

Handheld AR for Collaborative Edutainment

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Abstract. Handheld Augmented Reality (AR) is expected to provide ergonomic, intuitive user interfaces for untrained users. Yet no comparative study has evaluated these assumptions against more traditional user interfaces for an education task. In this paper we compare the suitability of a handheld AR arts-history learning game against more traditional variants. We present results from a user study that demonstrate not only the effectiveness of AR for untrained users but also its fun-factor and suitability in environments such as public museums. Based on these results we provide design guidelines that can inform the design of future collaborative handheld AR applications.

Keywords: AR education, collaborative AR, usability studies

1 Introduction

Augmented Reality (AR) interfaces have been developed for many application areas such as medicine, engineering and gaming. Recently, PDAs and cell phones have reached a level of performance where they can be used for mobile AR. With built-in cameras and 3D graphics chips, these handheld devices can readily be turned into video-see through magic lenses, providing an AR view of the user's real world.

In our ongoing work to build a handheld AR platform [1], we have targeted edutainment as a suitable application area for real world deployment of multi-user AR. Our efforts towards developing high-quality AR edutainment applications is driven by the belief that collaborative handheld AR can surpasses traditional media in user satisfaction, intensity of collaboration and learning efficiency.

Although edutainment AR applications are becoming more common, few studies have compared learning in an AR setting to more traditional educational tools. Research is needed to explore the educational value of mobile AR applications and inform the design of these interfaces. In this paper we present a user study comparing learning in a collaborative handheld AR environment to more traditional PC interfaces. This was done using an application, Virtuoso, that has similar gameplay across a handheld AR platform, desktop computer and a set of playing cards.

2 Related Work

Our work on handheld collaborative AR games in a museum is built on related work in handheld AR, collaborative AR, AR games, AR for museums, and comparative AR user studies. In this section we briefly review past work in these areas.

The Touring Machine [2] developed at Columbia University pioneered the concept of mobile AR almost 10 years ago. Since then, mobile AR interfaces have moved from cumbersome backpack computers to handheld AR devices. Initially these were tethered handheld AR displays such as Fitzmaurice's Chameleon [3] and Rekimoto's NaviCam [4] but in 2003 the first author developed the first fully self-contained handheld AR application [1]. Originally based on a PDA port of ARToolKit [6], this work has since then been extended into a full blown cross-platform version of *Studierstube* [7]. Most recently, mobile AR interfaces have been developed for cell phones by Möhring [8] and Henrysson [9].

Around the same time, Augmented reality as a collaboration tool emerged in a number of "shared space" systems [10][11][12][13] for face to face collaboration. Other work focuses on remote collaboration making use of multiple possibilities of mixed reality continuum [14] simultaneously [15][16].

AR as a new medium is attractive for education institutions such as museums. The incorporation of AR enhanced exhibits can range from a single high-performance AR display [17] to an entire exhibition realized using AR special effects [18]. Mobile AR technology can offer an attractive replacement for the traditional audio-tape tour guide. Tour guides are a recurring application theme for mobile AR research, partially because they show the strength of mobile AR, namely to present useful information registered to static locations in the real world, such as historic edifices. Some examples of outdoor AR guides are Situated Documentaries [19], ArcheoGuide [20], GEIST [21] and Signpost [22]. Work on mobile indoor AR has specifically targeted museums, for example the Guggenheim Bilbao museum [23] or Sweet Auburn [24].

As can be seen from the related work mobile AR interfaces have migrated from bulky backpacks to self contained handheld systems. Similarly the applications that people are using these systems for have evolved and more and more people are interested in educational use of AR technology. Despite this there have been few examples of user studies comparing education in a mobile AR setting to more traditional educational experiences. Our work is unique because it is the first paper that compares education with a handheld AR platform to more traditional tools. The application itself is also interesting as it provides one of the first examples of using handheld AR as a platform for producing educational content in a collaborative setting.

3 The Handheld AR Platform

We have created a component-based software architecture for the development of PDA-based handheld AR applications. This is the first feature-complete version of the *Studierstube* software framework that runs cross-platform on Windows, Linux and Windows CE. The technical details of the platform are beyond the scope of this paper,

see [5] for more details. This section summarizes the key capabilities of the *Studierstube* framework for handheld devices.

Graphics and multimedia: OpenGL ES is an emerging standard for 3D graphics on embedded devices. Klimt¹ is a software library that executes OpenGL compliant software on top of a third party hardware OpenGL ES implementation or Klimt's own built-in software renderer. Using Klimt, it is possible to execute a high-level object-oriented scene graph library such as Coin²; we call this version Coin ES.

Tracking: We have developed ARToolkitPlus³ as an optimized successor to the popular ARToolkit [6] marker tracking library. ARToolkitPlus shares the basic working principles with its ancestor, while the code has been rewritten in fixed point arithmetic and incorporates several novel computer vision algorithms. The resulting code tracks in real time on a high-end PDA (5ms per image on the Axim X51v).

Networking: Muddleware is a networking middleware loosely inspired by the idea of a Tuplespace. It provides state synchronization for multi-user applications, persistency and resource streaming.

Application framework: The *Studierstube* application manager coordinates the various system components mentioned above. It loads and executes concurrent applications.

4 Art History Application: Virtuoso

Using the Handheld AR framework we implemented an educational game called Virtuoso. Besides the AR version, the game was also implemented in Macromedia Flash on a desktop PC and as a paper game without any technology.

The players' objective in the Virtuoso game is to sort a collection of artworks according to their date of creation along a timeline – left means earlier and right means later. The timeline has a number of slots, each of which can hold exactly one artwork. Initially all slots are randomly filled with artworks. Each player can pick up one item from a slot and put it into another empty slot. If the desired target slot is full, the player can ask a team member to help by picking up the item in the target slot. When taking an item from the timeline, the player is provided with basic information about the item, such as its name and a brief description. The player can ask Mr. Virtuoso, the virtual arts expert, for more information about the item. The game ends when all items are correctly located on the timeline.

The art history application features an overall selection of 20 artworks from which the game master can select an arbitrary subset for play. The set of artworks covers a range from 20.000 BC to 2004 AD including pieces from western and eastern culture. We specifically created polygonal 3D models for each artwork. Most items are textured; some include audio or video features.

The PDA version of the Virtuoso game shows a video-see through AR scene. It runs on an arbitrary number of PDAs which are synchronized via WiFi using our Muddleware collaboration running on a hidden PC. Paper fiducial markers placed

¹ Klimt: open source 3D graphics library for mobile devices, <http://studierstube.org/klimt>

² Coin3D: open source scene graph renderer, <http://www.coin3d.org>

³ ARToolkitPlus: http://studierstube.org/handheld_ar/artoolkitplus.php

along a wall are used to mark the slots of the timeline (Figure 1). Every marker can carry one artwork which is only visible on the player's PDA. A player can pick up any artwork from the wall onto her PDA, by clicking on the artwork on the display. Next she can drop it onto a free position on the wall by clicking on an empty marker on the display. While an item is located on the PDA, the player can access basic information about it such as its name. To get more information the player can place the object onto the desk of Mr. Virtuoso, an animated virtual 3D character who plays the game's arts expert (Figure 3). Mr. Virtuoso will then be prompted to provide his expertise on the subject through the use of text, audio playback and animation. The player can take back the artwork onto her PDA at any time. After an artwork is placed at its correct position, it cannot be moved again.

Besides the explanation from Mr. Virtuoso, the game engine can provide more explicit help by showing arrows pointing "left" and "right" next to the artwork if it should be placed earlier or later on the timeline (Figure 2). Furthermore, the game engine can display an item's date of creation when the item is placed at its correct location on the timeline.



Fig. 1: Using the AR PDA version

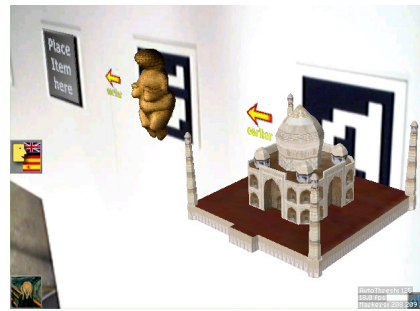


Fig. 2: Virtual arrows providing game hints



Fig. 3: PDA version

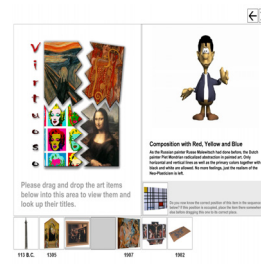


Fig. 4: PC version



Fig. 5: Paper version

The desktop PC version was programmed in Macromedia Flash (see Figure 4). Players can move artworks on the timeline displayed on the screen using drag and drop operations with the mouse. Consequently the PC version can only be operated by one player at the time. While this restricts the user interface of the game, it provides a more realistic example of typical PC-based edutainment application or museum installation. As usual, when an item is located at its final position its date of creation is displayed below of it and the item can no longer be moved. Moving an item to the

left-top pane provides basic information, while the animated Mr. Virtuoso on the top-right pane provides detailed explanations in text and audio. Items can be directly dragged from one slot on the timeline onto another.

For the paper version of the game we printed pictures of the artworks on playing cards (Figure 5). On the front, the playing cards show the introductory text, while on the back more detailed descriptions by Mr. Virtuoso are provided. Players are only allowed to hold one playing card at a time and must only put it back into a free position. A human game master takes care that the game's rules are not violated. The game master will also reveal an item's date of creation when an item is located on its correct position on the timeline. So this version of the game has the same functional characteristics as the AR PDA and desktop PC versions.

5 Experimental Evaluation

We compared our collaborative AR application with the two non-AR variants of the game (the desktop PC and paper-based version). In the experiment participants were grouped into teams of four. In each game, players had to sort seven items on the timeline. After a team finished its task they filled out a questionnaire about the game they just played including detailed art history questions about the items they just arranged, and how they felt about the game interface. Then all teams moved on to another version of the game. After the participants played all three versions of the game they filled out another questionnaire asking to rank the conditions in several categories. The introductory instructions to the participants emphasized the focus on collaboration and the need to learn about the artwork items, more than completing the task as fast as possible. To further motivate cooperation between players, players were told, that the goal of the game was to get a high team score, rather than personal scores on the arts history questions they had to answer.

6 Results

There were 48 participants 26 female and 22 male, aged from 20 to 43. 25 people stated that they had never used a PDA before. The experiment lasted about one hour for each subject including introduction and a short finishing discussion. Data analysis was performed by using SPSS version 13 and the main effect was tested with repeated ANOVA. If a main effect was found, pair-wise post-hoc comparisons using the Bonferroni adjustment for multiple comparisons were performed. The questions the participants had to answer after each game can be grouped into four main categories: collaboration, easiness of the task, learning effect and fun factor. Subjects were asked to mark on a Likert scale of 1 to 7 how much they agreed or disagreed with a number of statements (1 = Strongly Disagree and 7 = Strongly Agree).

We asked two questions about the way people collaborated:

Q1: I collaborated intensively with my team members.

Q2: I knew exactly what the others were doing.

Table 1 shows the average results for each of these questions. Subjects felt that they collaborated more in the Paper and PDA versions; an ANOVA test found a significant difference for Q1 ($F(2,94)=3.94$, $P<0.023$) and a post-hoc comparison found a significant difference between the PC game and the other two variants. Similarly, an ANOVA for Q2 found a significant difference between how well subjects felt they knew what the others were doing: $F(2,94)=6.13$, $P<0.003$. A post-hoc comparison found a significant difference between the PDA condition and the PC and paper versions of the game.

Table 1. Average results on collaboration.

Condition	Paper	PC	PDA
Q1	5.71	5.00	5.61
Q2	5.67	5.75	4.73

In the category *ease of the task* we asked the following five questions:

Q3: I always had a good overview of the timeline

Q4: I had sometimes problems with the user interface

Q5: The game was sometimes confusing

Q6: The user interface was easy to use

Q7: The task was easy to solve

Table 2 shows the average results. As can be seen, there is little difference for the conditions of the questions Q3, Q4 and Q5. An ANOVA test found significant differences for *Q6: The user interface was easy to use* ($F(2,94)=5.27$, $P<0.007$). A post-hoc comparison showed that the paper variant was rated significantly lower than the PC version and there was no difference between the PC and PDA conditions. For *Q7: The task was easy to solve*, ANOVA found significant differences ($F(2,94)=3.52$, $P<0.034$), and a post-hoc comparison showed that the PC version was rated significantly easier than the PDA version, but there was no significant difference between the other conditions.

Table 2. Average results for ease of use.

Condition	Paper	PC	PDA
Q3	5.10	5.27	4.81
Q4	2.27	2.21	2.69
Q5	2.56	1.98	2.65
Q6	5.38	6.27	5.86
Q7	5.60	5.94	5.44

To measure if people felt a learning effect we asked the question:

Q8: I believe I learned something about those artworks

Performing an ANOVA on Q8 did not find any significant differences. The last group of questions we asked after each game was about how much people liked the game and how much it would fit into a museum setting:

Q9: I enjoyed playing the game

Q10: Playing the game was a great experience

Q11: This game would fit well into a museum exhibition

Q12: I would like to play this game in a museum

Figure 8 shows the average results for each of these questions. There were significant differences between the results for all of these questions. As can be seen for every question the PDA version scored highest while the paper version was rated lowest. An ANOVA was conducted and *Q9: I enjoyed playing the game* resulted in $F(2,94)=5.472$, $P<0.006$. Post-hoc analysis found that the PDA version was rated significantly higher than the paper version. An ANOVA for *Q10: Playing the game was a great experience* resulted in $F(2,94)=32.916$, $P<0.001$. Post-hoc analysis showed that the results for all three conditions were significantly different. For question *Q11: This game would fit well into a museum exhibition* the PC and PDA version got very similar ratings. An ANOVA ($F(2,94)=25.713$, $P<0,001$) including a post-hoc analysis showed significant differences between the paper and the other two conditions but no differences between the PC and PDA conditions. Finally for *Q12: I would like to play this game in a museum*, an ANOVA resulted in $F(2,94)=30.716$, $P<0.001$. Post-hoc analysis found all three versions of the game were significantly different.

In general subjects thought the PDA version provided a greater experience than the other two conditions and they would like to play this in a museum more than the other two games.

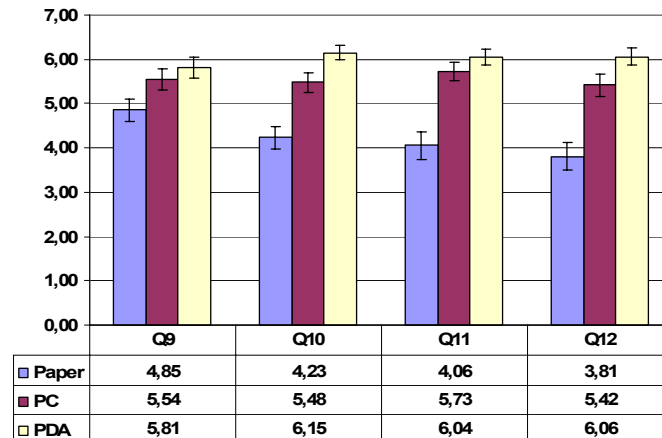


Fig. 8: Average results for Questions Q9 – Q12

In addition, subjects were also asked to rank each of the conditions in order according to the following criteria. For each criteria 1 = lowest, 3 = highest.

R1: How easy the game was to play

R2: How much you learnt

R3: How good the overview of the timeline was

R4: How much you collaborated

R5: How much fun the game was

R6: How much the game would improve a museum exhibition

Table 3: Average results for rankings R1 and R2

Condition	Paper	PC	PDA
R1	1.89	2.25	1.86
R2	1.82	2.09	2.09

The rankings for *R1* and *R2* did not produce significantly different results. As can be seen in Table 3, all conditions were ranked very closely. However, for ranking *R3: How good the overview of the timeline was*, an ANOVA found $F(2,90)=4.723$, $P<0.011$. A post-hoc analysis showed that the PC and PDA conditions were significantly different giving the PC version the best score of overview of the timeline (see Table 4). Interestingly, ranking *R4: How much you collaborated*, resulted in exactly the opposite ratings. Here the PC version scored significantly lower, while the paper and PDA conditions were rated almost equally well. An ANOVA plus post-hoc comparisons resulted in $F(2,88)=4.006$, $P<0.022$ and found significant differences between the PC condition and the other two conditions.

Table 4: Average results for rankings R3 and R4

Condition	Paper	PC	PDA
R3	1.89	2.35	1.76
R4	2.15	1.67	2.13

Finally, *R5: How much fun the game was* and *R6: How much the game would improve a museum exhibition* produced the results shown in Table 7. An ANOVA found $F(2,92)=43.607$, $P<0.001$ for *R5* and $F(2,88)=31.253$, $P<0.001$ for *R6*. For both *R5* and *R6* post-hoc comparisons showed that all results were significantly different resulting in the PDA version being ranked as the most fun and most appropriate for a museum exhibition.

Table 7: Average results for rankings R5 and R6

Condition	Paper	PC	PDA
R5	1.36	1.89	2.75
R6	1.36	2.00	2.64

7 Interviews

We interviewed the participants after each condition and several consistent themes emerged. For the paper version, subjects felt that they needed to organize themselves to prevent chaos, which was not a problem in the electronic versions of the game where strict rules were implicit. While many players said that it felt good to have a physical object in their hands they also added that the paper version was very “old school”. In general subjects felt the paper version was less appealing.

Although most participants rated the PC version as providing the best overview of the timeline in the questionnaires, some participants complained that too many items crowded the screen which confused them. Interestingly, the same audio recordings for Mr. Virtuoso’s voice-over was used in the PC and PDA version, but several users commented that the PC version’s virtual character sounded more pleasing. We assume the reason for this is the low quality of the PDAs’ built-in speakers. Subjects told us that collaboration was most difficult with the PC version because there was only one mouse to use and every action had to be first discussed with the other players. Players sitting more distant from the PC screen usually participated the least.

Some subjects said that the PDAs’ touch-screens were more difficult to use than the mouse interface which is expected since most subjects had never used a PDA before, and people were afraid to break the PDA, especially due to the attached camera. All participants complained that Mr. Virtuoso should speak louder which is a well known problem with PDA speakers. Participants noted that the small screens could not be seen by the other players so collaboration was more difficult than with the paper version. Mr. Virtuoso was identified as a bottleneck for the game progress because other players would have to wait until Mr. Virtuoso had finished describing the artwork. People thought the user interface and the graphics in general were very appealing although some participants argued that it was difficult to explore the 3D artworks on the small screen. As most users had only minimal computer science experience, they were very excited due to the high-tech feeling of the PDA game and commented that the handheld AR concept was “innovative” and “ingenious”.

8 Discussion

Although we tested three different game conditions, there was no difference in the educational outcomes. This could be because the learning task was essentially a memory task that wasn’t dependent on effective collaboration or the ease of use of the interface. However, there were significantly different user subjective results as a consequence of the different characteristics of each condition.

One of the most obvious differences between the conditions is in how space was used. In both the AR PDA case and the paper interface the art pieces were spread out in physical space allowing the four users to work on the game in parallel. This shows one of the advantages of AR, namely that it allows virtual content to move from the screen and into the real world. In contrast, with the PC interface the users are working on a much smaller screen with only a single input device. In this case it was impossible for users to manipulate objects at the same time. Thus users felt that both

the AR PDA interface and the paper version allowed them to collaborate more effectively than the PC interface.

Another key difference between the interfaces was in how much awareness they provided of what the others were doing. In the PC and paper versions all of the users could see all of the art pieces on the timeline at the same time. When a player moves a piece of artwork, everyone is aware of it. In contrast, in the AR PDA application, each of the users had a personal view of the virtual content, and unless they shared their PDA, they were not aware of which players had picked up which art pieces. One of the challenges of designing collaborative AR systems is providing independent views of virtual data while at the same time creating shared group awareness.

Despite the different interface conditions, there was not a significant difference in usability. Although the users had never used an AR PDA interface before, in general they found it relatively easy to use; as easy as using the mouse-based PC interface and manipulating real cardboard pictures. This is unusual for first time users of a novel interface, but is due to using an intuitive interface metaphor. In this case a magic lens metaphor in which the AR PDA becomes a virtual window on the real world. Users are able to view the virtual scene as easily as if they were using a real handheld lens.

Users ranked the PDA interface as the most enjoyable of the three conditions and the one that they would most like to see in a museum. The fun factor may be due to both the novelty and visually appealing nature of the AR interface. The AR condition provided 3D virtual imagery, animation, sound and text.

From these results we can infer several design guidelines for handheld AR interfaces that can inform future applications:

- Allow the user to experience the virtual content in space.
- Use an appropriate interface metaphor, such as a lens input metaphor.
- Seamlessly integrate 3D virtual imagery with animation, 2D images and text to create a multi-sensory experience.

In general, in a face to face collaborative AR interface, key elements of normal human face to face must be considered. This includes providing a mechanism for sharing user views to establish shared understanding, enabling users to work in parallel, and preserving the ability to share verbal and non-verbal face to face communication cues.

9 Conclusion and Future Work

In this paper we have described a handheld AR application developed for enhancing the museum experience, and a user study evaluating its effectiveness. This work is the first rigorous comparison of a handheld AR experience with more traditional PC desktop and paper-based applications. In general users felt that the AR PDA system provided the most fun of the three conditions and would most improve the museum experience.

Although these results are interesting and provide insight into designing AR museum experiences, the research is just beginning and there is a lot of future work that can be done.

First, other application areas for handheld AR should be explored, such as medicine, engineering and different games, among others. Each of these application areas have unique requirements that need to be designed for and evaluated in context.

Secondly, future user studies should use a wider range of analysis tools. In this experiment we have used subjective surveys, and interviews. In a collaborative setting, interesting analysis could also be performed on the language, gestures and group behaviour used, which can highlight more of the difference between collaborative process, rather than performance measures.

Finally, there are other devices than PDAs that could be used to provide AR experiences. It would be interesting to run a future experiment to compare user preferences and performance between AR experiences based on head mounted displays, PDAs and screen or projection based AR.

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