Joint Virtual Reality Conference of EuroVR - EGVE - VEC (2010)
T. Kuhlen, S. Coquillart, and V. Interrante (Editors)

Short Paper: User study for Mobile Mixed Reality Devices

A. Braun and R. McCall

Department for Collaborative Virtual and Augmented Environments
Fraunhofer FIT, Germany

Abstract

In this paper we present a user study comparing four different mobile Augemented Reality (AR) interfaces. The focus of the study was on the usability of the devices, with respect to the unique nature of AR experiences, especially in the context of MR games, namely: the user usually needs at least one free hand; the interface might be used outside, the users will move around and they have to carry the equipment with them. The study found that Ultra Mobile PCs (UMPC) are preferred to Head Mounted Displays (HMD) and presents a number of concepts to the design of such systems.

Categories and Subject Descriptors (according to ACM CCS): B.4.2 [Input/Output and data communication]: Input/Output Devices—Image display H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology H.5.m [Information Interfaces and Presentation]: Miscellaneous—Miscellaneous

1. Introduction

Past experiences with mobile AR interfaces have shown that the use of inadequate and inappropriate devices disturbs users' experiences of AR applications. Furthermore currently more mobile devices such as smartphones and ultra-mobile PC's are capable of supporting augmented reality experiences. These small and lightweight options contrast with the more traditional view of augmented reality which is often based on see-through head-mounted displays (HMDs). These HMDs seem to be best for AR experience, since free-hand operations are possible and the AR content is integrated seamlessly and mode-less in the real world.
In response to these changes this paper provides a user study of four common AR devices resulting in a number of useful design recommendations which can be used by other developers. We compared four different devices under a predefined test scenario - an Ultra Mobile PC (UMPC), a Tablet PC, a monocular Head-Mounted see-through Display and a binocular Head-Mounted see-through Display. For the scenario, we took into account the special circumstances of typical tasks of mobile AR applications. These are for example: the user usually needs at least one free hand; the interface might be used outside, the users will move around and they have to carry the equipment with them.

The paper consists of four sections, the first part explores related work on AR usability testing and the remaining sections focus on the study approach, results and conclusions.

2. Related Work

Billinghurst et al. [BBDM98] have shown that spatial head tracking displays provide benefits over screen stabilized approaches. The authors established the advantages regarding the ease of use and the intuitive handling of the display.
Livingston et. al [LSIG*03] conducted a comparison study of AR displays which explored attributes such as drawing style and opacity. Another study by Livingston et al. is [LA08] measured several error types to explore the users tolerance using an outdoor HMD-based AR system. The error types explored were noise, latency position error and orientation error.
Robertson et al. [RMW08] carried out a study of the effects of graphical contexts which are not situated in the task area. For the experiment four different types of AR systems were used: Fully registered AR, Non-registered AR, Heads-up display with permanently visible graphics and heads-up display with graphics which is not always visible.
The user's understanding of a scene wearing a see-through display compared to the understanding seeing the outdoor

DOI: 10.2312/EGVE/JVRC10/089-092

area on video is studied in [ATP08].
Özbek et al. [zGD04] compared video-see-through with optical-see-through displays.
Three different display types were compared in [WDH07] - two configurations of hand-held devices and a head mounted display. One hand-held display were used with a magic lens metaphor and the second hand-held display were hold at waist height. The user study was focused on cursor movement and visual search of physical and virtual objects.

3. Setup

Apart from the general acceptance and usability of the system, we were interested in comparing different interaction devices such as Ultra Mobile PCs, Tablet PCs, Monocular and Binocular Head-Mounted Displays (HMD) for their use in mobile AR applications. Although some advantages and disadvantages of each device are obvious, we particularly wanted to explore them with respect to pervasive games and collaborative environments.

Ultra Mobile PC

An Ultra Mobile PC (UMPC) was used with a so called "Magic Lens"-metaphor. A Sony Vaio VGN-UX280 equipped with an in-built camera at the back which provides the live video for augmentation was used. The screen size is 4,5“ and the weight without any attached sensors was 0,6 kg. The device has several buttons which can be used for interaction. In our case only the left mouse button function was used. The upper left button on the UMPC was chosen for this function, as it can be used conveniently with the left thumb.

Tablet PC

A Fujitsu Siemens Stylistic ST5111 Tablet PC was used. In common with the UMPC it augmented a live video stream with virtual objects. As this device does not contain a built-in video camera, an USB-webcam was mounted on it (Logitech QuickCam for Notebook Deluxe). The weight without any sensors was 1,5 kg and the size of the display was 10,4”. For interaction, we attached a touch pad on the left side, to enable the simple use of the left mouse button with the thumb.

Monocular Head-Mounted-Display

A Liteye 750 monocular Head-Mounted Display (HMD) was used. It was attached to a backpacked laptop. In contrast to the UMPC and the Tablet PC the HMD displays augmentations directly into the user's real world field of view. The user interacts using a Bluetooth mouse.

Binocular Head-Mounted-Display

The Binocular HMD is similar to the monocular HMD but consists of two Liteye 750s. The two optical units are mounted on a guide rail which can be adjusted according to the individual requests. The two graphical signals will be handled using a DVI splitter which is plugged in the laptop.

Figure 1: *The compared devices: Monocular Head-Mounted Display, Binocular Head-Mounted Display, Tablet PC and UMPC (from left to right).*

4. Scenario

The scenario was comprised of simple actions such as targeting and selection of 3D virtual objects. It was based on the scenario of the MR game TimeWarp [HBMB08]. In this game, the players have to solve small challenges by selecting virtual objects to rescue small elves which are trapped in time wholes. The scenario for this test consists of two different challenges (s. fig. 3) located at different places in an area of about 100 square meter.
In the first task, the user has to select the right coat of arms of Cologne, the city where TimeWarp has taken place. For the second challenge, the user has to work on a virtual future space station. His task is to repair the traffic lights by putting three relays to the central terminal by clicking on the 3D relays. Between the two challenges he has to pass a timeportal to make the space station visisble. He enters this timeportal by approaching physically to it.

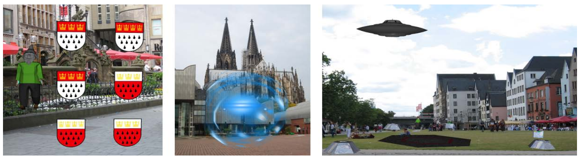

Figure 2: *The tasks which had to be done by the users.*

The user had to move physically in the real world to where the virtual challenges were located. Targeting was carried out using a 6DOF tracking device attached to the prototype, thus by turning and rotating the device the selection of a virtual object was possible. To choose the selected object, the user had to press the left mouse button.
The test scenario was implemented using the VR/AR framework MORGAN [OHL*04]. MORGAN provides the required functionalities for 3D rendering and media handling. As 6DOF tracking sensor we used the xSens MTi-G tracker, which is a combination of an inertial and GPS sensor with an integrated Kalman filter.
The interaction within this scenario was implemented with the MORGAN Interaction Prototyping [BHB08].
It has last between 20 and 35 minutes for the participants to solve the two tasks.

5. Methods

During the study the players were asked to complete a questionnaire. The questionnaire related to their feelings towards various devices and the interfaces (see table 1). These same questionnaire was used across each device, and was applied immediately after use. The responses are rated according to likert scale with 1 indicating strongly agree, 3 indicating no opinion, and 5 indicating strongly disagree. To avoid ordering effects each player experienced the devices in a random order. The test was conducted was 12 participants aged between 22 and 29 years - 10 male and 2 female. Within this group of 11 were IT professionals or students in computer science, and 4 were familiar with augmented reality.

6. Results

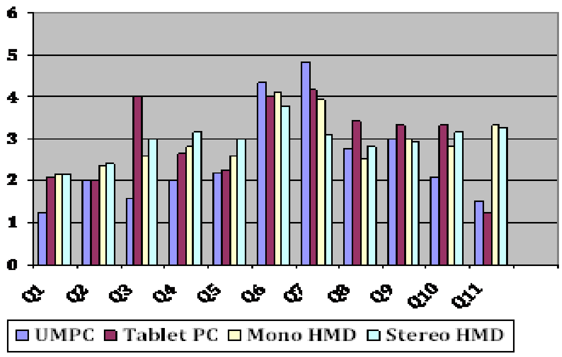

Figure 3: *Results of the user study. The questions Q1 to Q11 are listed in table 1*

A summary of the findings are presented with in figure 3. The figure indicates that for almost all questions (see table 1) the user's preferred the UMPC with the Tablet PC often becoming the second most preferred option. However, a more thorough statistical analysis using ANOVA (with $p<0.05$) indicated that there were few significant differences between the various devices even when the apparent score seemed to vary between each device. We suspect that the lack of significant differences is in part down to the sample size which is only 12 people. However, while we will present the results of the significant findings we will also discuss some of the ones which were found to be non-significant. Therefore the study should be taken as an indicator of future work as much as final results relating to the use of the various devices.

The UMPC was found to be the most easy to carry device, with a Tablet PC being rated the worst. The HMDs were broadly speaking found to be in between both the Tablet PC and UMPC ($p=0.0002$). It was not surprising that the Tablet PC was rated the least carryable as it is bulky, heavier and more difficult to carry than any of the others. While the UMPC must also be carried it is smaller and lighter and less likely to result in discomfort. What is surprising however is that the HMDs received lower scores than the UMPC, this could be related to the additional fact of having to wear the visor and associated hardware.

All devices were again rated positively with respect to the layout of the user interface (Q2), with the UMPC and Tablet PC receiving the almost same scores. Both stereo and mono version of the HMD were rated lower, with standard deviations ranging from 0.95 to 1.44, although no significant differences were found between devices. Players were also asked to rate how confusing they found both the user interface (Q6) and device (Q7). The UMPC was rated as the least confusing device, with the Tablet PC with the stereo HMD being rated the worst ($p=0.0019$). This could be down to the fact that the users had to interact with the objects in the HMD condition using an additional device, e.g. a mouse - which is not ideal within 3D location-based experiences. Although the data from Q6 was not significant the scores broadly speaking contained a similar pattern in that the users found the interface confusing, although the variation between each device was not so pronounced.However it should be noted that the players were positive across all devices when asked if they found either the device or interface confusing with mean scores being 3 or more (which is on the disagree side of the scale). In general all devices were found to make interacting with the content easy (Q4), again however the UMPC received a higher score. Interestingly though when asking if the specific device made interacting with content easy to read (Q11) it became clear that there were significant differences, for example the Tablet PC received the best rating closely followed by the UMPC. In contrast both HMDs received sigificantly worse scores in this respect, an ANOVA confirmed this conclusion ($p<0.0001$). This is perhaps due to a number of unique factors which effect each device, for example the field of view and consequently image size of the HMDs is very small. Furthermore they are much more prone to problems with sunlight and this can cause the colours and hence the interface to appear washed out.

None of the devices were rated as providing a strong feeling of naturalness for interaction either with respect to the application or the wider environment in which the game was situated (Q8/Q9).In general players were positive or neutral when asked if they liked interacting with the device (Q10), and although the variations were found to be non-signficant ($p=0.098$) the UMPC was preferred. Although the users preferred the UMPC, the negative point of this device is its small screen size. One user commented:

"Nice device but the screen is a bit small".

The Tablet PC on the other hand, which provides a bigger display, lacks in usability due to its weight. Some comments to this device:

"Too heavy for the duration of the test, but the size is of course better than the one of the UMPC"

"Too many buttons that may be clicked accidently"

The users had the biggest problems with the monocular HMD. Due to the see-through characteristic of the display, the visibility is affected by bright sunlight. Thus the virtual

Item	Device
Q1. The Interface was easy to use	UMPC
Q2. The Interface was well laid out	UMPC / Tablet PC
Q3. The device was easy to carry around	UMPC
Q4. The device made interacting with the content easy	UMPC
Q5. I was able to complete each task or interaction ... time	UMPC
Q6. I found the interface confusing	HMD stereo
Q7. I found the device confusing	HMD stereo
Q8. Using the device was a natural way to interact with the application	HMD mono
Q9. Using the device was a natural way to interact with the environment	HMD stereo
Q10. I really liked using the device	UMPC
Q11. The Screen layout was easy to read	Tablet PC

Table 1: *Results of the user study.*

objects are harder to see on sunny days. One user noticed: *Easy to select the objects, but the experience with the real world was missing, because of the distracting light.*
The stereo HMD had the same problems with visibility. Furthermore, it was difficult to adjust the glasses for both eyes, which is why the virtual objects sometimes did not appeared in stereo and it was therefore hard to focus. Nevertheless, the users appreciated the intuitive view-dependent interaction. Since the tracking sensor was attached to the head-mounted display, the targeting was undertaken by simple head movements.

7. Conclusion

By default augmented reality developers tend to assume that head-mounted displays offer the best solution. However our findings indicate that while HMDs offer some advantages in general they are not superior to UMPCs or Tablet PCs. This is in part due to the nature of current HMD technologies which often make graphics appear washed out or even invisible under bright sunlight conditions. Furthermore users often found using the HMDs confusing, but liked being able to interact via head movement.
Putting aside the technical limitations of the HMD, there are a number of useful design recommendations which can be used by other developers. One important aspect is making sure that the devices selected match the tasks undertaken by the users, for example as noted a heavy difficult to carry device such as the TabletPC is not suitable for interactions which require one free hand. Also the combination of devices is important, for example using a bluetooth mouse and HMD is not an appropriate method of interaction. Therefore care should be taken to either use a new device which is more suited to the task or one with which people are already familiar. Moreover HMDs offer the possibility to introduce more natural forms of interaction such as being able to point at objects based on head position without the needs to hold a device.

8. Acknowledgment

We thank all our participants who helped us conducting this user evaluation. The research presented here was in part funded by the European Commission under grant number: FP-2004-IST-4-2757

References

[ATP08] AVERY B., THOMAS B. H., PIEKARSKI W.: User evaluation of see-through vision for mobile outdoor augmented reality. In *ISMAR '08: Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (Washington, DC, USA, 2008), IEEE Computer Society, pp. 69–72. 2

[BBDM98] BILLINGHURST M., BOWSKILL J., DYER N., MORPHETT J.: Spatial information displays on a wearable computer. *IEEE Comput. Graph. Appl. 18*, 6 (1998), 24–31. 1

[BHB08] BROLL W., HERLING J., BLUM L.: Interactive bits: Prototyping of mixed reality applications and interaction techniques through visual programming. In *3DUI '08: Proceedings of the 2008 IEEE Symposium on 3D User Interfaces* (Washington, DC, USA, 2008), IEEE Computer Society, pp. 109–115. 2

[HBMB08] HERBST I., BRAUN A.-K., MCCALL R., BROLL W.: Timewarp: interactive time travel with a mobile mixed reality game. In *MobileHCI '08: Proceedings of the 10th international conference on Human computer interaction with mobile devices and services* (New York, NY, USA, 2008), ACM, pp. 235–244. 2

[LA08] LIVINGSTON M. A., AI Z.: The effect of registration error on tracking distant augmented objects. In *ISMAR '08: Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (Washington, DC, USA, 2008), IEEE Computer Society, pp. 77–86. 1

[LSIG*03] LIVINGSTON M. A., SWAN II J. E., GABBARD J. L., HÖLLERER T. H., HIX D., JULIER S. J., BAILLOT Y., BROWN D.: Resolving multiple occluded layers in augmented reality. In *ISMAR '03: Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality* (Washington, DC, USA, 2003), IEEE Computer Society, p. 56. 1

[OHL*04] OHLENBURG J., HERBST I., LINDT I., FRÖHLICH T., BROLL W.: The morgan framework: enabling dynamic multi-user ar and vr projects. In *VRST '04: Proceedings of the ACM symposium on Virtual reality software and technology* (New York, NY, USA, 2004), ACM, pp. 166–169. 2

[RMW08] ROBERTSON C. M., MACINTYRE B., WALKER B. N.: An evaluation of graphical context when the graphics are outside of the task area. In *ISMAR '08: Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (Washington, DC, USA, 2008), IEEE Computer Society, pp. 73–76. 1

[WDH07] WITHER J., DIVERDI S., HOLLERER T.: Evaluating display types for ar selection and annotation. In *ISMAR '07: Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality* (Washington, DC, USA, 2007), IEEE Computer Society, pp. 1–4. 2

[zGD04] ÖZBEK C. S., GIESLER B., DILLMANN R.: Jedi training: Playful evaluation of head-mounted augmented reality display systems. In *SPIE: Stereoscopic Displays and Virtual Reality Systems XI, Vol. 5291* (2004), pp. 454–463. 2