Wearable Mobile Augmented Reality: Evaluating Outdoor User Experience

Steven J Kerr, Mark D Rice, Yinquan Teo, Marcus Wan, Yian Ling Cheong, Jamie Ng
Institute for Infocomm Research, A*STAR[†]
Lillian Ng-Thamrin[‡], Thant Thura-Myo[‡], Dominic Wren[§]
Thales Solutions Asia Pte. Ltd

Abstract

Augmented Reality (AR) technologies offer the potential to aid users in a number of professional areas. However, to date, most studies have been tested in controlled laboratory conditions. This paper outlines a user experience study of a wearable mobile augmented reality system in an outdoor urban environment. We describe the use case of using a see-through monocular head-mounted display (HMD) with augmented imagery for orientation, and the use of gesture input for interacting with information while on-the-move. Participants had to navigate to a target location, whilst receiving information updates, and complete a series of gesture-based tasks. Despite participants managing to complete the tasks after some assistance, it was found that more improvements to the user experience are required for it to be viable in outdoor-use. In particular, better visibility, when see-through HMDs are used in a bright environment, and improved situation awareness. This paper further highlights the difficulties in using gesture input, and points to a number of areas requiring further research into the use of wearable mobile AR systems in the context of this work.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – Artificial, augmented, and virtual realities H.1.2 [Models and Principles]: User/Machine Systems – Human Factors.

Keywords: augmented reality, usability, user experience, field study, see-through monocular HMD.

1 Introduction

Computer-generated Augmented Reality (AR) technologies have improved immensely in recent years, and have been described as being on the verge of adoption to *"enhance our perception and help us see, hear, and feel our environments in new and enriched ways"* [van Krevelen and Poelman, p.1]. A number of professional fields where AR could be beneficial include large complex construction projects, emergency medicine, search and rescue, tourism, military, geographic fieldwork and maintenance work in large scale environments e.g. oil refineries [Höllerer and Feiner 2004; Träskback and Haller 2004; Phan and Choo 2010]. In particular HMDs with AR afford the advantage of providing real-time navigation and information updates as well as alerts in a 'heads up' and 'hands free' manner.

Nevertheless, despite their potential, up to now a significant amount of research carried out on AR systems has centered on the technology itself, often tested under artificial conditions by examining a narrow range of behavior. Whilst user evaluations have increased over time, they are recognized as not being a common practice in this area [Dünser et al. 2008]. As such, there remains an absence of understanding of human-computer interfaces and associated user requirements within real-world use.

In this paper, we describe a user study of a wearable AR system using a monocular see-through Head Mounted Display (HMD) in a real-world environment using hand gesture input to gain insights into how the environment affects the user experience. We propose a number of limitations and factors contributing to the usability and user acceptance of the system, and prescribe areas that need to be further addressed. In Section 2, we illustrate relevant research. We then move on to describe our system architecture in Section 3. Section 4 discusses the tasks and procedure. Sections 5 and 6 present the results and discussion, while Sections 7 draws on the conclusions and future directions of this work.

Figure 1. In situ - the HMD system in action.

2 HMDs in the Field

Accessing information on-the-go in a hands-free, heads-up manner is a major draw to the use of HMDs. Nevertheless, in orientating to a specific destination, wayfinding tasks can be affected by the accuracy of detecting a user's location and how such navigational

[†]e-mail: {sjkerr; mdrice; yqteo; tsmwan; ylcheong; jamie}@i2r.a-star.edu.sg
[‡]e-mail: {lillian.ng; thuramyo.thant}@asia.thalesgroup.com
[§]e-mail: domwren@gmail.com

VRCAI 2011, Hong Kong, China, December 11 – 12, 2011.
© 2011 ACM 978-1-4503-1060-4/11/0012 $10.00

information is presented to them. Goldiez et al. [2007] found that using AR and HMD displays improve traversal accuracy, but increase the performance time due to divided attention on following directional instructions. Examples of aided directions can be egocentric maps or steering arrows in three-dimensional space [Hicks et al. 2003], including near field target arrows in military vehicle maintenance [Henderson and Feiner 2009]. Information in an AR display can also add new, or reveal hidden objects, as well as present 2D overlays of navigational information not integral to the scene [Livingston and Ai 2008]. However, presenting this information in an effective manner is a major challenge, given few established user interface guidelines are available for AR systems [Gabbard and Swan 2008].

An attribute of the human visual system that can impact how information is viewed is *accommodation*. Accommodation refers to the focal action of the eye, whereby the lens adjusts to see objects at different depths [Liu et al. 2010]. Accommodation is an issue in current HMD technology, as information is effectively perceived at one constant distance from the user. New technology, in the form of retinal scanning displays, use a laser to generate pixels directly onto the eye, allowing for the visualization of AR objects at different depths. However, at the present time, this is likely to be in monochrome, and therefore is not suitable for displaying color rich information [van Krevelen and Poelman 2010]. Liu et al. [2010] created a see-through display that, like the lens in an eye, could adjust the focal plane to see objects at different depths. Whilst this was successful in showing that the eyes could accommodate at the same depth for both real and augmented objects, the system involved a manual process of adjusting the lens with no immediate solution for auto-adjustment. Therefore, there is a tendency for the need to switch focus between the information being displayed on the AR view and the real-world view. For example, Huckauf et al. [2010] found that switching attention between AR graphics and the real-world scene resulted in additional 10% attention load under lab conditions, and hypothesized that the real-world cost in switching would be much larger.

For outdoor use, a main issue for visual clarity is being able to see the graphics in daylight. In an outdoor experiment, Peterson et al. [2008] found that augmented elements have to be 10-15% brighter than the background to be visible on their stereoscopic display. Text or icon colors could also appear altered or washed out [Pingel and Clarke 2005]. This could render user interface design choices counterproductive, especially in domains where color encoding is critical. Red for instance may become de-saturated against a white background, while if a color shifts hue, it can result in an entirely different color being perceived e.g. yellow shifting to green [Gabbard et al. 2010]. Seeing graphics and their colors clearly will also depend on the background. Gabbard and Swan [2008] argued that there are often cases where the color and brightness of a real-world background could visually conflict with graphical user interface elements, resulting in poor or nearly impossible legibility. Experimentally, they identified that information presented on plain backdrops, such as a concrete wall, was easier to see than visually 'busy' backdrops such as a brick wall. Leykin and Tuceryan [2004] looked at determining the readability of text depending on the background and Tanaka et al. [2008] tried to solve this problem by evaluating the user's view and determining the best place to display information or direct the user to look elsewhere for a suitable place. However this goes against a basic user interface principle of design consistency, and the assumption that the user would be static and only looking at a plain background, which is unlikely in a real-world context.

2.1 Gestural interaction

In the context of this study, the use of gesture with wearable mobile AR interaction in an outdoor environment is still somewhat untested. However, there are numerous studies of input devices for AR systems including a wearable on-the-wrist smartphone [Henderson and Feiner 2009], handheld devices, e.g. the Wii mote [Caruso and Re 2010; Hoffman et al. 2010], eye tracking [Nilsson 2007] and gesture recognition [Buchmann et al. 2004; White et al. 2007; Lee et al. 2008]. Which is more appropriate depends on the main use case of the technology and the task at hand. Yet, while many of these studies were found to be effective they were usually tested in carefully controlled conditions. Studies looking at improving the robustness of hand recognition in the field recognize the complexity of interacting in a cluttered environment [Choi et al. 2009; Mizuchi et al. 2010]. As such, whether gestures can be used effectively in an outdoor environment still remains an important question.

3 System Architecture

Our proposed wearable system consists of a monocular see-through HMD, with graphics and information being provided through an attachable smartphone (see Figure 1). The color display of the HMD has a resolution of 800x600 pixels and a luminance value of 400 cd/m². The HMD is worn on the head via a head support consisting of a headband and cheek guard. Input control on the smartphone is provided through a secondary smartphone linked via Bluetooth, and worn on a lanyard round the participant's neck, using hand gesture detection techniques as described below. The smartphones used have a computing power of 1GHz CPU, 128MB GPU, and 512MB of RAM, running on Android 2.2. Advantageously, a smartphone was used instead of a conventional laptop as: 1) it is lighter and offers greater mobility; 2) has GPS to determine geolocation; and, 3) includes a magnetometer with accelerometer to determine the orientation of a user's head.

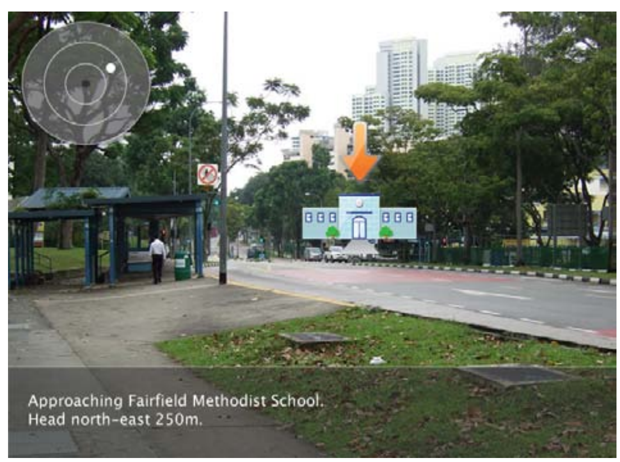

Figure 2. HMD user interface.

For the user interface (UI), the user sees a top-down egocentric 2D rangefinder on the top left of the screen (see Figure 2) with target location denoted as a white dot placed in a relative position and distance to the user. An objective target icon (e.g. a school building graphic) is displayed in the user's horizontal field of view. The size of the icon is inversely proportionate to the distance between the user and the destined location. Distances are calculated using real-time location data obtained from the GPS of the smartphone.

As we wanted a largely heads-up and hands free experience, we opted to use gesture for user interface The hand gestures implemented use a black glove with colored markers instead of skin tone, as outdoor light illumination on the skin can cause the system to invoke 'false positives'.

For our application, the user can initiate three control features relating to the displayed icons on the HMD without having to look down. These are *showing details*, *activation* and *hiding details*. Tracking the red marker on the hand shows a cursor positioned relative to the HMD interface. To keep the interaction simple, using this cursor as feedback, the user is able to select different icons by hovering the red marker over a particular icon, subsequently showing specific information associated with that icon. *Icon activation* is initiated by detecting both the red and blue markers, while *closing information* is achieved by detecting the red and green markers (see Figure 3).

Figure 3. Gesture commands. (*Left*), icon activation; (*right*), information closing.

4 Study Methodology

The aim of this study is to determine the general usability and acceptability of using a wearable AR application (described in section 3) in an outdoor urban environment. Given the dynamic range of real-world situations, our intention was to limit the range of functionality to identify key usability issues encountered in using our HMD system outdoors. In particular, to use this pilot work as an opportunity to identify the user requirements for a more refined phase of software development work.

In the present sample, 8 participants (mean age of 24.7 years, S.D. 3.1 years) took part in the study. All were professional research staff with no previous experience in using HMD or AR technology. Each session was completed individually, over the duration of 80-90 minutes. For logistical reasons the study was set within a 2 kilometers radius of the research institute (Figure 4).

4.1 Tasks

Each participant was asked to complete a total of three tasks to utilize the fundamental benefits of an HMD – i.e. heads up navigation, including the receiving of geospatial information and live information updates whilst on the move. These tasks were quite generic in their application to determine the feasibility of using a HMD for a set of navigational procedures.

In summary, the first task required the participant to orientate their position using the location icon and an on-screen radar (Figure 2) to a target location (initial HMD information displayed: *"Head towards [address] – Distance to location 800m*"). As they approached the location they received a series of visual updates on the HMD, e.g. position on radar updating, location icon getting larger, distance to location updates. Once in proximity, using the gesture controls, the participant was then required to select an appropriately colored *'acknowledgment icon'*. This was positioned anywhere within a 20-meter radius of the target location. Once correctly selected, a text box confirmed the task was complete.

Following on, for the second task participants were asked to orientate to a new location (*"Now head West 300 meters to [address]"*) and again, directions were provided on screen. However, to test for awareness of real-time updates, on approaching the location participants were given an alternative task (*"Previous objective cancelled, new objective at [address], please respond. Head South"*). Through further direction prompts, to complete the third task, participants were required to follow the same procedure as the first task.

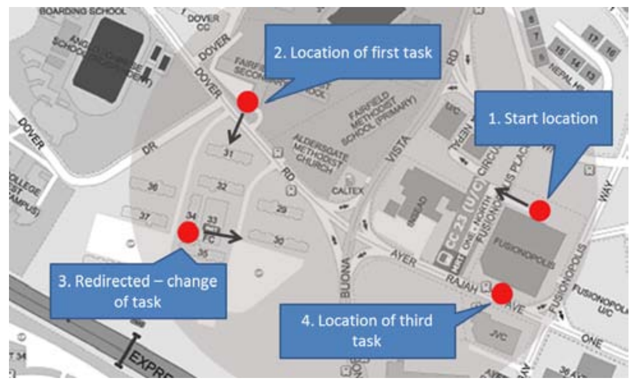

Figure 4. The location of tasks.

4.2 Procedure

Participants were briefed on the purpose of the research. After giving informed consent, they were then taken to the start location of the wayfinding tasks. To limit any learning bias they were given 5 to 10 minutes to practice using the equipment. For the pre-task test, this included identifying a set of icons on the display using the gesture interface. This was done to familiarize them in using the system. Participants were then verbally reminded of their role in the tasks and were informed that they would be regularly updated with additional information from the system. For personal safety, a member of the research team accompanied each participant. An additional member video-recorded each session using a portable digital camera.

On completion, in returning to the research institute, the participants were then asked to fill in a questionnaire and individually rate (1 = not at all important; 5 = very important) the importance of 14 questions (see Table 1). Each session then concluded with a 20-minutes semi-structured group interview, to allow participants to elaborate on their experiences, and for the facilitator to probe further into aspects of their interaction. Finally, participants were debriefed on the study. To assist in this analysis, we transcribed the video data to summarize the observational findings. For the questionnaire data, given our small sample size, descriptive statistics were used to determine differences in the mean scores.

5 Results

In wearing the HMD for less than 45 minutes, all participants completed the tasks with various degrees of success. Whilst they saw the integrated system as novel and a 'cool technology', their experiences highlighted difficulties in using such devices. In particular, at times we found that participants could contradict themselves. This included reports of finding the tasks easy to perform, despite, for example, complaining of not being able to read the on-screen text. Moreover, we found noticeable variations in the questionnaire results (all questions were appropriately answered) compared to the observational findings.

As documented in Table 1, in terms of looking at the *Physical Devices* (PD) while participants' rated the comfort of the head-mounted display relatively low (Ques.1), the associated equipment was not reported as being heavy to carry (Ques. 2). As described in section 5.5, this was a surprising result given the associated problems of physical discomfort with the HMD setup. Similarly for the *Hand Gesture* (HG), there is conflicting evidence of the gestures being too complicated for the tasks (Ques.7), despite higher ratings of 'intuitiveness' (Ques.9). Encouragingly the mean scores of the *Graphical User Interface* (GUI) questions support the observation findings of poor on-screen visibility (see Sections 5.1 and 5.2), however we find the generalized answers in the *Usability* (U) questions a somewhat poor reflection of the observational results (in particular Ques. 11 & 12).

PD	1. The head-mounted display was comfortable to wear	1.88 (1.12)
	2. The equipment was heavy to carry	2.13 (.64)
	3. The head-mounted display was tiring to use	1.50 (.75)
GUI	4. There was too much visual clutter on-screen	3.87 (.83)
	5. I was able to clearly focus on the on-screen information whilst looking at the real world	1.88 (.83)
	6. There was good on-screen contrast	2.00 (.75)
HG	7. The hand gestures were too complicated for the tasks	4.25 (.70)
	8. The response time of the gestures was slow	2.88 (1.35)
	9. The hand gestures felt intuitive to use	3.38 (.74)
U	10. It would be easy for me to become skillful at using the AR application	4.00 (.75)
	11. I learned to use the AR application quickly	3.75 (.88)
	12. I recovered from my mistakes quickly and easily	3.38 (1.06)
	13. Using the AR application was effortless	2.75 (1.38)
	14. I found the AR application to be flexible to interact with	3.25 (.70)

Table 1. Mean scores of questionnaire results with standard deviations in parentheses.

Across the observations, we found more consistent patterns of behavior. To illustrate, a selected summary is given of our main findings.

5.1 External environment

A significant issue in the study was the inability of participants to see the display clearly outdoors. This effect was often worse in bright sunlight and later in the day when the sun was lower in the sky. The implications of this meant that graphical content would appear faint or washed out as the following comments reiterated:

> *"It actually washes out the details of the icon, so I can only see the outline."* (P2)

> *"The display is meant to be translucent… because of that, when strong light comes in it's almost impossible to see the display clearly."*(P4)

Furthermore, it was identified that the manual adjustment of the brightness of the HMD had little effect on improving the situation. The observations identified participants employed a number of similar strategies to improve the display's visual clarity. These included waiting until they were in the shade to look at dark surfaces nearby, or more consistently placing a hand over the left eyepiece when walking, and/or closing with their right eye to block out sunlight (see Figure 5). In particular, holding the hand over the eyepiece could last for up to 30 seconds at a time, somewhat diminishing the 'hands-free' attribute of an HMD. The closing of the right eye was also thought to help cut-out conflicting views. Consequently, the inability to see the display clearly affected the task performance, with participants repeatedly adopting a strategy of only occasionally looking for the navigational icon to check that they were going in the right direction, and pausing to cover the eyepiece to see if any information had been updated. This meant that participants commonly missed incoming 'visual' alerts in the AR view.

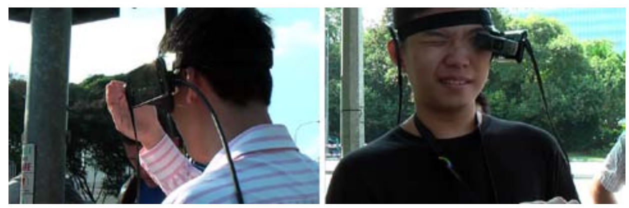

Figure 5. Common visual problems. Shielding display and shutting or squinting of right eye.

5.2 Understanding of the graphical content

Icons (especially larger ones) were recognizable when they suddenly appeared or disappeared directly in a participant's field of view, e.g. an acknowledgment icon appearing when the participant arrived at the objective. Indeed, in a few instances, these were the only UI features visible in the external environment. However, not all the participants noticed the transitory changes in icon sizes, which were designed to change relative to their location (with one person assuming the smaller icons were some sort of 'bubbles'). In addition, participants mostly used icons over the radar to navigate, even though the radar was designed to give a better indication of how close the user was to their target. This was partially because the graphical changes in the radar were too subtle to be adequately perceived. However, it is not clear if the participants prefer the radar to be as visible as the graphical icons, or if there is a need for a 360 degree view of multiple locations. Moreover, as previously reported, given the problems of visual clarity outdoors, many of the participants also described great difficulties in reading the on-screen text. This became a problem even when the eyepiece was physically shielded. As a consequence, there was a heavier reliance on the use of graphical content (namely icons) to direct participants in the tasks.

5.3 Situation awareness and orientation

A supposed benefit of monocular HMDs is that they offer better situational awareness. However, in our test, the majority of participants reported having a significant loss of peripheral vision on their left side, to the extent that they often failed to notice oncoming traffic or red lights when approaching a pedestrian crossing. This was less of an issue at busy crosswalks, but heightened as a noticeable problem at smaller intersections where oncoming traffic was less obvious to see. Although it is difficult to determine if this is a significant deviation in participants' normal wayfinding behavior without the HMD, it clearly has significant safety implications for anyone wearing such a device and walking around in a busy urban environment. Positively, a few participants reported a heightened awareness of their surroundings, particularly with street traffic; however, given the loss of peripheral vision, it also seems that more significant effort was required to stay aware of the surrounding environment and associated obstacles. In particular, there appeared to be noticeable discrepancies between what they perceived they could accomplish, compared to the documented mistakes observed by the researchers.

> *"This HMD is blocking my peripheral vision. So I've got to turn all the way back to actually see where the car is. Actually realized I'm turning at an awkward angle."* (P2)

The observers did not see significant effect of the HMD on the participant's ability to walk normally, although some subjects felt they were walking in a *zigzag* fashion (described as 'focusing too much on the left eye'). However, because of the requirement to maintain icons in the field of view, there was a need to keep their head up to maintain navigational focus, resulting in a number of participants failing to notice slight gradient changes or obstacles at their feet. Failing to be fully aware of their surroundings could also be attributed to divided attention, as participants were sometimes too focused on the task at hand, in shifting between visual elements on the screen and the outside world. Indeed, many of the participants reported a selective use of the display, only viewing it intermittently when it was perceived needed.

> *"You tend not to look up and down. You tend to keep your eye at the level. If you turn round the weight will change… so I think I will be less aware of things above and below me."* (P2)

> *"Not possible to pay attention to your surroundings when looking at information on the screen."* (P4)

Although in some cases it was found to be engaging, comments were further raised that information presented in kilometers was not always a practical measurement of distance, and therefore proximity to the location could be difficult to determine. Suggestions in this regard include a *progress bar* to prompt the distance to the target. Other suggestions include increasing the frequency of on-screen prompts, or separating the radar into two types of information: 'where to go' and 'where I am'. In each case, this indicated a misunderstanding of the egocentric viewpoint displayed in the radar.

> *"Let's say you are given one kilometer. Sometimes it is very hard to judge how far you are walking, cause sometimes you are not walking straight, you're walking sideways, turning here and there. So sometimes you might lose your distance."* (P6)

5.4 Gesture interaction

Whilst participants appeared to remember and perform the right gesture accurately, there were a number of technical issues that made the experience temperamental and difficult. During the testing, the gesture recognition camera had to be faced towards the participant (shielding the lens) so as not to be accidentally triggered by colored areas similar to those used on the glove markers. This meant that to interact with the device, the camera had to ideally face a plain colored surface (i.e. not large red, green or blue colored areas), which usually meant positioning the camera to face the ground. Thus participants tended to hold the camera with one hand, whilst using the glove hand to interact with the device, somewhat negating the original purpose of a 'hands free' experience. Furthermore, there was no option to then shield the eyepiece from bright sunlight.

> *"I can't really see the icon and cursor…. one hand I need to grab the camera, and the other hand is for my finger gesture. Then I don't have a third hand to cover the HMD display, so I think I fumbled quite a bit."* (P2)

Moreover, if the cursor did not appear straight away, then there was often an awkward attempt to see if the hand was in alignment with the camera, rather than looking at the HMD display (at times temporarily losing sight of the graphical cursor). Difficulties judging the physical orientation of the hand to the camera highlighted problems of accurately positioning color markers within the camera's field of view. Indeed, accidently revealing the thumb whilst pointing the index finger meant the system could wrongly infer the command for 'activation' rather than 'selection' (see Figure 3). In terms of accuracy, participants reported a lag in the system, namely because they failed to realize interaction events were not being accurately captured. Despite these limitations, the cursor size, coloring or speed was not deemed to be an issue in selecting on-screen objects.

5.5 Physical equipment

Seven participants rated the HMD (including the attached smartphone) to be uncomfortable at the end of the task, and some complained of discomfort after about 10 minutes of usage. A few individuals also complained of mild headaches after prolong usage, indicating a discomfort in the tightness and fitting of the HMD head strap, with half of the participants feeling mildly dizzy after completing all tasks. The longest any participant wore the headset was about 45 minutes, indicating that further long-term research is required. One suggested solution would be to have the eyepiece fitted onto a helmet, which could make the headset easier to setup, and better distribute the weight of the smartphone device.

Not many participants complained of eyestrain during the test, however there was a general reluctance to wear the equipment beyond the study, as individuals were largely self-conscious of using the HMD outside. For those people who wore glasses, some participants found the lenses would steam up if positioned too close to the eyepiece. In addition, the position of the HMD meant some of the participants were conscious of seeing a 'black frame' (i.e. rim of the display) in their peripheral vision, described as being an annoyance more than a physical obstruction. This was mainly because the eyepiece was forced to be a little further away from the eye due to wearing glasses, making the display appear smaller, and therefore more difficult to see the on-screen information.

> *"It's not really affecting my ability. It's something that there you have to cautiously overcome."* (P2)

5.6 Setting up the system

Each participant required having the system setup at the beginning of the tasks. The HMD was positioned to feel comfortable, but close enough to their eye for information to be clearly visible. The smartphone had to be positioned so that geospatial information was accurately matched to the tilt or angle of a person's head. Add on to this, the cables and battery pack being fitted and linked to the HMD, the setup took several minutes to complete. Clearly minimizing the time and effort for putting on a wearable AR device would be desirable.

6. Discussion

The most important issue by far in the test was the inability of participants to see the display clearly outdoors. Although it was possible to adjust the brightness of the HMD, there was no convenient setting provided. Even if the display brightness could be set appropriately, constantly adjusting the settings manually to varying light levels e.g. shade to light, indoors to out, would not be very feasible. The color display used has a luminance of 400cd/m², which requires competing with daylight conditions, which can range from 1000cd/m² (dark and cloudy) to well above 35,000cd/m² (bright cloudy). Luminance can reach 5500cd/m² using a monochrome display of green, but whether this would improve the usability for the tasks set is yet to be tested. It is hoped that new generation HMDs coming to the market will have higher luminance displays. For outdoor visibility, a luminance value of about 3500 cd/m² (possible in current high end military systems) combined with a dark filter which can reduce daylight brightness seven times are recommended [Harding et al. 2006]. Situation awareness should be a selling point of a monocular see-through HMD, although in our study it was clearly an issue from a safety point of view and suggests there is still room for improvements.

Whilst all participants encountered difficulty using the HMD display being tested in a bright outdoor environment, some graphical elements were more visible than others. Navigation icons were easier to see than the radar or on-screen text, and therefore were used and trusted more often. In addition, more attention needs to be given to the design of the interface e.g. text size, icons, color-coding and appropriate feedback on task status, with an intelligent balance between enough information to perform the task successfully whilst avoiding visual clutter.

Sound modality was not used in our system, which could be added for additional feedback or alert purposes, particularly in situations where visual information is missed. Indeed, the use of auditory prompts may help draw attention to situations when users are intentionally looking through the display to concentrate on a wayfinding task. Similarly consideration needs to be given to the appropriate means for users to reply to information they receive (e.g. text or speech input), for a more complete application.

A multimodal system should help in giving the participant more opportunities to acknowledge and receive information. Participants also requested for clearer and more visible instructions. When elements such as icons or text appear small in the display, care must be taken so that users do not misinterpret what they see. Whilst it is anticipated that professionals would learn to distinguish icon sets after frequent use, they should still be noticeably and easily distinguishable as there is a limit to how small they can appear within the screen resolution.

Not only must information be visible, it must appear reliable and current. In our use-case, participants need to have the confidence that the direction and distance information is most up-to-date. Whilst it is appreciated that obtaining GPS or other location data could involve some lag in the system, the effects of this should be minimized as far as possible.

If gestures are to be used as a form of input, then a more robust system is required to avoid alignment and accidental activation problems. Design solutions will also be needed to allow users to interact with information in either a heads-up or heads-down manner, depending on situational needs. Participants stated they had wanted to be able to see where their finger was pointing through the HMD display. This was the initial design intention, though problems of deploying a camera solution at eye level that could be aligned properly with the participant's hand (and not be accidentally activated) meant we had to use a temporary solution.

A redesigned system must also be comfortable to wear and quick to setup. Users were quite conscious of wearing the HMD, but thought it could be designed to be potentially less 'obvious'. Extended use of the system will also need to be investigated for visual fatigue issues as well as to determine how long our proposed smartphone solution can last in terms of battery life, or to understand how this can be prolonged.

7. Conclusions and Future Work

In this paper we describe a number of usability and acceptability issues of wearable mobile AR devices for a set of wayfinding tasks. This study was an initial investigation into the practical issues faced in real-world conditions when wearable mobile AR devices are used. There are limitations to our work given the nature of this pilot study. The tasks were fairly limited as we intentionally kept them generic so as not to be related to any one field of use, concentrating instead on the general usability of the system outdoors. Other limitations were that participants only had a brief amount of time to try out the system during the testing setup, and we used a relatively small sample size. For future studies, we plan to give more extensive training to the subjects to learn all the interactive features and processes prior to the evaluation. This would more accurately reflect the situation of professional use and reduce the effects of any learning bias. Other plans include increasing the sample size, introducing experimental control measures to empirically test specific AR system elements (again in a naturalistic setting), as well as determining performance issues under different lighting conditions, such as between day and night time use.

Future research should also involve professionals using such a system in a work context. This could lead to assessing when an HMD AR system is most suitable, and in what kind of use cases. Currently there are some technical constraints, which have a negative impact on the overall user experience, and so ways of resolving these issues will need to be addressed. Answers to these problems could lie in newer upcoming technologies, or could be entirely different solutions. One such question would be to determine the appropriateness of using a HMD AR system, compared to a mobile handheld device (e.g. a video camera smartphone). Other evaluations include the effect of monocular wearable HMDs that could be flicked away when not in use, stereoscopic see-through HMDS, or more adaptable positioning of gesture controls that are not directed around the head. Ultimately, the requirements and evaluation for understanding such features should be of key importance to the AR community.

Acknowledgments

This research was funded by A*STAR Science and Engineering Research Council (SERC) Human Factors Engineering (HFE) TSRP Research Grant and Thales Solutions Asia Pte. Ltd.

References

BUCHMANN, V., VIOLICH, S., BILLINGHURST, M., AND COCKBURN, A. 2004. FingARtips - Gesture based direct manipulation in augmented reality. In *Proc. Computer Graphics and Interactive Techniques*, Australasia and S.E. Asia, 212-221.

CARUSO, G., AND RE, G. M. 2010. AR-Mote: A wireless device for augmented reality environment. In *IEEE Symposium on 3D User Interfaces*, 99-102.

CHOI, J., SEO, B. K. AND PARK, J. I. 2009. Robust hand detection for augmented reality interface. In *Proc. Virtual Reality Continuum and Its Applications in Industry (VRCAI 2009),* 319-322.

DÜNSER, A., GRASSET, R., AND BILLINGHURST, M. 2008. A survey of evaluation techniques used in augmented reality studies. In *Proc. SIGGRAPH Asia'08* Courses, article 5.

GABBARD, J. L., AND SWAN II, J. E. 2008. Usability engineering for augmented reality: employing user-based studies to inform design. In *IEEE Transactions on Visualization and Computer Graphics 14*, 3, 513-525.

GABBARD, J. L., ZEDLITZ, J., SWAN II, J. E., AND WINCHESTER III, W. W. 2010. More than meets the eye: an engineering study to empirically examine the blending of real and virtual colour spaces. In *Proc. IEEE Virtual Reality'10*, 79-86.

GOLDIEZ, B. F., AHMAD, A. M., AND HANCOCK, P. A. 2007. Effects of augmented reality display settings on human wayfinding performance. In *IEEE Transactions on Systems, Man and Cybernetics, part C: Applications and Reviews 37*, 5 (September) 839-845.

HARDING, T.H., MARTIN, J.S. AND RASH, C.E. 2006. Performance Effects of Mounting a Head Mounted Display on the ANVIS mount of the HGU-56P Helmet, Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. *USAARL Technical Report 2006-13*.

HENDERSON, S. J., AND FEINER, S. 2009. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In *Proc. IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2009*, 135-144.

HICKS, J. D., FLANAGAN, R. A., PETROV. P. V., AND STOYEN, A. D. 2003. EYEKON: Augmented reality for battlefield soldiers. In *Proc. 27th Annual NASA Goddard/IEEE SW Engineering*, 156-163.

HOFFMAN, M., VARCHOLIK, P., AND LAVIOLA JR, J. J. 2010. Breaking the status quo: improving 3D gesture recognition with spatially convenient input devices. In *Proc. IEEE Virtual Reality'10*, 59-66.

HÖLLERER, T. H. AND FEINER, S. 2004. Mobile Augmented Reality, In *Telegeoinformatics: Location-Based Computing and Services*. H Karimi and A. Hammad (eds.). Taylor & Francis Books Ltd.

HUCKAUF, A., URBINA, M. H., BÖCKELMANN, I., SCHEGA, L., MECKE, R., GRUBERT, J., DOIL, F., AND TÜMLER, J. 2010. Perceptual issues in optical-see-through displays. In *Proc. ACM Symposium on Applied Perception in Graphics and Visualization (APGV'10)*, 41-48.

LEE, M., GREEN, R., AND BILLINGHURST, M. 2008. 3D natural hand interaction for AR applications. *Image and Vision Computing New Zealand*, 1-6.

LEYKIN, A. AND TUCERYAN, M. 2004. Determining text readability over textured backgrounds in augmented reality systems. In *Proc. International Conference on Virtual Reality Continuum and Its Applications (VRCAI 2004),* 436-439.

LIU, S., HUA, H., AND CHENG, D. 2010. A novel prototype for an optical see-through head-mounted display with addressable focus cues. *IEEE Transactions on Visualization and Computer Graphics 16*, 3 (May/June) 381-393.

LIVINGSTON, M. A., AND AI. Z. 2008. The effect of registration error on tracking distant augmented objects. In *Proc. IEEE International Symposium on Mixed and Augmented Reality (ISMAR'08)*, 77-86.

MACIEJEWSKI, R., KIM, S. Y., KING-SMITH, D., OSTMO, K., KLOSTERMAN, N., MIKKILINENI, A. K., EBERT, D. S., DELP, E. J., AND COLLINS. T. F. 2008. Situational awareness and visual analytics for emergency response and training, technologies for homeland security. In *IEEE Conference on Technologies for Homeland Security*, 252-256.

MIZUCHI, Y., KAWAI, H., HAGIWARA, Y., IMAMURA, H., AND CHOI, Y. 2010. Estimation for a hand position and orientation robust to motion of fingers using a web camera. *International Conference on Control, Automation and Systems 2010*, 187-190.

NILSSON, S. 2007. Interaction without gesture or speech – a gaze controlled AR system. *17th International Conference on Artificial Reality and Telexistence*, 280-281.

PETERSON, S. D., AXHOLT, M., AND ELLIS, S. R. 2008. Label segregation by remapping stereoscopic depth in far-field augmented reality. In *Proc. IEEE International Symposium on Mixed and Augmented Reality (ISMAR'08)*, 143-152.

PHAN, V. T. AND CHOO, S. Y. 2010. Using AR for real-time crosscheck of ventilator ducts at worksite. In *Proc. International Conference on Virtual Reality Continuum and Its Applications (VRCAI 2010),* 293-296.

PINGEL, T. J., AND CLARKE, K. C. 2005. Assessing the usability of a wearable computer system for outdoor pedestrian navigation. *Autocarto ACSM*, Las Vegas.

TANAKA, K., KISHINO, Y., MIYAMAE, M., TERADA, T., AND NISHIO, S. 2008. An information layout method for an optical see-through head mounted display focusing on the viewability. In *Proc. IEEE International Symposium on Mixed and Augmented Reality (ISMAR'08)*, 139-142.

TRÄSKBÄCK, M., AND HALLER, M. 2004. Mixed Reality Training Application for an Oil Refinery: User Requirements In *Proc. International Conference on Virtual Reality Continuum and Its Applications (VRCAI 2004),* 324-327.

VAN KREVELEN, D. W. F., AND POELMAN, R. 2010. Fast 3D: A survey of augmented reality technologies, applications and limitations. *International Journal of Virtual Reality 9*, 2, 1-20.

WHITE, S., LISTER, L., AND FEINER, S. 2007. Visual Hints for Tangible Gestures in Augmented Reality, In *Proc. IEEE International Symposium on Mixed and Augmented Reality (ISMAR'07)*, 47-50.