Design, Implementation and Evaluation of a Novel Public Display for Pedestrian Navigation: The Rotating Compass

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ABSTRACT
Important drawbacks of map-based navigation applications for mobile phones are their small screen size and that users have to associate the information provided by the mobile phone with the real word. Therefore, we designed, implemented and evaluated the Rotating Compass – a novel public display for pedestrian navigation. Here, a floor display continuously shows different directions (in a clockwise order) and the mobile phone informs the user when their desired direction is indicated. To inform the user, the mobile phone vibrates in synchronization with the indicated direction. We report an outdoor study that compares a conventional paper map, a navigation application running on a mobile device, navigation information provided by a public display, and the Rotating Compass. The results provide clear evidence of the advantages of the new interaction technique when considering task completion time, context switches, disorientation events, usability satisfaction, workload and multi-user support.

Author Keywords
Mobile navigation, synchronized displays, public displays.

ACM Classification Keywords
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies; Prototyping.*

INTRODUCTION
In recent years, there has been a great deal of interest, in industry and academia, regarding mobile navigation solutions. Almost all approaches focus on providing the user with: information on their current location, nearby points of interest, directions, and navigation. These solutions are essentially intelligent replacements for paper maps that provide additional features to the user. One important disadvantage of these two approaches (a paper map and showing a map on a mobile phone) is that the user still has to associate the navigation information with the surrounding world.

Proposed alternative approaches are the provision of personalized navigation information using public displays and the synchronized usage of private and public displays, such as the Rotating Compass [22] (illustrated in Figure 1). Here, a public display (installed at a crossing) continuously iterates a set of directions in a clockwise order. Each possible direction iterated is highlighted for a short time period.

In a scenario where two users (carrying a mobile phone with a preinstalled navigation application) are approaching the crossing, nothing occurs when an undesired direction is indicated (Figure 1 left). However, when the correct direction is indicated (*straight on* for the left user and *right* for the right user) the mobile phone vibrates, thus conveying to the user that their desired direction is currently indicated.

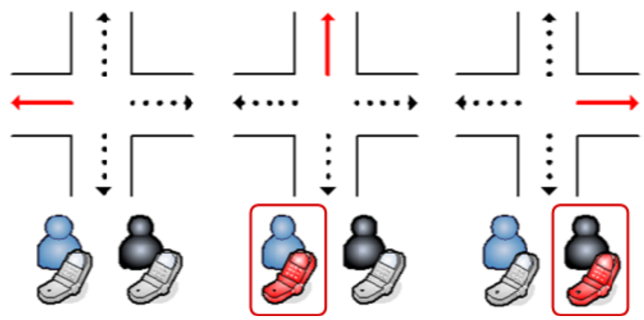

Figure 1. Rotating Compass interaction technique.

Although the idea of using public displays for the provision of navigation information has been discussed several times in the last years [4, 12, 19, 22, 26], it has not yet been evaluated in a realistic context. This paper is the first that presents a comparative evaluation of the advantages and disadvantages of providing navigation information:

1. Using a personal display ((a) using paper map and (b) using a mobile phone),
2. Using the environment (via a public display)
3. Using the combination of both (synchronized private and public display as in the Rotating Compass interaction technique).

The four corresponding interaction techniques (1a, 1b, 2 and 3) have been implemented and evaluated in a user study, which was conducted in an outdoor environment.

The results provide clear evidence in favour of using a public display when considering: task completion time, context switches, disorientation events, usability satisfaction, and workload. Ideally, a public display would provide individual information to each user; however, this restricts the system to use in a single-user context. The study shows that the Rotating Compass (suitable for multi-user scenarios) performs better than the map-based interaction techniques and performs almost equal when compared with a public display showing individual navigation cues. The study also proves again the advantages of a paper map when compared with a mobile phone navigation application, as the latter is used on a device with very limited output capabilities [27].

BACKGROUND

There exists a broad variety of location-based mobile applications and devices that range from navigation systems for cars or hikers to solutions for mobile phones. This paper focuses on systems for conventional mobile devices, such as mobile phones or PDAs that are used for indoor and outdoor navigation. Most systems described in this section are outdoor solutions, as indoor localisation is still far away from the simplicity and pervasiveness of GPS or cellular network based localisation systems [14].

The usage of mobile devices for location-based services, such as navigation and tourist guide-based applications, has been the focus of many research projects in the last decade [1, 5, 6]. These applications typically present a map to the user, and show the current position of the user on the map. They may also include a visualisation of nearby points of interest or present additional route instructions [13, 28].

One of the first commercially successful location-based mobile services is i-area, a network-based localisation system introduced in 2001 by NTT DoCoMo in Japan [18]. Another approach is to equip the mobile device with a GPS receiver and corresponding pre-installed map-based applications (e.g. Nokia Maps on the Nokia N96 or Maps on the iPhone3G).

Because of these developments and the advances in technology, it is expected that device and network-based localisation technologies will be increasingly employed for location-based mobile services [14].

Kray et al. discuss [13] 5 different approaches for presenting route instructions on mobile devices:

1. Textual or spoken instructions (e.g. “Turn right at the next crossing”),
2. 2D route sketches (e.g. an arrow that points in the correct direction, as used in car navigation systems, with no map is displayed),
3. 2D maps (e.g. showing a map with a visualisation of the route and the current position of the user),
4. 3D route maps showing a 3D representation of the environment (e.g. as discussed in [20])
5. Combinations of the previous approaches (e.g. a 2D map and additional spoken instructions).

2D maps are the most popular option, owing to the availability of the maps and users’ familiarity with 2D maps. However, important disadvantages with 2D maps are that the user has to switch very frequently between the environment and the small mobile phone screen. In addition, a large cognitive load is required to associate the information provided by the map with the surrounding world [10]. The latter problem is addressed when using 3D maps, but unfortunately, it is very expensive to create such maps.

Using spoken instructions or 2D route sketches, the user does not need to think about the relationship between the map and the environment. However, the user must be actively attentive to the system at all times since the system defines when the information is transmitted to the user. There may be cases when the user may be not prepared for instructions, for example, when speaking to another person or when concentrating on unrelated tasks. Furthermore, the system has to be aware of the current orientation of the user. This can be inferred by analysing the direction in which the user was travelling, or through the usage of a compass as described in [4].

Beside the usage of spoken information and the visualisation of information is haptic feedback, a further possibility to transmit directions to the user. One example for this is the ActiveBelt whereby 8 vibration motors (attached every 45 degrees onto the belt) inform the user about the direction to travel using corresponding vibration patterns [25]. A further solution is to use augmented reality-based navigation systems that overlay the real world with virtual navigation information [21]. Although these systems are very promising, they still require a heavy infrastructure that consists of an exact localisation system, an accurate model of the environment and a good deal of processing power.

The approaches discussed so far were based on the usage of a mobile or wearable device, but as public displays occur in more and more public spaces, they can be also used for the provision of personalized navigation information to the user. Moreover, mobile navigation applications also have some disadvantages (e.g. the small screen), which leads to the fact that persons using high-resolution paper maps often perform better [27]. Examples of the usage of public displays for the provision of location information are the GAUDI display system [12] and the Smart Doorplate [26].

The advantages of these systems are that the user does not have to understand a map, the navigation information is personalized (e.g. *lead the user directly to the right meeting* *room instead of following conventional signs*), and there is also no need for a sophisticated indoor localisation system. This approach demands knowledge of the user's location. Therefore, a beacon is worn by the user and sensed by the displays, which in turn, provide information on the location of the user. However, as it is very difficult to present navigation information to many users via one display, and as a result, this approach is not particularly scalable.

The REAL system was one of the first that proposed the combination of a mobile device and public display for the provision of navigation information [4]. In this case, the high-resolution public display showed similar information as on the mobile phone and was consequently not particularly useful in a multi-user context.

This problem was then solved by the Rotating Compass [22] and the CrossFlow [19] systems. Here, the public displays (floor projections in these cases) show a repeating sequence of different options (e.g. four different directions) and the user's mobile phone indicates (e.g. through vibration) when the relevant option for the user is indicated. The mobile device acts as an unobtrusive personal display which tells the user when the relevant information is displayed. The most important advantage of this approach is that the public display can be used by a potentially large number of users. Using such an unobtrusive navigation system, the users do not have to listen to spoken instructions and do not have to view or to interact with a map.

One disadvantage of this approach is that these public displays are absent in the majority of public spaces, but one can imagine finding them at each crossing in airports, train stations, hospitals, office buildings, etc. For instance, the new terminal 5 of Heathrow Airport (UK) provides 206 flat-screen displays that can show flight-specific advertisements [24]. Another example is Lancaster University (UK) where one can find a large number of displays on campus [7] and also 40 door displays in one of the buildings [9]. A further example is the compass-shaped decals on sidewalks currently installed in New York. These show directions (north, east, south and west) and the names of the nearest streets [3]. Although the displayed information is static, one can imagine that they might be replaced in a few years by dynamic displays. Other examples for using the floor as a display are the EyeStep system (used mainly for marketing purposes) [8], the Nintendo Floor Vision [16], or the Asian Civilisations Museum [2] in Singapore, which uses floor projections to guide its visitors through certain exhibitions.

Although previous research discussed the usage of public displays for the provision of navigation information, no study has yet shown whether the envisioned advantages are actually true in a realistic context when compared with existing approaches. Therefore, this paper compares the provision of navigation information using a personal device, a public display, and a combination of both.

DESIGN OF THE ROTATING COMPASS

As previously discussed, the mobile device is synchronized with the public display and provides individual navigation cues for different users.

The mobile device runs a navigation application that supports conventional guidance, based on maps and GPS (as known from Nokia Maps) as well as the Rotating Compass interaction technique. When considering a trip from the office to the correct gate at the airport, the map and GPS approach is used to travel to the airport. Once within the terminal, the Rotating Compass system is used as no GPS signals can be received within a building. Upon entering the terminal, the mobile device downloads a GPS referenced floor map that provides information about all crossings and installed Rotating Compasses.

As depicted in Figure 2, each Rotating Compass constantly broadcasts:

- its location in form of GPS coordinates,
- the number of visualized directions (n),
- the duration for which each direction is highlighted (t_h),
- the time when the Rotating Compass highlighted the direction north previously (t_n)

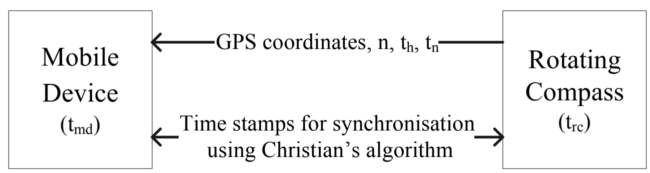

Figure 2. Communication between mobile device and rotating compass.

Based on this information, the mobile device calculates the time of circulation ($n * t_h$). It is very important that the clocks of the mobile device (t_{md}) and the rotating compass (t_{rc}) are synchronized so that the mobile phone vibrates exactly in the moment when the correct direction is indicated. There are several clock synchronisation approaches available which could be applied in this context. For instance, using the Network Time Protocol, both clocks, t_{md} and t_{rc}, would vary circa 10 milliseconds from the Coordinated Universal Time (UTC). Another approach is the usage of Cristian's Algorithm whereby the mobile device can estimate the difference of the two clocks, t_{md} and t_{rc}, after exchanging time stamps with the Rotating Compass.

Using the information provided by the downloaded terminal floor map and the Rotating Compass, the mobile device can calculate when and how long the correct direction is indicated, and vibrates correspondingly.

The previously described information, broadcasted by the Rotating Compass, is only sufficient for designs in which the visualized directions are equally distributed and there is no delay between displaying two consecutive directions. Considering other designs, the broadcast might be extended with information about angles of the different indicated directions, durations for which each direction is highlighted, or durations indicating delays between the visualisation of two consecutive directions.

Depending on the range of the short-range network used (e.g. 10 meter for Bluetooth Class 2 devices) and the distances between different crossings, the user may see more than one Rotating Compass. Using the built-in magnetic compass of the mobile device, as e.g. available in the Nokia 6210 Navigator, it is possible to estimate at which compass the user is currently looking on. Furthermore, it is possible to use other approaches for indoor localisation [14], in combination with movement tracking, in order to identify the Rotating Compass the user is currently looking on.

When considering the communication between the mobile device and the Rotating Compass via current versions of Bluetooth or WLAN, the time needed for pairing the two devices is too long. The device discovery and pairing process of Bluetooth takes usually a few seconds during which the user would have already passed the Rotating Compass without any indication from the mobile phone about the correct direction. This problem will hopefully solved through the usage of future Bluetooth or WLAN standards or through the usage of GSM/3G for the communication between mobile phone and Rotating Compass.

When considering synchronized displays, it is also possible to use different kinds of public displays. For instance, it is possible to use existing signs which can be highlighted for certain times. Furthermore, the users could be informed through audio cues (e.g. “beep” when listening to an MP3 song) or visual cues (e.g. through a LED attached to the glasses) instead of the used mobile phone vibrations.

FIELD EXPERIMENT

The goal of the experiment was to compare four different interaction techniques for mobile navigation as shown in Figure 3 – using a paper map, using map-based mobile application (*phone-only*), Rotating Compass (*synchronized displays*), and personalized navigation information presented by a public display (*environment-only*). Effectiveness was measured in terms of task completion time, context switches, errors, disorientation events, usability satisfaction and workload.

Participants

12 paid participants, 6 female and 6 male, took part in the user study. All of them were students or employees of Lancaster University, were aged between 25 and 46 (mean = 29.9) years, and are not involved in the presented research.

On average, they rated themselves with a high experience with computers and medium-high experience with mobile phones (scale used: 1=none, 2=poor, 3=medium, 4=high, 5=expert).

All participants owned a mobile phone, but none of them had experience with using maps on mobile phones. The participants were asked how well they knew the area where the study was conducted. 1 participant responded that they have never been there, 6 said that they have been there a few times and 5 said that they know the area very well. However a paired-samples t-test, between the unfamiliar group and very familiar group, revealed no significant differences when considering task completion time ($t(4) = .452$, $p = .674$). The reason for this is likely due to the fact they have not encountered the specific routes as most lead the user around unfamiliar accommodation.

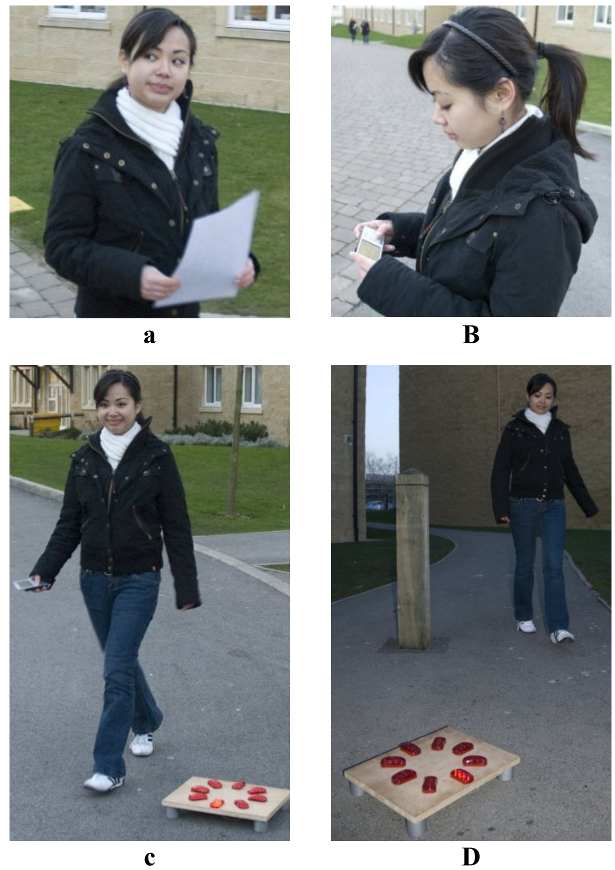

Figure 3. Usage of the four interaction techniques: (a) – paper map, (b) – phone-only, (c) – synchronized displays and (d) – environment-only

Experimental Design

The experiment used a within-subjects design and therefore, all participants participated in all conditions of the experiment. The independent variable *interaction technique* contained four levels: paper map, phone-only, synchronized displays and environment-only.

The routes and conditions were counterbalanced in order to control route and order effects. All participants in the user study experienced the routes in the same sequence;

however, they experienced the conditions in one of four different sequences using a Latin square.

Routes

Four different routes were designed in Alexandra Park which is part of the Lancaster University campus. The routes are presented in Figure 4. This area is occupied by many 5-floor student houses and was selected because of its small size, high number of crossings and its winding streets and lanes.

Each route had a mean length of 210 meters (standard deviation = 58.3) and participants had to decide on the direction to take for 5 crossings per route. In total, users made 20 correct turns for the 4 predefined routes. Unfortunately, it was not possible to use longer routes and more crossings, as the study was conducted under very cold and windy conditions. With the routes provided, the participants already required one hour for the overall study and we did want to risk the well-being of the participants.

Figure 4. Four different routes used in the experiment.

Materials

Prototype 1: Paper map

A simple coloured printout (25 x 20 cm) of the routes, depicted in Figure 4, was given to each participant. The official campus map (provided by the university) was used for the map. The start point was indicated by three interleaved circles, the route was marked red and the destination was illustrated using a chequered flag. The printout had an approximate scale of 1:1200 (one centimetre on the map corresponds to 12 meters in the real world).

Prototype 2: Phone-only

A Java ME (MIDP 2.0, CLDC 1.1) application was developed which showed parts of the overall map on a Nokia N95 using the whole resolution (240 x 320 pixels) of the 4.0 x 5.3 cm display (see Figure 5). The map shown had an approximate scale of 1:2000 (one centimetre of the map shown on the mobile phone corresponds to 20 meters in the real world). The start point was (as in prototype 1) indicated by three interleaved circles, the route was marked red, and the destination was illustrated through a chequered flag.

The Location API for J2ME (JSR 179) was used to acquire location information from an external GPS receiver (Nokia Wireless GPS Module LD-3W). An external GPS device was used instead of the built-in GPS receiver of the Nokia N95 as the latter did not provide sufficiently reliable and permanent location information.

The current location of the user was indicated through a green dot (Figure 5) and was updated in accordance to the user's movement. The functionality is very similar to GPS-based map applications on mobile phones such as Nokia Maps [17]. We were not able to use such an existing application as the area we used for our study was built recently and is not yet included in most commercial maps. Furthermore, the participants of our study also navigated along small footpaths, which are anyway not often included in commercial maps.

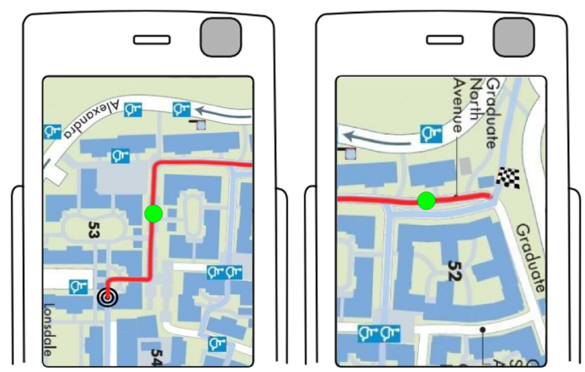

Figure 5. Maps as visualized on the mobile phone.

Prototype 3: Synchronized displays (rotating compass)

The synchronized displays consisted of two different components: the mobile phone (Nokia N95) and the public display that is depicted in Figure 3c and Figure 6. The latter consisted of 8 bicycle rear lights (manufactured by Electron), which light up sequentially in a clockwise direction (n=8). Each of the 8 rear lights illuminates for 0.6 seconds in a clockwise direction (t_h = 0.6), resulting in a time of circulation of 4.8 seconds (n * t_h).

The 8 lights are controlled by a 16 Bit PIC microcontroller (Microchip PIC 18F252) which is connected to a Bluetooth module (LinkMatik 2.0) and is used for the communication with the mobile phone.

The software, running on the microcontroller, waits for a start command that is received via the Bluetooth module. After receiving this command, the public display begins to illuminate each light in a clockwise direction. The inner diameter of the public display is 14.5 cm and the outer-diameter is 28 cm.

The application on the mobile phone was implemented in Java ME (MIPD 2.0, CLDC 1.1) and communicates via Bluetooth (Java APIs for Bluetooth, JSR 82) with the public display in order to control it.

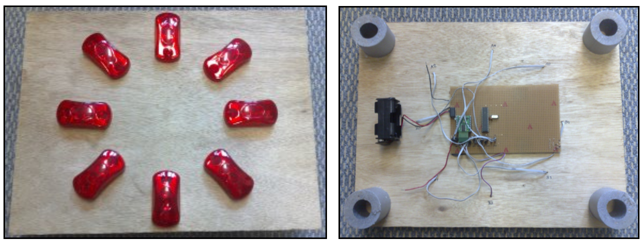

Figure 6. Front and back side of the public display.

The participants of the study viewed a basic visualization on the mobile phone screen which indicated whether the phone is still connected to the public display. Beside this, the mobile phone vibrated for 0.6 seconds when the correct direction was indicated.

The prototype did not use any of the previously discussed clock synchronisation approaches as it was sufficient for the study if the two devices were in synchronization for circa 15 minutes. Before the participants used the prototype, the experimenter switched the public display on. Subsequently, the experimenter started the mobile phone application which sent a “start to rotate” command to the rotating compass via Bluetooth. As there was a constant delay of circa 300ms between sending the “start to rotate” command on the mobile device and its reception on the rotating compass, it was very easy to consider this delay in order to synchronize the clocks of the two devices.

Prototype 4: Environment-only

Here, the previously described public display was used again. One experimenter used an additional Java ME application running on a Nokia N95 to control the public display in such a way that just one direction is indicated all the time; the participants who were in this case not using a mobile phone simply had to approach a crossing and to check which direction is indicated (Figure 3d).

Dependent Measures

The performance of the navigation task was measured in terms of task completion time, context switches, errors, disorientation events, usability satisfaction and workload. The participants were filmed using the different interaction techniques when navigating the four different routes. The video material was used to analyse the task completion time, disorientation events, context switches and error rate.

Task completion time is the time a participant needed to navigate from the start point to the destination. An error was counted when the user left the predefined route by more than 5 meters. Disorientation events were counted when a participant stopped for more than 5 seconds. Context switches were counted also using the recorded video. A single context switch occurred when the user’s view switched from the environment to the phone or paper map.

Selected questions of the IBM Computer Usability Satisfaction Questionnaire were used to ask the participants about their opinion for each technique regarding simplicity, speed, comfortableness, easiness to learn, provided information, likability and satisfaction [15]. Three questions of the NASA Task Load Index (TLX) regarding mental demand, effort and frustration level were used to measure the perceived workload [11]. Additionally, the participants were asked to rank the four interaction techniques according to their preferences for them.

Procedure

Participants took part in the study individually. At the beginning of the experiment they were told to navigate four different routes using four different interaction techniques. The interaction techniques were explained to them and discussed using a handout providing a compact description and illustrations for each of them.

Using a training route, the participants had to use each interaction technique independently using the described prototypes. Once completed, they were able to use the paper map, the mobile phone applications and the public display in a practical context.

Each participant in the study experienced the routes in the same order: route 1, 2, 3 and 4. The interaction techniques’ respective conditions were counterbalanced using a Latin square in order to control order and route effects. The participants were told to navigate as quickly as possible, but to walk with the speed they would use when walking in the city centre or on their way to work. Two experimenters accompanied each participant on each route, one was recording the video and one was carrying the public display when using the synchronized displays and environment-only interaction techniques.

As only one prototype of the public display was developed, one of the experimenters ran ahead of the participant to place the prototype in the centre of the next crossing before the participant’s arrival. The routes were designed in such a way that there was enough time for moving the public display without the need for the participant to slow down or stop. The experimenter, who was carrying the public display, waited for the participant to determine which direction to take. When the participant walked towards the determined crossing, this prompted the experimenter to carry the display to the next crossing, where the participant was travelling to anyway. Therefore, despite using a single display, the study results remained uninfluenced.

If the participants made an error (left the predefined route by more than 5 meters) then one of the experimenter said "*stop*" and the participant knew that they had to return back on course.

After each interaction technique, the participants were able to give comments and answered questions. At the end of the study, they were asked for their preferences and additional comments. The participants needed, on average, one hour to complete the whole procedure.

RESULTS

Timings, Context Switches, Errors and Disorientations

Figure 7 shows slight differences when analysing the task completion time of the different interaction techniques.

A 1-Way Repeated Measures ANOVA showed no significant differences in time between the four techniques ($F_{3,33} = 1.47$, $p > .05$). This was expected as the user's walking time is the main contributor to the overall task completion time rather than the interaction techniques themselves. A further reason was that the participants were informed when they left the route by more than 5 meters in order to limit the time each participant was involved in the study to one hour. Environment-only was the fastest technique, followed by synchronized displays, paper map and finally phone-only.

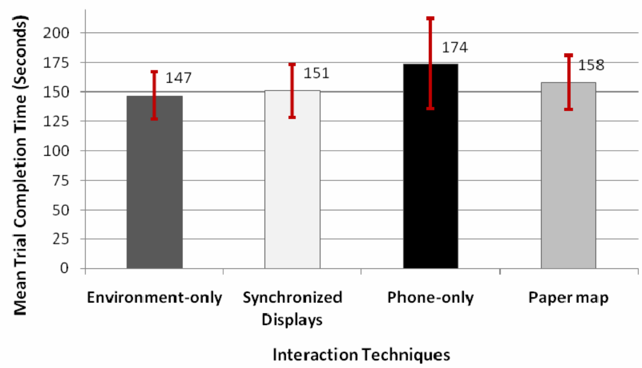

Figure 7. Mean task completion time with confidence intervals.

As expected, the usage of phone-only and paper map resulted in a relatively high number of context switches between mobile phone or paper map and the environment. Using the paper map, the participants looked on average every 5.8 seconds on the map and using the phone-only, the participants looked on average every 6 seconds on the mobile phone.

The overall number of errors (situations in which the participants left the predefined route by more than 5 meters) was very low. In total, 3 errors occurred when using the phone-only technique (0.25 errors per participant) and a total of 2 errors occurred when using the paper map (0.17 errors per participant). No errors at all occurred when using the environment-only and synchronized displays interaction techniques.

Disorientation events were counted when the participants stopped for more than 5 seconds. This occurred 10 times when using phone-only, 4 times when using the paper map, once when using the synchronized displays, and never when using environmental-only. Disorientation events occurred when using phone-only and paper map techniques involved the participants turning the map and trying to re-establish a match between the map and their surroundings.

Usability Satisfaction

The results of the selected questions from the IBM Computer Usability Satisfaction Questionnaire [15] are depicted in Figure 8 which shows the mean results of all participants. The results of a Friedman's 1-Way ANOVA show significant differences in the IBM questionnaire results ($\chi^2(27) = 186.23$, $p << .001$). Wilcoxon follow-up tests were used to analyse the results in more detail. All questions show significant results favouring the environment-only and synchronized displays over the paper map technique. Additionally, questions 2, 3, 4, 5, 6 and 7 show both environment-only and synchronized displays with significant results over the phone-only approach. For all questions, there are no significant differences between environment-only and synchronized displays. Moreover, there are no significant differences between phone-only and paper map techniques.

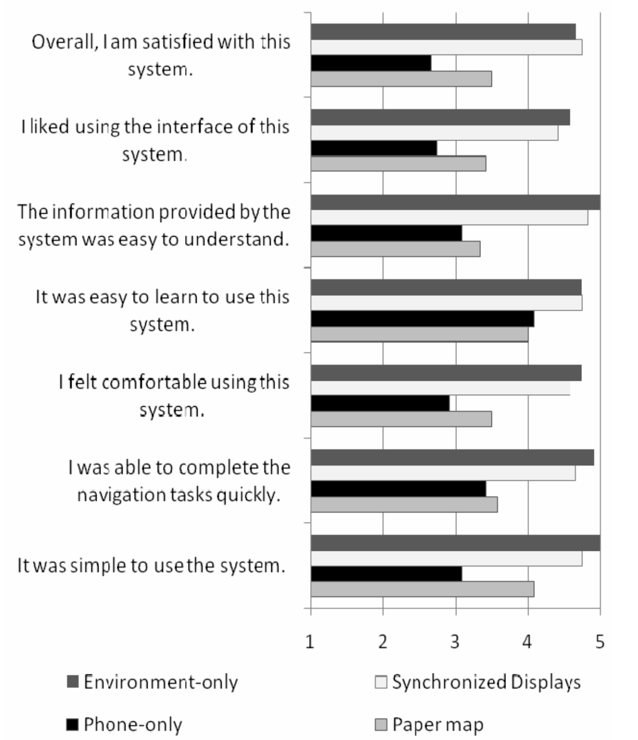

Figure 8. Mean results regarding usability satisfaction (scale: 1 – strongly disagree, 2 – disagree, 3 - neither agree nor disagree, 4 – agree, 5 – strongly agree).

In general, it could be said that the mean results for all four interaction techniques are, for the most part, in the range between 3 (neither agree nor disagree) and 5 (strongly agree). From this, one could conclude that the participants were on average somewhat satisfied with the usability of the four interaction techniques.

Workload

The results of the selected questions of the NASA Task Load Index [11] are depicted in Figure 9 and show the mean results of all participants. Frustration level was described in the questionnaire as - *How insecure, discouraged, irritated, stressed or annoyed did you feel during the task?* Effort was described as *How hard did you have to work (mentally and physically) to accomplish your level of performance?* Mental demand was described as *How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)?*

A 1-Way Friedman's ANOVA shows significant differences in the NASA Task Load Index results ($\chi^2(11) = 91.01$, $p << .001$). Wilcoxon follow-up tests showed that – for all three questions – environment-only and synchronized displays have significantly ($p < .05$) better results than phone-only and paper maps. The only significant difference between environment-only and synchronized displays is for *mental demand* ($p < .02$), in favour of the environment-only technique.

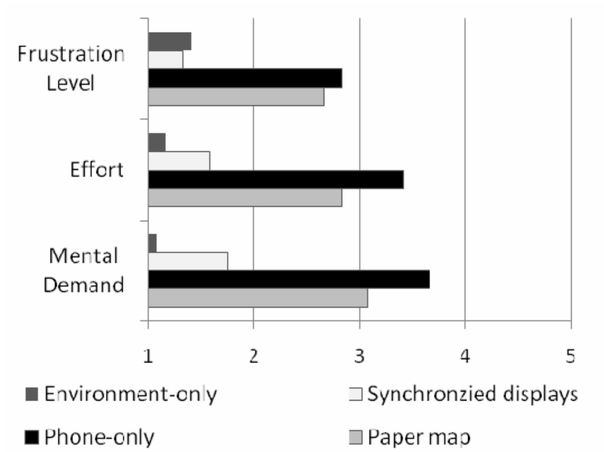

Figure 9. Mean results regarding workload (scale: 1 – very low, 2 – low, 3 – undecided, 4 – high, 5 – very high).

From Figure 9, it can be seen that environment-only and synchronized displays outperform phone-only and paper map considerably regarding frustration level, effort and mental demand. Using the synchronized displays leads to a higher effort and mental demand when compared with environment-only. However, pertaining to frustration level, the results for synchronized displays were slightly better than those for environment-only.

Preferences

At the end of the study, the participants were asked to state their first, second, third and fourth interaction technique preference. The results are depicted in Figure 10.

The mean position for environment-only was 1.6, 1.7 for synchronized displays, 2.9 for the paper map, and 3.7 for phone-only. 7 out of the 12 participants (58%) ranked environment-only as their first choice, 8 participants (67%) ranked synchronized displays as their second choice and 8 participants (67%) ranked phone-only their fourth choice.

Participant feedback & video observation

The following results were gathered while analysing both the video (showing the usage of the interaction techniques by the participants) and by analysing the comments of the participants made whilst filling in the questionnaires.

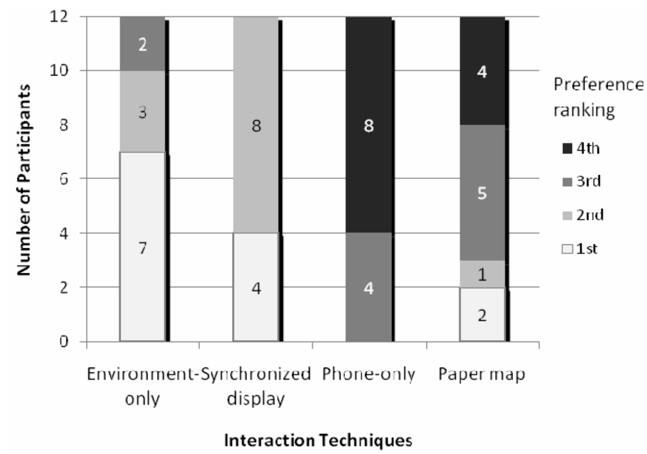

Figure 10. Preferences of the participants.

Focusing on the map. At the end of the study, many participants mentioned that they did not pay attention to the environment in general when using the paper map or phone-only techniques. We also recognized that the participants did not pay a much or enough attention to the traffic and other pedestrians when using the map-based interaction techniques. On the other hand, it was observed that people were more relaxed and paid attention to their environment while using the public display approaches.

Map and environment. As already indicated by the quantitative results, the participants have the mental effort of establishing the relationship between the information visualized by the map and the environment. So it was mentioned by some participants that they often asked themselves questions like *Where am I? What is the correct orientation of the map?* or *Where on the map is this building or street in front of me?*

Stopping at public display. A few participants stopped in the beginning at the public display for a second or two when using the synchronized displays or environment-only techniques. There is actually no advantage in doing this as the highlighted direction can be seen at least from a distance of 10-20 meters depending on the lighting conditions. Furthermore, they only stopped for a very short time which was not sufficient to see a complete rotation when using the synchronized displays interaction technique. It was observed that this behaviour occurred typically on only the first one or two crossings.

Looking back. A few participants looked back to the public display after passing it in order to check whether they selected the correct direction. This can be seen as an advantage of this approach as it is easily possible to check your decision by just looking back to the previous crossing.

Alignment of maps: Most participants rotated the map (when using the paper map and phone-only version) in such a way that rotation of the map corresponds to the walking direction of the user. This preference was already widely studied in previous research [23].

Hands-free: The user study was conducted while having cold and windy weather conditions. Most participants therefore put their hands in their pockets when using the synchronized displays and environment-only interaction techniques, as they did not have to look on a paper map or mobile phone display.

Pervasive display. Many participants mentioned explicitly how easy to use the synchronized displays and environment-only interaction techniques are. However, one participant mentioned that it is difficult or impossible to use shortcuts as the user is not really aware of their current location, the route, and the location of the destination.

Environment-only. It was mentioned that every bystander could see which way a user will or has to go, thus indicating the related privacy implications. Three participants mentioned explicitly the fact that the environment-only technique works only for a single user and that the synchronized displays works for many users. One participant mentioned a possible solution for this, which is based on the usage of different colours for different users.

SUMMARY & DISCUSSION

This section summarizes the quantitative and qualitative results in a compact way and visualizes them in Table 1. When considering the task completion time of the four interaction techniques, environment-only is the fastest technique followed by synchronized displays, the paper map, and phone-only. With reference to context switches, one can see a high number for phone-only and paper map techniques. The usability satisfaction of the public display based interaction techniques is high with slightly better results for environment-only. Paper map and phone-only techniques have a moderate usability satisfaction although the paper map performs slightly better. The workload is low when using the environment-only and the synchronized display, and once more, the two personal displays have the worst results. For the majority of participants, environment-only is the preferred interaction technique, followed by the synchronized displays, paper map, and phone-only. All interaction techniques support multi-user usage except the environment-only technique. The synchronized displays option has the advantage that the results are comparable to the environment-only technique and that multiple users can use one public display at the same time. However, it is somewhat unrealistic to find a display at each crossing. So there has to be an interplay between mobile phone-based navigation and the usage of synchronized displays. One could imagine that the mobile phone guides the user to the airport itself (e.g. using Nokia or Google maps), then synchronized displays are used in the airport.

	Personal display		Synchronized private and public display	Environment-only
	Paper map	Phone-only		
Number of context switches	High	High	Low	N.A.
Usability satisfaction	Average	Average	High	High
Workload	Average	Average	Low	Low
Average preference	3rd	4th	2nd	1st
Multi-user	+	+	+	-

Table 1. Summary of study results.

Furthermore, there maybe the case where a user wants to see exactly where they are and which points of interest are nearby. So the public display-based interaction techniques should be always accompanied by a corresponding map-based application running on a mobile phone. Provided with this combination, the user is able to switch between interaction modes and can benefit from the advantages of both.

The study was conducted in an outdoor environment as a corresponding large building with many crossings was not at hand. Although public displays can be installed outdoors, it is more likely to find them in buildings and therefore the results of this paper might be more applicable in an indoor context.

CONCLUSION

The paper presents the design, implementation and evaluation of the Rotating Compass, a novel interaction technique for pedestrian navigation. Here, a public display shows different directions sequentially and the mobile phone informs its user when the correct direction is indicated. This system was compared in a user study with approaches presenting location information on a personal display (paper map or phone-only) and a public display showing individual navigation cues. The study was conducted in a realistic outdoor context and the results provide clear evidence of the advantages of the Rotating Compass interaction technique for the provision of navigation information. The findings described in this paper will hopefully encourage more research on the usage of public displays in this context and might lead to the deployment of such systems in a practical context.

We currently plan to extend the presented research through a study using longer routes in order to get more insights when comparing the Rotating Compass with other navigation techniques, the usage of different interaction techniques in parallel for navigating one route and the usage of projector phones for displaying navigation cues.

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