Evaluation of an Arm-mounted Augmented Reality System in an Outdoor Environment

Steven J. Kerr, Mark D. Rice, G.T. Jackson Lum and Marcus Wan
Institute for Infocomm Research, A*STAR
1 Fusionopolis Way, #21-01 Connexis, Singapore, 138632
sjkerr@i2r.a-star.edu.sg

***Abstract*—Research into Augmented Reality (AR) devices for professional use has largely focused on hand-held devices and Head Mounted Displays (HMDs). There are advantages and disadvantages to both solutions, and which is used will largely depend on the context of use. In this paper, we present an outdoor user evaluation of an alternative wearable AR device mounted on the forearm to allow hands free movement. Findings on the strengths and weaknesses of the system along with user recommendations were obtained, and serve as an indicator to its potential applicability for wider use, particularly in comparison with a hands free HMD solution.**

Keywords- augmented reality; wearable computing; HMD; user evaluation.

I. Introduction

Augmented Reality (AR) is a functionality becoming more prevalent as mobile devices grow in power, capabilities and features, allowing users to easily access information about their surroundings while 'on the go' [1]. Typically this involves information related to shops and restaurants, tourist information etc. Another application of AR is to assist professionals in their work; with potential uses including complex construction projects, emergency medicine, military and maintenance work amongst others [2]. There are different types of devices, including handheld systems and Head Mounted Displays (HMDs) that a professional could use to access augmented information on a display. Which system is used depends on a number of factors such as cost, when and where information needs to be accessed, whether hands-free interaction is required, or whether the user needs to multi-task.

HMDs are seen as offering a heads-up, hands-free experience, whereas handheld devices can be cheaper and more comfortable to carry. How an AR system affects a user's experience in the real world requires qualitative evaluation methods, but currently few studies have used this approach [3]. One such study by the authors [4] evaluated the user experience of a see-through monocular HMD AR system in an outdoor environment. A study of 8 participants found that there were visibility issues in being able to see information clearly on the display, while some users had issues with the comfort and situation awareness of the device caused by a loss of peripheral vision.

In this paper we propose an alternative wearable system that could offer some of the benefits of a HMD by allowing a mainly heads-up and hands-free experience, but like a handheld device is designed to be a low cost solution, be clearly visible outdoors, and allow for good situation awareness in an unfamiliar environment. We present a novel arm-mounted AR solution, and discuss a largely qualitative user evaluation study, utilizing a set of in-situ navigation and interaction tasks to gauge the device's potential in comparison to a HMD.

II. Related Work

There is little available research on wearable AR displays that do not involve HMDs. Research has examined wearing information displays on the arm that can interface with an AR system as a controlling input device [5], and there are wearable flexible information displays being designed for the U.S. military that can also be worn on the arm [6]. However, neither of these applications produces augmented imagery on the worn device itself. There are watch-like devices available that link to a smartphone via Bluetooth, watch phones with inbuilt video cameras and wrist worn devices that give haptic feedback to a user [7, 8] - though these solutions have no augmented video imagery and any displays are small.

Mobile AR has evolved from laptop computers attached to people's backs and connected to a HMD [9, 10] to smaller handheld devices that have been proposed as a suitable solution for professional use [11, 12]. One and two hand solutions for handheld AR have been tested with pros and cons for each. A two-handed solution is deemed steadier (especially for heavier devices) and can cause less fatigue over longer use periods - although a one-handed design allows a user to multitask and interact with other devices [13]. With the advent of touchscreen smartphones, the potential for mobile augmented reality systems has become even greater. Attention has mainly focused on using devices for navigation. In particular research has focused on how best to use the limited space available on a phone, creating interfaces that can facilitate pedestrian navigation, which unlike car navigation is much more exploratory [14]. Mobile applications must also take into account that whilst on the move people can only devote limited attention to a device [15].

Grasset et al. [16] give a good overview of exploratory and goal orientated navigation with AR. For large outdoor environments, presenting navigation information in context is important to help orientate users. Context can include an overview such as a map, with detail added to show the relative position of the user and intended points of interest. Studies have looked at how users can see both a contextual overview plus the detailed view of their immediate surroundings on a small display [17]. Zoomable interfaces have been examined by Alessandro et al. [18] that can smoothly zoom between a real world view and contextual information, and found this might be useful for on-screen browsing when exploring an area. McGookin et al. [14] switched between a map of where they were going, with an image of the location to avoid issues with highlighting a target through AR, due to GPS inaccuracies. They suggest that a combination of automatic and manual switching could be combined to help users navigate to a desired location.

Whilst navigating, places or objects out of the field of view (FOV) of the navigation device may need to be brought to the user's attention, with solutions such as directional arrows, compasses, 3D arrows, attention funnels and semi-transparent maps [16, 19, 20], and ground grids used to help users estimate viewed distances [22]. Burigat et al. [21] compared using distant marked arrows against scaled circles to indicate off screen objects. They found no significant difference for simple tasks, but suggested that when the cognitive load of the user was high the arrows might perform better. It is argued that users should not be overloaded with information, especially in situations where they may be stressed or required to maintain a level of situation awareness that some professionals may need (e.g. the military) [22].

III. SYSTEM DESCRIPTION

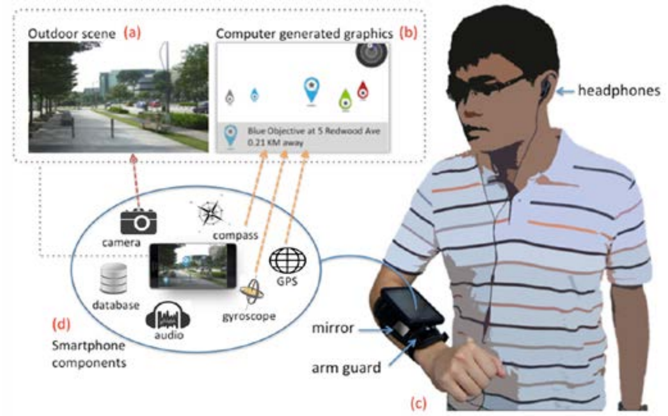

Figure 1. Set-up and system architecture.

Our proposed wearable AR system is shown in Fig. 1. This consists of a smartphone (1GHz CPU, 128MB GPU, and 512MB of RAM, running on Android 2.2), and worn on the forearm via a velcro strap positioned to a fixed arm guard. Due to the phone's inbuilt camera facing downwards, a juxtaposed mirror is attached to the guard to feed the forward facing view into the camera lens. As the view is a reflected image, software is used to 'flip' the video feed, allowing the user to see ahead of them when their arm is in a 'telling time' position (illustrated in Fig. 1c). An anti-glare filter is attached to the display to improve its visibility outdoors, while headphones are attached to the phone, and a single earphone worn by the user to hear incoming audio alerts in a noisy environment.

The smartphone has embedded GPS, a magnetic compass, 3D gyroscope, accelerometer and database storage capabilities (Fig. 1d). These afford the real-time computer-generated augmented graphics, rendered in response to the phone's current location and 3D orientation (Fig. 1a), by superimposing graphics on the incoming video feed from the phone's camera at 30 frames per second (Fig. 1b); thereby allowing the user to see an augmented view of the world around them with information overlaid directly on real-time objects.

Figure 2. The mobile user interface.

The user interface was designed to be similar to that used in a previous HMD study [4], so that differences due to the physical affordances of the systems were more apparent, though updated graphics and modalities were included. This meant keeping a minimal interface that did not clutter the screen, but concentrated on giving directions, distance and location information through graphics and text (Fig. 2). The UI consists of a top-down egocentric 2D rangefinder with a target objective icon denoted as a blinking dot, placed in a relative position and distance to the user. Objective icons are displayed in the augmented forward facing view, fixed geospatially to their intended location. At the bottom of the screen, textual information such as the location address and distance is also displayed to aid understanding. The objective's description and its corresponding GPS coordinates are stored in a database prior to the user study. During run-time, the system fetches this data together with the phone's GPS coordinates to compute the relative distance and angular displacement from the user to the objective (if the GPS signal is blocked this position is determined through inbuilt Wi-Fi triangulation). When within the vicinity of the objective, the user is notified through an audio alert, and a set of acknowledgement icons.

IV. USER STUDY

The aim of this study was to determine the general usability and acceptability of using an arm-mounted AR application in an outdoor environment. In particular we were interested in 1) posture, position and comfort, 2) information modality, 3) situation awareness, 4) reliability, and 5) navigation, as they were similar areas of interest in the HMD study [4]. 9 participants (M = 26.8 years, SD = 6.5 years) took part in the study. All were professional research staff with no previous experience of using AR technology. Each session was completed individually, over the duration of approximately 80 minutes. All participants were unfamiliar with the task route.

A. Tasks

Each participant completed a total of three generic tasks. The tasks were designed to ensure a number of user interactions occurred that a professional dealing with live information on the move might experience. These were navigating to a target location, receiving and acting upon live information updates, looking for and interacting with geospatial information, and the awareness of unexpected alerts.

Task 1: required each participant to navigate to an objective location using an *on-screen rangefinder* and *objective location icon* (Fig. 2). Text instructions were also given, e.g. approximate address and distance to objective. Once within range, the participant was audibly alerted and given an updated task requiring them to select an appropriate color matched 'acknowledgment icon' from a series of 3 icons, spatially positioned around the user's environment, requiring them to potentially look around 360 degrees. If correctly selected, a text box confirmed the task was complete.

Task 2: participants then navigated to a new location and again, directions were provided on screen. On approaching the location a visual and audible alert was activated to inform that the objective had been changed to a different location. The participant was then required to acknowledge the alert and follow a new set of directional prompts.

Task 3: upon approaching the final location, an alert informed the user they were nearby. Once at the location, they were required to select the appropriate matching icon by following the same procedure as the first task.

B. Procedure

Participants were initially briefed on the purpose of the research before being taken to the start location. They were then given 10 minutes to familiarize themselves with the equipment and UI by identifying and selecting an acknowledgment icon color, matched to a location icon. Participants were then verbally reminded of the overall tasks and were informed that they would receive regular information updates through the system. A member of the research team accompanied each participant for safety, while another member video-recorded the interaction. On completion, participants were then asked to fill in a short questionnaire based on an earlier HMD study [4]. The study concluded with a 20-minute semi-structured interview to allow participants to elaborate on their experiences. For analysis, video data was transcribed to summarize observational findings, while descriptive statistics were used to review the questionnaire data. The *Findings* section shows the mean scores relating to the questionnaire, ranging from 1 (strongly disagree) to 5 (strongly agree).

V. FINDINGS FROM THE FIELD

First impressions in using the mobile AR device reported it to be 'quite cool', 'fun' and 'unfamiliar'. In turn, perceptions of the usability of the device were positive (*I recovered from my mistakes quickly and easily*: M = 3.89, SD = .60; *It would be easy for me to become skillful at using the AR application:* M = 4.22, SD = .44). In more detail, a selected summary of the main findings is given below.

A. Posture, position and comfort

In terms of weight, most users reported that when walking with their arms at their side the device did not feel 'too heavy' to wear (M = 2.44, SD = .88). Some participants were conscious of a light pressure exerted from the arm guard, which was perceived to be more prominent the longer the device was worn. Variations were observed in the time the arm was raised to view the navigational screen. This could vary from a few seconds, to over a minute in duration, commonly comprising of holding the right arm at a 90-degree angle in front of the chest, and dipping the head downwards, while leaning over the device when standing still (Fig. 3). Both arm and head movements appeared as a single, synchronized action when viewing the display, as lowering the head imposed restrictions on a user's field of view. We identified little upper body rotation, however when users did turn to orientate themselves they tended to keep their arm in the same position. Moreover, adjusting the forearm in a 'telling time' motion was seen as somewhat unnatural: *"unlike a watch where you can view in any orientation… there is a fixed orientation to this device, in which you have to align it in such a manner, so that is restricting"*. Recognizing its novelty, the attachable arm-mount was perceived to require more effort to orientate to obtain navigational information than physically hold the smartphone by hand.

Figure 3. 'Telling time' pose – interacting with the AR device.

B. Information modality

Most participants were able to see the UI on the screen even in bright conditions, with the intuitive means of tilting the display to reduce reflective glare. Graphics overlaid on top of the video feed posed few difficulties in their readability (*There was too much visual clutter on-screen:* M = 1.67, SD = .50), with few learnability concerns (*I learned to use the AR application quickly*: M = 4.22, SD = .44). In comparison, the use of audio was perceived to be a beneficial navigational cue (*I knew straight away when an alert of status update occurred:* M = 4.11, SD =.33), with recommendations for the inclusion of basic voice commands for a more 'hands free' experience.

C. Situation awareness

An advantage to the HMD is that an arm-mounted device does not physically block a user's field of vision and so should be able to offer better situational awareness. However, when walking to a location we observed participants repetitively switch attention between the display and the environment. Over the duration of a task, this pattern of behavior could be repeated over 30 times. Noticeably, the closer to the location target, the longer participants tended to fixate on the screen to determine their location accuracy. This issue also related to a lack of trust in the system and/or apprehension in losing track of the on-screen target: "*at the beginning I trusted the system, but later I didn't…. at a certain stage I had to check the system like all the time"*. The resultant divided attention brought up some noticeable safety concerns. At least four participants failed to notice they were approaching a road junction, and had to be warned of the approaching traffic.

D. Reliability

A technical issue regarding GPS is that it only works outdoors with a clear line of sight to the sky. In many urban settings where walkways are covered or sheltered with trees, this will result in the system switching to less accurate Wi-Fi triangulation. The intermittent loss of a network signal was evident in a number of the sessions, causing some disorientation, by individuals slowing down or stopping, or physically waving their arm towards the sky to ascertain a signal. This clearly had an impact of the reliability and trust of the system with some participants, suggesting they required visual feedback in the form of a confidence level as to the accuracy of a given location.

E. Navigation

Assuming the GPS was working and updating regularly, participants were generally able to navigate to the objective location (*I found it straightforward to both navigate and concentrate on the task:* M = 3.89, SD = .60*; It was disorientating to look at the augmented view on screen*: M = 2.33, SD = .70). Participants used both the augmented navigation icon (as it was the largest graphic in the center of the display) and the rangefinder (as it gave both directional and distance information) at different stages of the tasks. Most users checked the distance information to determine if they were getting closer to the target location, while providing feedback to confirm that the system was still working. The address information was seen as useful if the user knew the area well, though for unfamiliar places, or places with few landmarks the rangefinder and target icon could be more beneficial, e.g. "*it's good for rural settings*". Users however struggled to use the rangefinder when close to a target, as the relative position of targets close to the user became harder to determine (given the rangefinder's scale was fixed). The exact position of the objective icon while fixed could also be difficult to understand: "*I won't know if it is pointing to the tower, the thing behind it or the thing in front of it. But if you could just illuminate just that tower and darken everything else, then I would know you are talking about that tower".*

An element missing from the UI used in this study was a 2D map overlay, which six participants suggested during the study would help them in their navigation tasks. Specifically, they felt this could help give better contextual location information, identify what lay between them and the target and so help them strategize how to get there. This was evident when situated at a junction, where having general direction created indecision: *"it's just that the way to get there is never stated"*, *"I felt tempted to just cross diagonally*". Consequently, in an urban environment, there was interest in wanting to know the quickest or shortest route to the target location and how to get there, e.g. 'cross using left pedestrian crossing'.

VI. Comparison To A Mobile HMD Display

The aim of examining an arm-worn AR device was to see if it offered an alternative hands-free experience to a HMD system (Fig. 4). We therefore compared these findings with that of a previous study, which used a very similar set of wayfinding tasks and questions [4]. This was done to identify any general differences between the HMD and arm-worn AR device that could warrant further investigation. Statistical comparisons on the clarity of the displays were avoided given the number of variations in the graphical design of the UIs, screen resolutions and input controls. Despite this, on average the arm-mounted display was rated higher for *good on-screen contrast* (mobile: M = 3.11, SD = .78, HMD: M = 2.00, SD = .75) and lower for *too much visual clutter on-screen* (mobile: M = 1.67, SD = .50, HMD: M = 3.87, SD = .83). Likewise, exploring the physical affordances of the two devices, the arm-worn display scored noticeably higher in *being comfortable to wear* than the HMD (mobile: M = 3.22, SD = .83, HMD: M = 1.88, SD = 1.12).

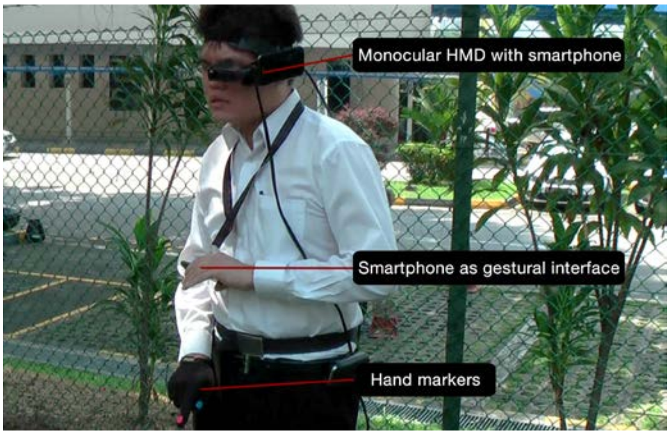

Figure 4. HMD linked to an attached smartphone for navigation and computational processing. Input is controlled via a second smartphone.

In more detail, an analysis of the video data was used to identify the general differences and pros and cons between the HMD and arm-mounted device. These findings are summarized in Table 1.

TABLE 1. COMPARISON BETWEEN HMD AND ARM-MOUNTED DEVICES.

	HMD	Arm-amounted
Comfort	Not regarded as heavy, no signs of eyestrain, but uncomfortable to wear after some time.	Not too heavy to wear. Maintaining arm posture to view the screen for long periods of time a likely strain.
Movement	Users in keeping heads-up approach tend to miss ground-based objects when walking.	Users kept a rather stiff arm posture, rather than swing freely.
Visibility/ Environment	Screen brightness not sufficient to see well outdoors.	UI visible on screen in bright conditions. User may tilt arm to reduce reflections.
Graphical Content	Distance sized augmented objects can become too small to recognize on a small screen.	No visual clutter. Graphics could be distinguished against a video background.
Navigation	Users capable of finding target locations. Proximity to target not always easy to determine.	If GPS is working, users capable of finding objective location, though with similar proximity issues to the HMD.
Situation Awareness	Loss of peripheral vision and divided attention.	Divided attention between the screen and the environment.
Input	Hand gestures triggered accidentally in outdoor environment.	No issues using the touch screen.
Reliability	In both cases GPS inaccuracies can result in a lack of trust in the system, resulting in more frequent system checking.	

VII. DISCUSSION

Posture, position and comfort: The arm-mounted device, whilst not heavy, had some levels of discomfort reported due to the way it was held. This was largely down to two reasons. Firstly due to the nature of the prototype, users perceived it to be more fragile and so were careful in how they used the device. Secondly there was a need to constantly check the interface to find out where they were going, partly due to not trusting the GPS and to check that the information was updating. Having a more robust looking prototype may help in it being used in the way envisaged, where the user can walk with arms moving freely and only occasionally looking at the device for navigation and information updates.

Information modality: The addition of sound alerts as well as the visible screen meant users were more likely to be aware of them. Users recommended that sound could also be used to aid with navigation commands so as not to require the need to look down at the device. Nevertheless, some users felt that having too many audible cues, especially within close proximity to a target may become an annoyance. This requires further investigation in how best to combine the different modalities, including haptic feedback with the arm-mounted device, given variable environmental considerations, e.g. background interference.

Situation awareness: It was expected that the arm-mounted device would afford better situation awareness, as unlike the HMD it did not block the users view. However, as users had to glance down to see information, this caused divided attention. Similar findings in the use of in-car navigation systems have shown that a ‘heads up, heads down’ action takes time and attention away from what should be looked at, and also involves the cognitive load in interpreting between real world and on-screen graphics [24]. In particular, the repetitive switching between an arm-mounted device and the real world will require effort in the mental rotation of information. A HMD on the other hand can maintain a heads up view of the real world at all times, but the design of current devices restricts the user’s field of vision with low luminance displays difficult to see [4].

Reliability: Improving the trust with regards to GPS might also reduce a need to constantly check the device. The consequences for GPS inaccuracies for pedestrian navigation are more impactful than car navigation, where cars can use speed and other information to help pinpoint their location. Burigat and Chittaro [24] studied a number of visualizations to help with GPS signal degradation in wayfinding, using time and orientation of the user to predict where they were going. They did not find that any visualization helped in navigating better, but that some may involve less cognitive workload.

Navigation: Users were able to find their way to target locations and could visually see the information displayed. A higher screen resolution means it is not surprising they found it easier to use than a HMD. Some users reported they would like a map on the interface to help them make better navigation decisions. Our system was designed not to be cluttered, indicating a balance is required between extra navigation aids and cognitive load. Therefore it is not as simple as saying adding a map will help. Navigational decision making takes place at nodes [16], and in our case a major decision point was at a crossroad. Contextual information could help in determining which side of a busy road to cross, and could be of great importance if a user eventually finds themselves on the wrong side, with difficulty crossing back. In addition, some users thought the radar and AR icons might be more useful in locations they were not so familiar with, and it has been suggested that these types of cues might be good for people who have difficulty in using maps [18]. Creating algorithms to filter different types of information or data modalities depending on the situation have been applied within military applications [22], and could be investigated further in the context of the arm worn system.

The factors discussed here along with other current mobile navigation findings need to be refined and tested further with our wearable system in specific test cases. Moreover, given the feasibility for unrestricted movement, something that gives information to related footpaths and other landmarks in an urban environment would be useful. For example, users felt that if a building were augmented (i.e. highlighted) then this would make it easier to determine the target location.

VIII. Conclusion And Future Work

From the present limitations described in this paper, we propose that a lighter more robust solution, with more reliable positional information is required to allow users to move naturally, and minimize the amount of time required to look at the screen. The versatility of movement however means that when a user walks with their arm at their side, the phone's inbuilt compass could give misleading information (as facing in a different plane), especially via audible cues when the user is not looking at the phone. That is, any information relayed to the user that requires knowing the direction they are facing cannot rely on the phone's compass alone, and appropriate solutions need to be considered to resolve this.

The generic nature of this study meant a few participants commented that they might prefer to just hold or wear the device around their neck on a lanyard. A more comfortable/discreet device may negate this preference somewhat, but the context of use is a key issue in its applicability, e.g. for professionals requiring hands-free interaction as part of their job or daily activities. Therefore, the authors recognize future studies will need a more context specific use case, and involve users trying different solutions. This could include a comparative study with a more conventional mobile phone, or even one where an AR device is worn or held up by the hand depending on circumstances. Findings can further determine the strengths and weakness of different approaches, whilst undertaking a real task that involves users needing to be aware of their surroundings and require the use of their hands. Further navigational aids will also need to be investigated taking into account the context of use, and in particular the cognitive load should be measured, as this could be a key differentiator in what solution works best for different professionals.

While we found marked differences between the HMD and arm-mounted devices, these findings are based on relatively short-term usage, as the work presented in this paper is still in an early development phase. We have presented a novel system that offers a different way of accessing augmented information, which initially appears to offer a comparable alternative solution. Additional research is now required to objectively evaluate an enhanced arm-mounted device with a larger sample size, over longer periods of use.

Acknowledgment

This research was partially funded by A*STAR SERC Human Factors Engineering TSRP Research Grant and Thales Solutions Asia Pte. Ltd.

References

[1] M. de Sá, J. Antin, D.A. Shamma and E. Churchill. Mobile augmented reality: Video prototyping. In Proc. CHI'11, 2011, pp. 1897-1902.

[2] T.H. Höllerer and S. Feiner. Mobile augmented reality. In Telegeoinformatics: Location-based computing and services. H Karimi and A. Hammad (Eds.). Taylor & Francis Books Ltd, 2004, pp. 221-260.

[3] A. Dünser and M. Billinghurst. Evaluating augmented reality systems. Handbook of Augmented Reality. F. Borko (Ed.). Springer, 2011, pp. 289-307.

[4] S.J. Kerr, M.D. Rice, Y. Teo, M. Wan, Y.L. Cheong, J. Ng, L. Ng-Thamrin, T. Thura-Myo and D. Wren. Wearable mobile augmented reality: Evaluating outdoor user. In Proc. VRCAI'11, 2011, pp. 209-216.

[5] S.J. Henderson and S. Feiner. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In Proc. ISMAR '09, 2009, pp. 135-144.

[6] R.R. Hoffman and L.R. Elliott. Using scenario-based envisioning to explore wearable flexible displays. Ergonomics in Design: The Quarterly of Human Factors Applications, vol 18: 4, 2010, pp. 4-8.

[7] LG 3G Watch Phone: http://www.lg.com/au/mobile-phones/all-lg-phones/LG-GD910.jsp

[8] J. Pasquero, S.J. Stobbe and N. Stonehouse. A haptic wristwatch for eyes-free interactions. In Proc. CHI'11, 2011, pp. 3257-3266.

[9] S. Feiner, B. MacIntyre, T. Hollerer and T. Webster. A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. In Proc. ISWC'97, 1997, pp. 74-81.

[10] W. Piekarski and B.H. Thomas. The tinmith system – Demonstrating new techniques for mobile augmented reality modelling. In Proc. AUIC'02, Australian Computer Society, 2002, pp. 61-70.

[11] S. White and S. Feiner. SiteLens situated visualization techniques for urban site visits. In Proc. of CHI'09, 2009, pp. 1117-1120.

[12] G. Schall, E. Mendez, E. Kruijff, E. Veas, S. Junghanns, B. Reitinger and D. Schmalstieg. Handheld augmented reality for underground infrastructure visualization. In Personal Ubiquitous Computing, vol 13, Springer Verlag (2009), pp. 281-291.

[13] E. Veas, and E. Kruijff. Handheld devices for mobile augmented reality. *In Proc. MUM'10*, 2010, article 3.

[14] D. McGookin, I. Herteleer and S. Brewster. Transparency in mobile navigation. In Proc. of CHI 2011, 2011, pp. 1903-1908.

[15] L. Chittaro. Designing Visual User Interfaces for mobile applications. In Proc. EICS'11, 2011, pp. 331-332.

[16] R. Grasset, A. Mulloni, M. Billinghurst and D. Schmalstieg. Navigation techniques in augmented and mixed reality: Crossing the virtuality continuum. Handbook of Augmented Reality. F. Borko (Ed.). Springer, 2011, pp. 379-407.

[17] L. Chittaro. Visualizing information on mobile devices. Computer vol 39, 3 (Mar), 2006, pp. 40-45.

[18] M. Alessandro, A. Dünser and D. Schmalstieg. Zooming interfaces for augmented reality browsers. In Proc. MobileHCI'10, 2010, pp. 161-169.

[19] F. Biocca, A. Tang, C. Owen and F. Xiao. Attention funnel: omnidirectional 3d cursor for mobile augmented reality platforms. In Proc. of CHI '06, 2006, pp. 1115-1122.

[20] V. Buchmann, M. Billinghurst and A. Cockburn. Directional Interfaces for Wearable Augmented Reality. In Proc. CHINZ'08, 2008, pp. 47-54.

[21] S. Burigat, L. Chittaro and S. Gabrielli. visualizing locations of off-screen objects on mobile devices: A comparative evaluation of three approaches. In Proc. MobileHCI'06, 2006, pp. 239-246.

[22] M. Livingston, L.J. Rosenblum, D.G. Brown, G.S. Schmidt, S.J. Julier, Y. Baillot, J.E. Swan II, Z. Ai and P. Maassel. Military applications of augmented reality. In Handbook of Augmented Reality. F. Borko (Ed.). Springer, 2011, pp. 671-705.

[23] Z. Medinica, A.L. Kun, T. Paek and O. Palinko. Augmented reality vs. street views: A driving simulator study comparing two emerging navigation aids. In Proc. MobileHCI'11, 2011, pp. 265-274.

[24] S. Burigat. and L. Chittaro. Pedestrian navigation with degraded GPS signal: Investigating the effects of visualizing position uncertainty. In Proc. MobileHCI'11, 2011, pp. 221-230.