an interface offers push or pull modes for navigation support.

Author Keywords
User control; urban navigation; tactile interface; mobile interface.

ACM Classification Keywords
H.5.m.

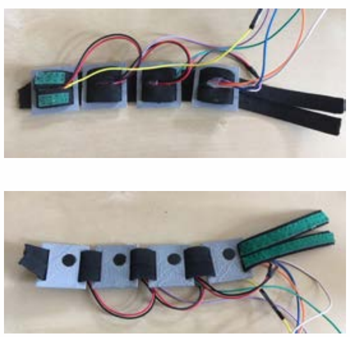

Figure 1: The tactile wrist interface that was used to provide updates on direction. The width and relative positions of the four vibrotactile actuators could be adjusted to accommodate individual wrist dimensions.

Introduction

Using smartphones for personal, pedestrian navigation is commonplace. A problem with using mobile maps, however, is that display and environment compete for the user's visual attention, which can be dangerous, for instance when negotiating traffic. Auditory displays (e.g., [13]) may be hard to hear at times. Various suitable tactile alternatives have been suggested (e.g., [5,7,15,17,21,22]). For these, it remains unclear, however, first, when and how often tactile information updates should be provided. And, second, who should best initiate an update: the user or the system? This contribution addresses the latter question, via an exploratory study using a tactile display.

Information *push* is the classic mode for navigation support (cp. [4], or *system pace*): the system decides when to offer information updates. Determining suitable times usually depends on the system's state (*Does an update exist?*) and on the user's geolocation (*How far is the next turn?)* and heading*.* It does usually not depend on whether the user can spare attentional resources, on whether the environment physically allows for receiving such communication (e.g. in bright or loud contexts), or on whether the user would like to receive communication at that point in time. As a remedy, user tracking and modeling may be used to better assess how much attention can be spared. Alternatively, one may outsource the decision to the user: Let her determine when, and how often, she likes to receive updates (information *pull*, or *user pace*).

Our exploratory study compares a tactile push mode, where the system decides when to communicate updates to the user, with a pull mode, where she decides when to receive an update. Measures include navigation efficiency and user experience.

Related Work

For context-aware computing, [2] investigated personalized interaction with different levels of context-awareness. While users felt more in control with personalized interaction, they preferred context-aware modes, possibly as these were perceived as worth the trade-off with decreased control. A study of a museum guide [10] found similar results: users' feeling of being in control decreased with increasing context-dependent proactiveness of the system. This finding is important for user experience, as a decreased feeling of being in control should lead to lower user satisfaction (see [1]). [4] compared context-aware information push and with information pull for a tourist guide system. They report varied preferences for push and pull modes.

Comparably little work exists on information push vs. pull for tactile displays, and even less regarding tactile navigation support. Most existing tactile systems implement variations of information push (e.g. [20]). Arguably, comparisons of tactile and visual displays also compare information push and pull when the employed tactile display pushes information at system pace, while any conveying of information through a visual display depends on whether and when a user decides to look at it (see e.g. [3,19]; participants preferred either push or combined push/pull modes). Only one study we are aware of [21] compared two tactile conditions: a context-dependent push mode and a pull mode, in which users had to stand still for a moment to trigger updates on bearing. Users preferred the push mode and performed better with it. Unfortunately, [21] only holds limited information for

Figure 2: Using the wrist interface for urban navigation. This user is just executing the arm gesture to trigger an update.

interface designers, as the two conditions differed in amount and quality of information. For non-tactile systems, [6] investigated how instruction timing should depend on perceived waypoint distance.

People differ in their navigation abilities and in how they process spatial information, such as when integrating information about distinct places [8]. Similarly, individuals with good and poor sense of direction differ in their ability to build up accurate survey knowledge about an environment [23]. To the best of our knowledge, no previous study investigated the relationship between individual navigation abilities and preference for push and pull in navigation support.

Study

25 participants were recruited for an exploratory study that compared push and pull modes during pedestrian navigation with a tactile interface. Participants were mostly (under-)graduate students [age: 22-29; 20 male, 5 female]. Participation was voluntary, and participants received neither credits nor remuneration. Self-reported technical affinity was generally high (mean: 6.04, sd: 1.3). Trials were conducted in winter season; one participant had to be excluded from the study, as limbs became too cold and numb.

Our guiding research questions were: Which mode will result in higher navigation efficiency? Which in a greater feeling of being in control? Which mode will be better suited for which navigation contexts? And, which mode will users prefer, as well as when and why? Our hypotheses are that users will be more efficient with the push mode, but will prefer and feel more in control when pulling updates. As users with low navigation abilities should generally have more problems building up accurate mental representations of the space through which they are navigating [23], we suspect that they will utter a stronger preference for the push mode (potentially, as this will induce a stronger feeling of safety through leading them more consistently).

For the study, we decided to focus on providing *directional* navigation support, that is, participants received information about the bearing from their current location to previously unknown target locations. Information on distance was not provided.

For the interface design, we had to make sure that push and pull modes provided exactly the same information. They should differ only in whether an information transfer was initiated by the system or by the user. The system should further be intuitive to use, easy to learn, provide predictable interaction, and permit users to explore an unfamiliar environment. Triggering an update during pull mode should be initiated by a gesture that would be easy to perform and would not be perceived as awkward in a social environment (compare the discussion in [24]).

We chose a hands-free tactile interface to not hinder users from using their hands as they normally would in urban space (carrying a bag of groceries, waving at a friend across the street, operating a traffic light, etc.). Consequently, users should not need to carry a mobile device in their hand. On a practical note, we decided against using belt-based systems, as these may not be suitable on an everyday basis (e.g., when wearing a dress or some other outfit worn without belts).

Based on studies of which body parts are most suitable for tactile interfaces [12,9], we selected placement on the wrist. Also, even though wrists (and arms) tend to move when walking, such movement does not seem to reduce recognition of tactile signals, nor their mapping to egocentric directions around the user's body [18].

For direction coding, we relied on a mapping similar to that of [18]; through a pilot study, we developed the tactile signal patterns depicted in Fig. 3. As coded by the colors, signals for eight directions were conveyed by four tactile actuators placed on a band around the wrist: the actuator on top (underneath the wrist) for *forward* (*backward*), the one on the left (right) for *left* (*right*). Simultaneous activation of two adjacent actuators was used to encode the directions in-between the four main directions. As indicated by the different lengths of the bars in Fig. 3, signals furthermore differed in length, with 500ms for *front*, 1000ms for the three directions involving *backward*, and 750ms for all other directions. The rationale for such differences is to provide sufficient signal discriminability, while ensuring that more frequent signals (e.g., *front*) should be short.

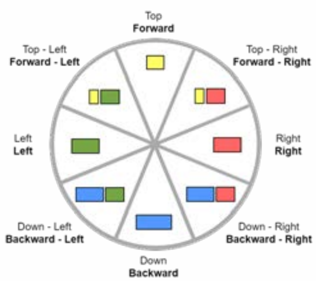

Figure 3: Eight vibration patterns encode eight egocentric directions around the user. The four wristband actuators are color-coded; each pattern is produced by one or two actuators. Pattern duration is proportional to the length of the bar.

Fig. 1 shows the constructed prototype with a Sparkfun ProMicro board, a BLE breakout board, four vibrotactile Seed Grove actuators, and an Adafruit compass and accelerometer module. Control of the board is through an Android app, which ran on a Motorola E2 with Android 6.0 and API 23. The actuators were integrated into a wristband which combined textile elements for flexibility with 3D printed elements for robustness and durability. All other elements were sewn into a pouch that could be comfortably strapped to the lower arm (see Fig. 2). The carrying pouch of the prototype was constructed with durability and flexibility of fitting in mind; miniaturization was no chief concern in pouch design at this stage.

To trigger a tactile signal on current bearing to the navigation target in pull mode, users simply had to lift their lower arm from a vertical into a horizontal position. We chose this gesture as, in an explorative pilot study, we had found it easy to learn, execute and detect while walking or sitting, with few false positives. In push mode, we chose to emphasize regularity and reliability and provided a signal every 10 seconds.

Study design

The study took place in town <TOWN>. We carefully selected two routes through an urban environment with which participants reported as unfamiliar. Routes did not overlap. They were comparable with respect to minimal length (mean: 675m), distances as the crow flies (mean: 547.5m), and minimal numbers of turns needed to reach a target. Each participant tested both push and pull mode, and walked both routes. Combinations of mode and route, as well as order, were balanced in a 2x2 Latin square.

Participants started by providing informed consent, filled in a questionnaire on general demographics (including technical affinity) and individual navigation ability (regarding orientation; confidence and initiative in navigation; and dead reckoning). Participants were then fitted with the wristband and given an explanation of the task. They had to successfully detect two random series of 24 tactile signals each in order to participate in the experiment: the first to determine which actuators on the wristband were signaling, and the second to match signals to directions around the user (detection rate per series >80% to pass).

Participants navigated to their first target while their geo-location was logged. An experimenter with a GoPro camera shadowed them. After completion, participants filled in the User Experience Questionnaire (UEQ, [11]) and a three-item measure on feeling of control and trust (inspired by [10]). This was followed by a semi-structured interview. This sequence was repeated for the second route. The route in pull mode was preceded by a short training session for the trigger gesture. The study was concluded with a final semi-structured interview in which the two conditions were compared.

Results

All participants reached their targets. Travelled route lengths were computed based on GPS logs. A Wilcoxon signed-rank test showed a significant difference between average route length for pull (mean: 865.45m, sd: 201.23) and push modes (mean: 729.55m, sd: 94.69; $p < 0.01$, $r = 0.4$). As walked routes differed in length, we chose to compare walking speed instead of duration. A t-test was used since data was normally distributed; it showed no significant difference in walking speed between modes ($\alpha = 0.05$; this level was also used for all tests reported below).

In pull mode, 21 out 24 participants triggered updates at intersections, 11 participants triggered updates in-between intersections, and 3 participants assumed a regular pattern of triggering updates or triggered updates regularly after stark changes of walking direction. In push mode, 15 participants found the update interval of 10s suitable, while 3 participants each would have preferred longer or short intervals.

The pull mode was rated as better on several dimensions: Ratings of feeling in control were significantly higher for pull (push mean: 3.13, sd: 1.94; pull mean: 5.42, sd: 1.41; $p = 0.001$), with large effect ($r = 0.5$). In pull mode, participants also felt significantly more autonomous (push mean: 4.46, sd: 1.77; pull mean: 5.38, sd: 1.69; $p < 0.05$, $r = 0.31$). The pull mode was perceived as being more stimulating (push mean: 1.54, sd: 0.61; pull mean: 1.88, sd: 0.65; $p < 0.05$, $r = 0.36$) and more original (push mean: 1.77, sd: 0.8; pull mean: 2.11, sd: 0.79; $p < 0.01$, $r = 0.44$). Both modes were perceived as equally reliable, controllable, perspicuous, and efficient. Wilcoxon signed-rank tests were used for comparisons.

No significant relationships were found for mode preference with self-reported ratings of either orientation ability, navigating confidence, initiative shown during navigation, and dead reckoning ability.

In the final interview, 14 participants voiced a preference for the pull mode, for example as they “felt more in control” or it felt “more like a part of me”. 9 participants preferred the push mode, with very divergent reasons given, from “I didn’t have to become active” to it feeling more secure, or to that interpreting the regularly pushed update became quite automatic. 1 participant had no preference. 5 participants suggested combining both modes, for example with a regularly pushed update at long intervals and the option to always pull an additional update when needed.

21 (22) participants would use the pull (push) mode outside of the study. Participants suggested using pull for sightseeing or on longer routes. They suggested using push when trying to travel on the most direct route, such as towards a hotel or a parked car. They also suggested using push whenever their hands were not free, such as when riding a bike or carrying things.

Discussion

The initial hypotheses regarding feeling of control being better in pull mode was confirmed by our exploratory study. Moreover, participants felt slightly more autonomous (in both cases they could choose their own way). The pull mode was rated as significantly more stimulating and original, e.g. as ‘activating’, and as more innovative.

Unexpectedly, we found no significant correlation between mode preference and navigation abilities, counter to our assumption that people with poorer abilities would prefer being steered by the system. One possible explanation might be that these people felt more insecure during navigation and therefore preferred to have the security of requesting the information as often as needed. Many participants liked being able to trigger the feedback. Also, many participants with good navigation abilities preferred the push-mode. We also did not find any significant relationship between whether participants normally prefer other people to manage navigation and their mode preference. Overall, people seemed to have individual differences in whether they prefer to be led by the system or to be more in direct control.

We used walking speed as a measure of task efficiency. While navigating in push-mode resulted in shorter routes being taken, walking speed was not affected. We assume the former is because regular updates reduce the likelihood of missing a turn. Push may thus be more efficient if people walk in roughly the correct direction and navigation updates are sent more often than if users would trigger these.

Based on our findings, we suggest that haptic navigation systems should offer a choice between push- and pull-modes. Since the majority of users wants to have control over when information is provided, a purely push-based system does not seem advisable.

If the system is only used for specific situations, having one mode is deemed sufficient. For example, if during navigation other tasks are executed or navigation hints are rarely needed, the pull mode is more appropriate. This would be the case e.g. for tourists during sightseeing (automated navigation information during photo stops would be annoying) or during hikes, when direction is not often changed. If on the other hand, when users want to quickly navigate from A to B in a town, or cannot freely move their hands and arms (such as when carrying bags or pushing a trolley), the push mode will be more appropriate. Likely, a busy mind falls into the same category as busy hands, as being preoccupied with a mentally demanding task (especially, with a visually demanding one), tends to decrease people’s navigation efficiency [16]. In such situations, the push mode may well offer the better option, since users won’t have to invest further mental resources in deciding when to pull an update. Also, with push, simply forgetting to update for a while because of other demands is not a problem.

As for dynamically switching between push and pull modes depending on the user’s navigation situation, research on switching control in automated driving [14] suggests that being mentally occupied (such as with a secondary task on a mobile device) may impair users’ ability to quickly take back control. As a consequence, having the system falling back to push mode if the user fails to initiate a pull for a while, or if the user is judged to be currently distracted by some other task, may turn out be an effective strategy.

An open question remains whether a user's navigation behavior with such a system and their preferences regarding push/pull mode might adapt and change over a longer period of usage. Also, it would be interesting to repeat the study with variants of the push mode, such as with longer intervals, as well as with triggering information push solely based on the user's actual or estimated distance to the next waypoint (cp. [6]).

Conclusion

The aim of our exploratory study was to investigate effects of being in control of information updates in a tactile navigation system on navigation efficiency and user experience. To the best of our knowledge, this study is a first in providing a useful comparison of push and pull for tactile navigation, in the sense that both modes provide exactly the same information. We suggest a first design guideline on what scenarios a push or pull based approach should utilize.

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