Unconstrained Pedestrian Navigation based on Vibro-tactile Feedback around the Wristband of a Smartwatch

David Dobbelstein
Ulm University, Ulm, Germany
david.dobbelstein@uni-ulm.de

Philipp Henzler
Ulm University, Ulm, Germany
philipp.henzler@uni-ulm.de

Enrico Rukzio
Ulm University, Ulm, Germany
enrico.rukzio@uni-ulm.de

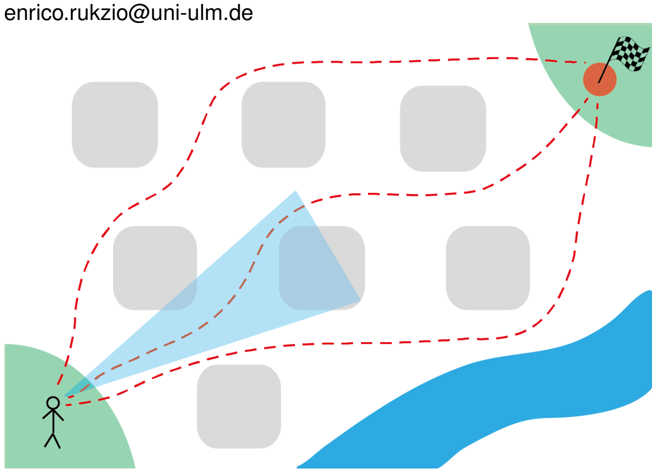

Figure 1: A pedestrian choosing their own way to a target destination.

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Abstract
We present a bearing-based pedestrian navigation approach that utilizes vibro-tactile feedback around the user's wrist to convey information about the general direction of a target. Unlike traditional navigation, no route is pre-defined so that users can freely explore the surrounding. Our solution can be worn as a wristband for smartwatches or as a standalone device. We describe a mobile prototype with four tactors and show its feasibility in a preliminary navigation study.

Author Keywords
Pedestrian Navigation; Vibro-tactile; Wrist; Watch

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces

Introduction
Pedestrian navigation is nowadays widely available with the prevalence of mobile devices. However, much like navigation for cars, pedestrian navigation is mostly turn-by-turn based and optimized to find the shortest path to a given target, dictating the user's route. This can take away much of the exploratory nature of an individual and has an influence on their behavior [2].

When exploring cities, pedestrians much like tourists, tend to choose their own way based on their personal liking, such as favoring to wander through a historic city part or strolling along a riverside even though this poses a detour. In this regard the journey becomes the objective, while the navigational target is secondary. In these cases, classical turn-by-turn based navigation can take away much of the exploration and enjoyment of the surroundings. We want to reduce the complexity of the navigation task, so that users do not have to spend their visual or auditory attention on a handheld device, but rather get an idea of the general direction of the target and can reassure themselves they are heading in the right direction.

With the current trend of electronic wristworn devices such as fitnesstracker and smartwatches, we envision haptic-feedback around the user's wrist to convey the targets direction. Navigation using vibration is already built into smartwatches, e.g. the Apple Watch uses two different vibration patterns for left and right turns. However, much like on handheld devices this is based on turn-by-turn navigation. In contrast, we provide the user with a general sense of the direction of the target, so the user can find their own way.

We want to complement rather than replace traditional navigation systems in situations where users want to freely explore the surroundings while heading to a target instead of necessarily favoring the shortest or quickest path.

Related Work

Bearing-based pedestrian navigation has already been explored by Robinson et al. [11]. Users can make their own choice by scanning the environment with their handheld device to get vibro-tactile feedback when pointing in the general direction of the destination. In social gravity [16] this approach is used as a virtual tether for multiple users to find and meetup.

In multiple works, belts have been used to convey directional information around the user's waist via multiple vibrators [13] to either constantly vibrate towards the north as a sixth sense [9], or to keep the user on a route by continuous vibration in the direction that is to turn [3]. Erp et al. found that directional waypoint mapping on the location of a belt is effective for navigation, but that coding for distance does not improve performance [14].

Another possibility to code direction is by using different vibration patterns with a single vibrator. In PocketNavigator [10], length and sequence of two tactile pulses are used to convey direction. In Tactons [6], different rythms are used to convey left, right and stop signals. NaviRadar [12] uses a radar metaphor where a radar sweep rotates clockwise. Tactile feedback is provided for each full radar sweep and whenever the sweep hits the direction of the next turn.

Other vibro-tactile navigation techniques use different on-body placements: Meier et al. [8] embed multiple vibrators into the sole of a shoe. Bosman et al. [1] placed a vibrator on both wrists to convey left and right turns on the respective wrist.

Tactor placement on the wrist has been explored by Lee et al. [4]. Using a 3x3 tactor matrix on the back of a potential watch, the vibro-tactile intensity on the outer areas was perceived as stronger as the same stimulus on the inner areas of the wrist. In Buzzwear [5], three tactors got placed in a triangle on top of the wrist. In a thorough user study, intensity was the most difficult parameter to distinguish, while temporal pattern was the easiest. Tatscheko et al. [7] compared placing four tactors underneath a wrist watch against embedding them into a wristband. Around the wristband, a higher perception bit rate was achieved.

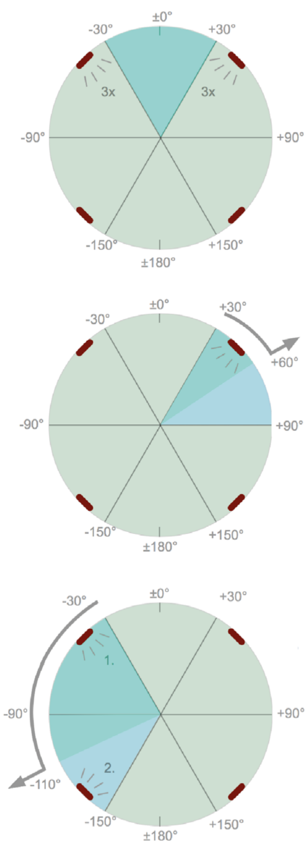

Figure 2: Direction is coded into 6 areas using 4 tactors. Temporal length of the vibration conveys the angular offset of the user to the target. When heading towards the target, the front tactors vibrate simultaneously three times.

Concept

Our bearing-based pedestrian navigation system utilizes vibro-tactile feedback around the wrist embedded into a wristband. While other body locations are possible (i.e. the waist using a belt), the wrist is promising due to the ongoing trend of smart wrist-worn devices. While nowadays these devices contain only one tactor if any at the watch position, it is possible to extend the functionality with smart accessories within the wristband to include multiple tactors around the wrist.

We embedded four vibration motors into an elastic fabric wrist band (see Fig. 3). The elastic band was chosen to include different wrist sizes of participants without having to alter the position of the tactors. For the distance of the sensors, similar to [7], we followed the suggestions of Weinstein [15], which is 38mm on the forearm to differentiate two tactile stimuli. We chose the outer wrist areas for the four tactors (see Fig. 4) as related work suggests that these areas are more sensitive towards the perceived intensity [4]. This accords with our own informal testing with different locations, e.g. in a top / bottom / left / right arrangement it was difficult to differentiate tactile feedback between top and bottom of the wrist, while left and right was easy to differentiate. For this reason we chose top/left, top/right, bottom/left and bottom/right as the four tactor locations (see Fig. 2).

We allocated six distinct directional areas, each occupying 60° (see Fig. 2). The simplest case is the user heading in the correct direction so that the target is within 30° to the left or right in front of the user. In this case, the upper left and upper right tactors vibrate simultaneously multiple times (we chose an arbitrary number of three times). Whenever the user is heading too far in the wrong direction (i.e. further than 30° away from the destination), they will get different information about their drifting. In this case the top left, respectively top right, tactor will vibrate. The duration of the vibration conveys the angular offset, starting from 0.5 seconds for 30° up to 2 seconds for 90°. Whenever the user passes the target (i.e. it is more than 90° behind him), in addition to the top left (or top right) tactor, the bottom left (or right) tactor will join the vibration after 2 seconds for up to another 2 seconds (for the maximum of 150°). By this, the length of vibration is a linear function of angular offset. Also, the addition of the second tactor on the bottom activating is a strong indicator for the user of heading in the wrong direction, so that they might consider making a turn. When facing the opposite direction, both of the bottom tactors vibrate simultaneously multiple times. For the front (and back) the exact angle is not conveyed. This was chosen to not let the user get the impression that they should steer in a straight line to the target, e.g. jaywalking a street, which could pose a threat to pedestrian safety.

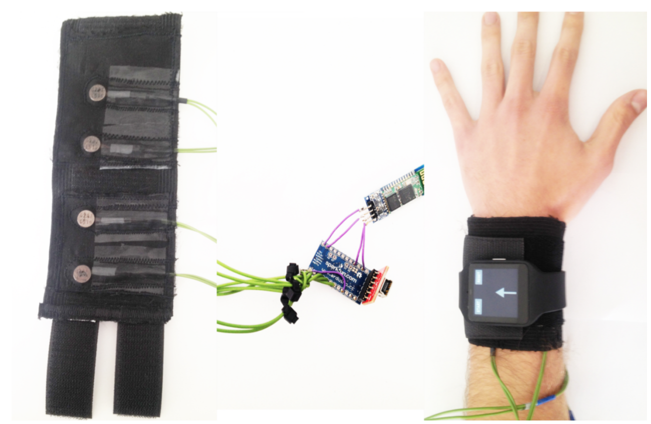

Figure 3: The watchband prototype. Elastic wristband with embedded tactors, Arduino and Bluetooth module for connection and the worn prototype.

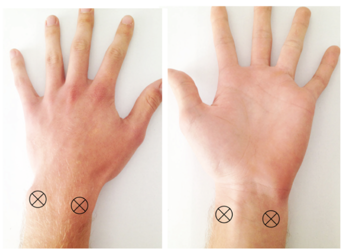

Figure 4: Positioning of the four tactors on the top and bottom on the user's wrist.

The frequency of vibro-tactile feedback is based on the directional area and increases the more the pedestrian is heading off-target to raise their awareness. When heading opposite the tactile feedback is displayed every 7 meters and up to 25 meters for the correct direction. In cases where the general direction to a target poses very large obstacles that are difficult to bypass, single waypoints are added. Such cases include rivers that can only be crossed by a bridge in far distance and sparse railroad crossings.

Besides the ongoing vibro-tactile feedback, the user can glance on the watch to get information about the map, and the direction and distance of the target. Also the user can pause and resume the navigation. e.g. for visiting a street shop or sitting down at a cafe.

Implementation

For the four tactors units we used DealMux vibration DC micro motors (3V, 70mA, 12000rpm). Unfortunately, with current commercially available smartwatches, it is not possible to simply attach vibro-tactile accessory. For this reason we used an Arduino Pro Mini 328 5V that powers the tactors and is wired to an HC-06 Bluetooth module to communicate with the watch. We chose a Sony Smartwatch 3 running Android Wear which features a built-in GPS module.

For the tactors, we wanted to make sure that active units are distinguishable. We glued them into the inner side of an elastic fabric bandage and sewed a very thin fabric mesh layer on top (see Fig. 3) so that the tactors were still in contact with the skin when the band was worn. The elastic fabric was chosen to fit multiple wrist sizes in the user study and to prevent vibration of the whole band which occured in testing with more sturdy prototypes. We envision more common looking watchbands with integrated tactors in the future.

User orientation is difficult to detect and can be errenous. With neither the phone, nor the watch being in a horizontal position during walking, magnetometer data is not a reliable indicator for orientation. For this reason, we use the user's recent walking trajectory. This however means, that a user standing still and turning around causes problems for the detection.

Experiment

We conducted a preliminary user study to learn more about the feasability of wrist-worn tactors for unconstrained navigation. We were especially interested in whether participants would be able to navigate to a target with only the general direction provided. We recruited 16 participants (4 female) between 16 and 55 years old ($M=26.25$ $SD=12.93$). None was working in areas related to HCI. The study was split into two parts that were conducted after another in two different settings. In the first part, participants were made familiar with the concept, areas and direction of the tactile feedback. They were seated in a quiet room on a table wearing the prototype and were first exposed to the different areas following a defined sequence of angular directions (0°, 30°, 90°, 150°, 180°, -150°, -90°, -30°) 2-3 times in a row until the participant stated to be familiar with the concept. After that, users had to recognize area and angle of a second set of angular directions one time each (0°, 40°, -40°, 70°, -70°, 100°, -100°, 140°, -140°, 180°) and mark their answer for each trial on a sheet of paper. The sequence of these trials was counterbalanced. A sketch showing the six areas and their angular boundaries (similar to Fig. 2) was provided throughout the study. Participants had to wear headphones with music on to prevent audio feedback of the tactors.

Participants could differentiate the six areas very well with an accuracy of 97.5% of identifying the correct direction

Direction	0°	-40°	40°	-70°	70°	-100°	100°	-140°	140°	180°
Est. Mean	0°	-32°	34.06°	-64.67°	57.50°	-114.38°	108.67°	-144.33°	142.19°	180°
Std. Dev.	0°	5.61°	6.12°	23.18°	20.98°	16.32°	15.52°	15.68°	14.70°	0°

Figure 5: Results of the first part of the user study. Participants tended to underestimate small angles and to overestimate large ones.

area that was displayed via tactile feedback. For the top areas, participants slightly underestimated the angles, while for the bottom areas, they tended to overestimate (see Fig. 5). 72% of the overall estimates were within a width of $\pm 10°$ of the displayed angle while 88% were within $\pm 20°$. These first results show that it is possible to estimate the general direction of a target using vibro-tactile feedback around the wristband. In previous work it was found that the vibrotactile angular width does not need to be particularly small and that in fact larger angular widths can help to minimize user frustration [16].

The second part of the user study was a navigation task which was conducted subsequently in the city of Friedrichshafen. The target was unknown to the participants and approximately 450 meters away from the starting position (see Fig. 6). Participants were told to reach the target but to choose their own route as they like to. Since we wanted to learn about the feasibility of wrist-worn tactile-feedback for navigation, we disabled the visual feedback of the watch. All participants reached the target without any navigational help of the presenter. At the beginning, participants started wandering off in different directions. This was due to the target (and target direction) being unknown. However, very soon participants got a good idea of the general direction and headed towards the target on slightly different routes. Most participants took the shortest and quickest path, while a few strolled a little bit off but eventually turned towards the target (see Fig. 6). Participants rated the mental load in the navigation task slightly lower (M=2.44 SD=0.81) than in the previous angle detection task (M=2.94 SD=0.68) on a 5-point likert scale. This suggests that while the exact angle detection requires some concentration, the actual detection during navigation is easier, because the user quickly develops an idea of the general direction that is then getting confirmed which each new vibration. It was observed that the different pattern for the front area triggered assurance and satisfaction with participants increasing their pace when heading in the right direction. Sometimes the vibration was missed. For these cases a possibility was requested to repeat or actively requery the direction. In these situations the watch display that was disabled for the study could be helpful. One suggestion was to use a shake gesture with the wrist to repeat the last feedback. Participants were having small talk with the presenter while navigating which further suggests that the navigation task is not very demanding and liberating the user's attention.

Figure 6: Participants took different routes to the target. While most took the shortest path, some went off for a small detour, but eventually turned towards the target.

References

[1] Sal Bosman, Bas Groenendaal, Jan-Willem Findlater, Thomas Visser, Mark de Graaf, and Panos Markopoulos. 2003. Gentleguide: An exploration of haptic output for indoors pedestrian guidance. In *Human-computer interaction with mobile devices and services*. Springer, 358–362.

[2] Gary E Burnett and Kate Lee. 2005. The effect of vehicle navigation systems on the formation of cognitive maps. In *International Conference of Traffic and Transport Psychology*.

[3] Wilko Heuten, Niels Henze, Susanne Boll, and Martin Pielot. 2008. Tactile wayfinder: a non-visual support system for wayfinding. In *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*. ACM, 172–181.

[4] Jaeyeon Lee, Jaehyun Han, and Geehyuk Lee. 2015. Investigating the Information Transfer Efficiency of a 3x3 Watch-back Tactile Display. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 1229–1232.

[5] Seungyon Claire Lee and Thad Starner. 2010. BuzzWear: alert perception in wearable tactile displays on the wrist. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 433–442.

[6] Ming-Wei Lin, Yun-Maw Cheng, and Wai Yu. 2008. Using tactons to provide navigation cues in pedestrian situations. In *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*. ACM, 507–510.

[7] Michael Matscheko, Alois Ferscha, Andreas Riener, and Manuel Lehner. 2010. Tactor placement in wrist worn wearables. In *Wearable Computers (ISWC), 2010 International Symposium on*. IEEE, 1–8.

[8] Anita Meier, Denys JC Matthies, Bodo Urban, and Reto Wettach. 2015. Exploring vibrotactile feedback on the body and foot for the purpose of pedestrian navigation. In *Proceedings of the 2nd international Workshop on Sensor-based Activity Recognition and Interaction*. ACM, 11.

[9] Saskia K Nagel, Christine Carl, Tobias Kringe, Robert Märtin, and Peter König. 2005. Beyond sensory substitutionâĂŤlearning the sixth sense. *Journal of neural engineering* 2, 4 (2005), R13.

[10] Martin Pielot, Benjamin Poppinga, Wilko Heuten, and Susanne Boll. 2012. PocketNavigator: studying tactile navigation systems in-situ. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 3131–3140.

[11] Simon Robinson, Matt Jones, Parisa Eslambolchilar, Roderick Murray-Smith, and Mads Lindborg. 2010. I did it my way: moving away from the tyranny of turn-by-turn pedestrian navigation. In *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services*. ACM, 341–344.

[12] Sonja Rümelin, Enrico Rukzio, and Robert Hardy. 2011. NaviRadar: a novel tactile information display for pedestrian navigation. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*. ACM, 293–302.

[13] Koji Tsukada and Michiaki Yasumura. 2004. Activebelt: Belt-type wearable tactile display for directional navigation. In *UbiComp 2004: Ubiquitous Computing*. Springer, 384–399.

[14] Jan BF Van Erp, Hendrik AHC Van Veen, Chris Jansen, and Trevor Dobbins. 2005. Waypoint navigation with a vibrotactile waist belt. *ACM Transactions on Applied Perception (TAP)* 2, 2 (2005), 106–117.

[15] Sidney Weinstein. 1968. Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In *the First Int'l symp. on the Skin Senses, 1968*.

[16] John Williamson, Simon Robinson, Craig Stewart, Roderick Murray-Smith, Matt Jones, and Stephen Brewster. 2010. Social gravity: a virtual elastic tether for casual, privacy-preserving pedestrian rendezvous. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1485–1494.