Towards an Objective Comparison of Scanning-Based Interaction Techniques

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Abstract. The direction where a user points a mobile phone to can be measured with the phone's integrated compass. Pointing over time and with varying direction is often referred to as "scanning", which is an emerging interaction technique and increasingly applied in the field of mobile navigation and orientation. Because there is no need to look at the screen while scanning, often haptic or audio feedback is used. In fact there exist several different scanning-based interaction concepts. However, until now it is impossible to analyse and compare these techniques systematically to identify the best concept for a certain scenario. In this paper we investigated how our own Tactile Compass scanning technique has been used in a field study. Based on our observations we identified a set of measures, which we propose to become a standard set for the analysis and comparison of scan-based interaction techniques. We further argue that our contribution may be beneficial for the creation of guidelines and support designers in selecting a proper scan-based interaction technique.

1 Introduction

Today's smart phones often come with a digital compass, which allows to measure the device's heading. In situations where the user holds the phone in his/her hand, the device heading equals the pointing direction of the user (see Figure 1). Pointing over time and with varying direction is often referred to as *scanning*. Scanning is an emerging, often whole-body interaction technique. The actual scanning can be done without spending visual attention on the device, which facilitates the use of, e.g., audio or haptic feedback. The interaction technique is most prominently used in the domain of user orientation and navigation, e.g., [2,10,7]. There it is applied to, e.g., convey the direction to the next way point of a route by, e.g., presenting a tactile cue once the user points in the right direction. It is argued that this interaction technique supports exploratory navigation [9].

The design space for scanning-based interaction concepts is huge, as it has to be decided which feedback is presented for which angles. Consequently, several

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Fig. 1. Scanning is a novel interaction technique and often used in the domain of pedestrian orientation and navigation systems. A user holds a mobile phone almost parallel to the ground, points it to varying directions, and receives feedback.

different multi-modal interaction concepts have been investigated and published. Most of the concepts come with studies, which show that a scanning-based interaction concept is, e.g., less distracting or more efficient than a traditional interaction technique like a map [7]. More rarely, scanning-based interaction concepts are compared against each other or with other novel techniques. Unfortunately, most studies and comparisons use different, imprecisely defined measures to assess the advantages and disadvantages of the individual interaction concepts. Until now there is no standard test to analyse the qualities of a certain scan-based interaction concept. Consequently it is hard for a researcher to relate a novel scanning-based interaction technique to existing ones. Further, it is impossible for an application designer to assess which scanning-based interaction concept is best suited for a certain purpose or scenario.

In this paper we investigate the essential characteristics of a scan interaction and derive an initial set of measures for the objective analysis and comparison of different scanning metaphors. To do so we recorded the scanning behaviour of 15 study participants, which have been testing our own Tactile Compass scan interaction concept and a map as comparison. We used the logging observation method to ensure that only objective measures, i.e., sensor data, were recorded. The identified set of measures covers the frequency and duration of a scan event, the walking speed while scanning, and which angle span is covered. We argue that this set allows researchers and designers to do a technical, low-level comparison of different scanning-based interaction techniques. We further claim that some measures can give initial indications how, e.g., intuitive, physical or mental demanding a scanning technique is.

The paper is structured as follows. In Section 2 we discuss the related work on scanning interaction techniques and the comparison of these. Section 3 describes the PocketNavigator software, which is a pedestrian navigation application, and our understanding of the scanning metaphor. We used this application with three different conditions to conduct an experiment and record interaction data. We report our observations and discuss our set of standard measures in Section 4. We summarize our findings and illustrate for what the standard set of measures can further be useful for in Section 5.

2 Related Work

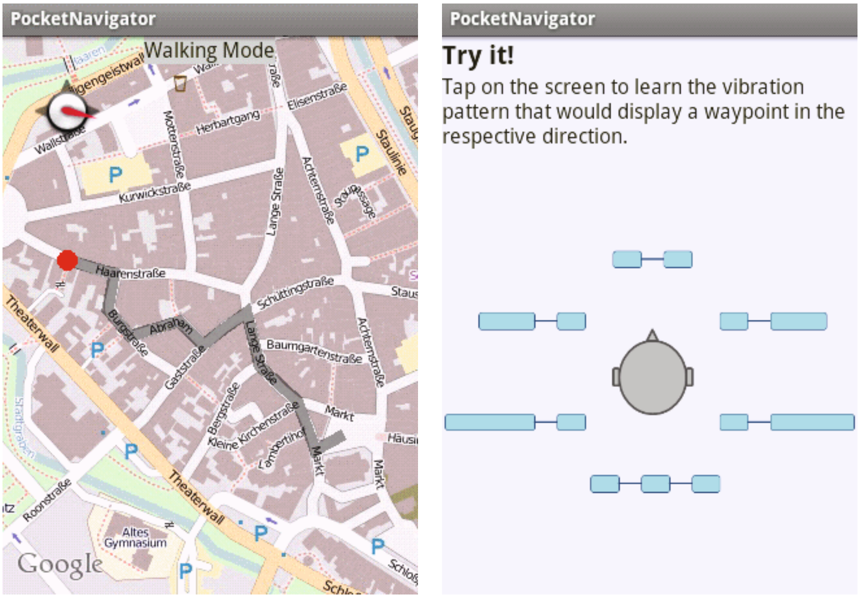
Robinson et al. used a scanning-based interaction technique to browse the environment for geo-located content [10]. Tactile feedback is received, if content has been discovered in a scan movement. They found that participants felt familiar with the scanning technique from the beginning and mostly interpreted the feedback while walking. They used the scan duration as measure for the effectiveness of finding content.

Pielot et al. introduced the PocketNavigator, which comes with vibro-tactile navigation support [5]. In a first study they compared the concept with a map and measured the task completion time, disorientation events, and distractions from the environment [7]. In a follow-up study [6] they extended their measures by navigation errors, occurred orientation phases, and by measuring the overall walking speed. They further discuss the task completion time more detailed and report total scan and interaction times. They argue that future work is needed to investigate if this technique can be made more intuitive.

Magnusson et al. [3,2] used audio feedback to indicate whether a user is pointing at the correct direction. Varying angles, ranging from 10° to 180° have been studied. The time to reach the destination, i.e., task completion time, has been used as effectiveness indicator. They found that a narrow 10° angle and wide 180° angle lead to rather long completion times. For exact track following 30° to 60° are recommended. If low cognitive load is important, angles between 60° and 120° should be chosen. They further report about different scan techniques, i.e., wrist flex, arm scans, and whole body rotation.

Rümelin et al. [8] compared their vibro-tactile navigation system NaviRadar with the PocketNavigator and regular spoken instructions in an outdoor study. To compare the systems they measured disorientations, i.e., stopping for more than 2 s, and navigation errors, i.e., travelling in an incorrect direction for more than 5 m.

As the related work shows, scan-based interaction techniques are typically evaluated or compared in a case-by-case field experiment. This is sufficient to show the effects of a novel technique in a real context. However, until now almost no technical measures are reported, which would allow a structured side-by-side comparison of interaction techniques. We aim to fill this gap with the proposal of a set of standard measures.



Try it!

Tap on the screen to learn the vibration pattern that would display a waypoint in the respective direction.

Fig. 2. The PocketNavigator is a pedestrian navigation application, which we used as apparatus for our study on scanning behaviour. These screenshots show an early release of the application, which we used during the study.

3 Background: The PocketNavigator

The PocketNavigator[1] is a pedestrian navigation application similar to Google Maps Navigation [5,7]. It shows the user's location on a visual map and can calculate a route to an arbitrary destination nearby (see Figure 2). One of the essential features of the application is that it is able to convey the direction to a route's next way point by vibration patterns. If the way point is ahead, two vibration pulses of equal duration are presented. If the way point is on the left the first pulse's duration is increased depending on how far left the point is. Accordingly, the right pulse's duration is increased if the way point is on the right. If the way point is approximately behind the user, three short vibration pulses of equal duration are presented. The concept is labelled *Tactile Compass* and visualized in Figure 2.

The application supports two different operation modes. The scanning mode is enabled if the roll and pitch angles of the mobile phone, which can be derived from the accelerometer, are between $-16°$ and $16°$, i.e., the device is held almost parallel to the ground. In scanning mode the device's compass is used to determine the direction to the next way point. The pocket mode is enabled if the device is not in scanning mode. Then the GPS heading is used to determine the direction to the next way point. For this paper only the scanning mode is

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[1] `http://www.pocketnavigator.org/`, last visited July 4, 2012.

of relevance. In this paper the PocketNavigator application serves as apparatus for our sensor-based observations to derive the measures on how to define a scan interaction. For an in-depth evaluation and discussion of the different interaction techniques, please read our earlier papers, e.g. [7].

4 Field Study

We conducted a user study to record a typical set of scan movements in the field. 15 volunteers (8 females) participated in our study. The participants were aged from 20 to 29 years (mean 23.6, sd 2.5). Thirteen participants were university students, two were part- or full-time employed.

We used a HTC Dream smart phone, which was running the PocketNavigator application as described above. The study was conducted in the city centre of Oldenburg, a city with about 160,000 inhabitants. We modified the software in a way that several sensor values (i.e., accelerometer, compass, GPS) were continuously saved to the device's memory card.

We decided for a within subjects, i.e., repeated measures, design. Each participant was asked to walk three pre-defined routes of approximately equal length (i.e, about 500 m, containing 10-11 way points) and complexity (i.e., number of decision points, like crossings). For each route one of three conditions was assigned: *tactile only*, *map only*, and *combined.* In the *tactile only* condition, the map was not shown to the user (i.e., a black screen was shown instead) and only tactile feedback was available. In the *map only* condition, the map was shown and no tactile feedback was provided. In this condition the map was by default rotating, i.e., aligning to the user's heading. The rotation of the map could be turned off by the participant, which resulted in a north-up oriented map. We also had a *combined* condition, where tactile and map feedback were both available. To cancel out potential sequence effects, we counter-balanced the conditions.

Initially we asked each participant to sign an informed consent. Before we started with the study we made the participants familiar with the device and our navigation software. We explained all the functions and the participants were able to explore how the device behaves in various situations. On a short training route we answered remaining questions. We particularly emphasized that the participants can grasp, hold and interact with the device as ever they like. We started the study with one of the three conditions enabled. The experimenter followed each participant and video recorded them. We did not assist or influence the users during the actual navigation and orientation task. Once a participant reached the destination of a route, the experimenter changed the condition and the user was then able to go on with the navigation. At the final destination we conducted a brief semi-structured interview, where we asked the participants about their subjective impressions on the different interaction methodologies. Finally, we thanked each participant and handed an USB stick as a reward for participation.

4.1 Filtering and Data Preparation

During the study, the mobile phone logged most of the available sensor data. Most important for this study, GPS location, three dimensional acceleration and the compass heading over time were recorded. For the actual analysis we first converted the acceleration values into roll and pitch angles. We then extracted what we refer to as *scan event*, i.e., if the user is actually doing a scan interaction. By definition a scan event starts, once the roll and pitch angles are between $-16°$ and $16°$. We removed the first second of the scan event, as here sensor values are probably imprecise. A scan event ends, if these angles are exceeded for more than 3 s. To cover only real and intended scan interactions we excluded scan events with a duration of less than 1 s and more than 120 s. We argue that the remaining data set covers only intentional scan interactions. The filtering was applied to all conditions in an equal manner.

Table 1. An overview on all identified measures, their values for our exemplary study, and their potential impact on the user

Measure	*Tactile*	*Map*	*Combined*	Potential Impact
Frequency	16x	13.5x	17x	Physical demand, context switches
Duration	21.05 s	17.35 s	18.87 s	Physical demand, mental demand, intuitiveness
Speed	$0.66\,\mathrm{m\,s^{-1}}$	$0.93\,\mathrm{m\,s^{-1}}$	$0.71\,\mathrm{m\,s^{-1}}$	Efficiency, mental demand, training level
Angle Span	136°	106°	122°	Physical demand, conspicuousness, insecurity

4.2 Scan Frequency

Based on our data set we investigated how often a user scanned. This measure is named frequency and is already used as measure how attentional resources are spend [4]. In the *tactile only* condition scanning means that the user made use of the higher precision of the compass and therefore perceived more responsive and accurate tactile feedback. In the *map only* condition scanning means that the user was probably looking at the display. In the *combined* condition it is unclear, whether a user relied on tactile feedback or was watching the screen.

We found that in the *tactile only* condition a user scanned approx. 16.0 times in average. For the *map only* condition a user scanned 13.5 times, while in the *combined* condition 17 times. Given the complexity of the route that means that a user scanned every 31.25 m (*tactile only*), 37 m (*map only*), or 29.5 m (*combined*). A conducted ANOVA omnibus test indicated that no significant differences can be found ($F(2, 42) = 0.71$, $p = 0.50$).

Each started scan interaction means a context switch, i.e., the user starts to pay more attention to the mobile device and less attention to the environment. Obviously the context switch itself and the following scan action takes time.

Therefore, the scan frequency is a very efficiency- and performance-critical measure. We further observed that users are most likely performing a scan movement if they feel insecure on how to proceed in the way finding/navigation task. Thus, scan frequency is an indicator on how often a user needs reassurance, probably because of insecurity.

4.3 Scan Duration

We also investigated the scan durations and found that for the *tactile only* condition, an average scan event took 21.05 s. For *map only* it took 17.35 s and in the *combined* condition 18.87 s. A conducted ANOVA indicated no significant differences between the three conditions ($F(2, 694) = 1.30$, $p = 0.27$).

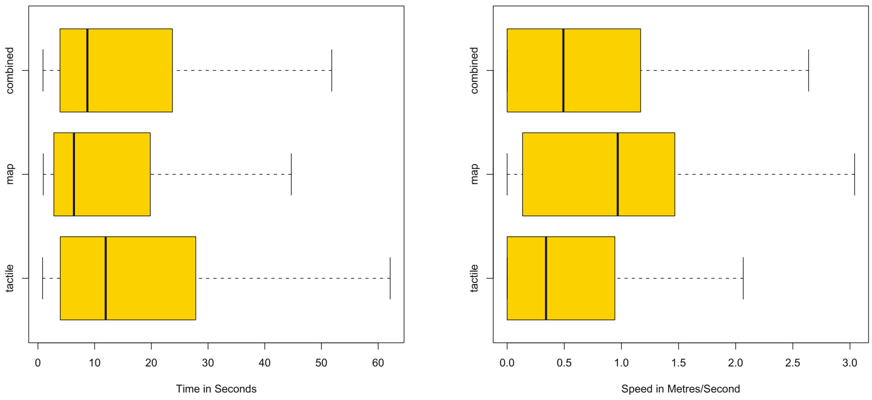

Fig. 3. Scan events in the *tactile only* condition take 21.05 s in average. The average walking speed is, compared to the *map only* condition, significantly lower.

The duration of scan events is an important characteristic of an interaction technique. We assume that the longer a user scans the greater the physical demand is. Further, the duration could give insights on how intuitive a technique is. I.e., a short scan duration could be an indicator for an intuitive technique. Missing intuitiveness means that a user has to actively think about what is perceived, which could be interpreted as an increased mental demand.

4.4 Walking Speed

As shown by other papers, the walking speed is an interesting measure not only for pedestrian navigation [1]. We found that the walking speed in the *tactile only* condition was $0.66\,\mathrm{m\,s^{-1}}$. For the *map only* condition the speed was $0.93\,\mathrm{m\,s^{-1}}$, while it was $0.70\,\mathrm{m\,s^{-1}}$ for the *combined* condition. A conducted ANOVA ($F(2, 694) = 5.53$, $p < 0.01$) and a Bonferroni-corrected post-hoc t-test showed that the walking speeds for the *combined* and *tactile only* condition are both significantly lower than for the *map only* condition ($p < 0.05$ and $p < 0.01$).

We observed that a user often continues to walk while scanning. Thus, the walked distance over time, i.e., walking speed, is also a criteria to characterize a scan interaction technique. We argue that if a user walks, compared to a non-scanning situation, significantly slower, this could be an indicator for the induced mental demand of the scanning-based interaction technique. We further argue that this value might be an indicator on how trained a user is to the interaction technique.

4.5 Covered Angle Span

We further investigated the span, i.e., the overall covered angle, of a scan event (see Figure 4). We found that an average scan motion in the *tactile only* condition spans 136°. For the *map only* condition we observed 106° and for the *combined* condition 122° in average. Compared to the *map only* condition that makes a difference of about 30° for the *tactile only* condition. A conducted ANOVA ($F(2, 694) = 4.17$, $p < 0.05$) and post-hoc Bonferroni-corrected t-test ($p < 0.05$) indicate that this difference is significant.

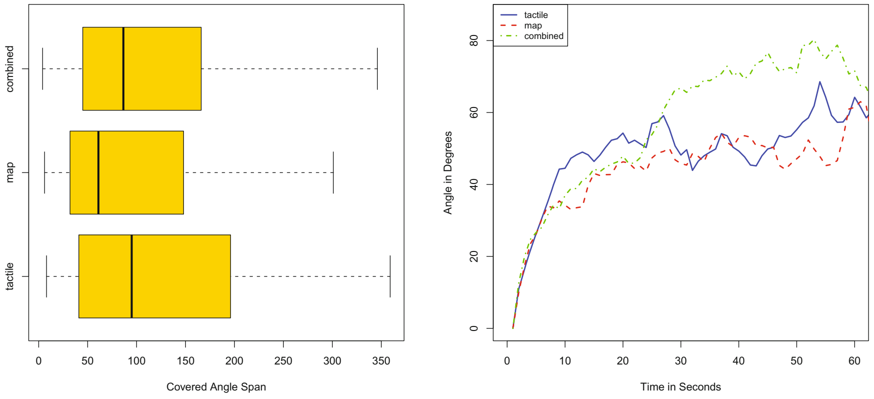

Fig. 4. When compared to the *map only* condition the angle span is significantly wider than in the *tactile only* condition (left). Within the first 10 s of an average scan event the device is moved rapidly, after that the angle remains almost unchanged (right). Note that less scan events contributed to the average angle for higher durations. Therefore, the impact of individual scan events becomes greater.

We analysed how the scan angle varies over time. To make the following analysis independent of the direction of scanning, we used the absolute value for each recorded angle. We found that the average angle dramatically changes in the first 10 s of a scan event from 0°, i.e., straight ahead, to about 50° for the *tactile only* and *map only* conditions, and about 70° for the *combined* condition. After the initial increase, the angle mostly remained unchanged.

A broad angle means that the user has to turn significantly towards left or right. At a certain point the user is unable to cover this angle with wrist or arm movements and inevitably needs to do full-body movements. If these obvious movements are necessary it is also more likely that passers-by notice the interaction process. We further observed that users tend to cover broader angles if they feel insecure with the provided feedback. Therefore, we argue that the covered angle span could give insights on how physical demanding and conspicuous an interaction technique is.

4.6 Limitations

One technical limitation is that out application used predefined angles to trigger the scanning mode in the *tactile only* and *combined* condition. This limited the user's interaction space in advance, but doesn't limit the potential set of measures itself. The automatic detection of scan events is another limitation, as this technique might come with inaccuracies, i.e., the detection of a scan event where is none. We further want to point out that the described study is by design not capable to give any insights on how effective the derived metrics are to actually distinguish between different scanning techniques. Finally, we want to emphasize that the vaguely illustrated potential impacts have been derived from mostly subjective impressions, i.e., the experimenter's observations and the participants' comments during the interview.

5 Conclusions

In this paper we identified an initial set of objective measures, i.e., frequency, duration, walking speed, angle span, with which a scan event can be technically defined independently of any concrete scenario. We argue that this set of measures potentially allows the systematic and objective analysis and comparison of scanning-based interaction techniques. We further illustrate the potential impact, e.g., increase of mental demand, each of the measures might have on a user.

It is important to understand and consider the set of measures as a mean to support and improve the overall design process. If a researcher or designer is going to design a new scanning-based interaction concept, the proposed set of measures can help to gain an understanding on what a scanning movement actually is and how the individual parameters might affect the user. Already existing interaction concepts could be analysed and thereby ideas for improvement can be revealed. If the research community starts to apply these measures, eventually some design guidelines for scanning-based interaction techniques might evolve.

We want to emphasize that the presented set of measures is a draft and the identified impact on the user have been derived from mostly subjective impressions. Obviously, future work is needed to establish the idea and validate the existing set. We plan to support the future efforts in this field by publishing our logging-based observation tool.

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