Design Aspects of Handheld Augmented Reality Games

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1 Introduction

Augmented Reality (AR) as a new user interface technology has yet to see its breakthrough into mainstream acceptance – but why? Generally speaking, new user interfaces are often employed first in professional applications, where potential gains in productivity can justify high investments and even allow for some user interface specific training if the learning curve is not too shallow. In contrast, entertainment applications must appeal to a mass audience, need to be self-explanatory and do not demand high hardware cost. On the surface it seems that serious applications have an edge over gaming as a vehicle for user interface research, but actually the opposite may be true: Players of computer games tend to tolerate to glitches in software quality that would be deemed unacceptable for professional applications, as long as play value and usability of the interface are outstanding. This makes games very suitable to test research on user interface technologies such as AR.

Returning to AR interfaces, the main barrier that has hindered bringing AR games to a mass audience is the lack of an inexpensive hardware platform. The advent of ARToolKit [10] as a free tracking/graphics starter kit has led to significant growth of individuals (most of them not researchers) experimenting with desktop AR. However, desktop AR with a stationary camera (webcam) looses a lot of appeal over direct viewpoint control with a head-mounted display (HMD), and neither HMDs nor high quality mountable cameras are standard peripherals available to a wide audience. The unavailability of a commercial off-the-shelf device to show AR content has severely affected the potential growth of this technology.

The proliferation of handheld computing devices may bring a solution to this problem. Handhelds in the form of tablet PCs, personal digital assistants (handheld) or smartphones are well-engineered, widely available and inexpensive. Using live images from their built-in cameras as a video background, they can display video-see through AR. This style of interaction is sometimes called magic lens metaphor [3][13]. The wide-spread adoption of handhelds allows researchers to draw from a large target audience of users already familiar with the general operation of the target device; many users may even be owning a handheld already.

Casual games are becoming increasingly popular on cell phones, so that handheld AR games are also perceived as socially acceptable, but at the same time new and exciting. The expectation that casual games should have short playtimes helps researchers to set up satisfactory experiences without having to produce a lot of game content. Possible target platforms range from conventional cell phones, on which software-only solutions could allow immediate commercial marketing, to high-end handheld and Tablet PC solutions which are useful for proof-of-concept implementations until the lower end of the market has reached sufficient performance levels.

In this paper, we describe the current state of the art in handheld AR games. We discuss technological constraints and user interface design aspects that pertain to this particular category of games, using our own research prototypes and other projects as examples where appropriate. The intention is to familiarize the reader with the design space of this extremely promising style of AR, and to establish a common ground for thinking about handheld AR user interfaces.

2 Technological Constraints

We will first examine some technical aspects of the problem space to develop an understanding of the solutions that are available. Understanding handheld AR platforms, be they cellular phones, handhelds or Tablet PCs (see Fig. 1), is important because each platform makes specific trade-offs between size, weight, computing power and costs. With an eye on large scale deployment, we rule out hardware options that require physical modification of the handhelds or extension with peripheral hardware, and focus solely on commercial off-the-shelf technology.

3D Graphics. Graphics synthesis is an integral part of AR – despite the small screens, the target audience demands high quality graphics. Handhelds must therefore be capable of rendering textured and lit, moderately detailed 3D geometry at interactive frame rates. While Tablet PCs based on notebook hardware offer solid graphics performance and are capable of running desktop computer games, smaller handhelds have no or only very limited 3D graphics performance. There is a trend towards embedded CPUs with on-board 3D acceleration capabilities, but the handhelds' limited energy budget will not allow performance levels equal to desktop computers for at least several years. To allow some level of cross-platform graphics development, leading graphics hardware vendors have agreed to promote OpenGL ES, a streamlined version of the original OpenGL standard, which can be implemented with a moderate hardware budget afforded by handhelds. While OpenGL ES is very efficient, it does not offer the same level of development richness that conventional, more established graphics libraries have. Overall, these circumstances imply that handheld games cannot compete

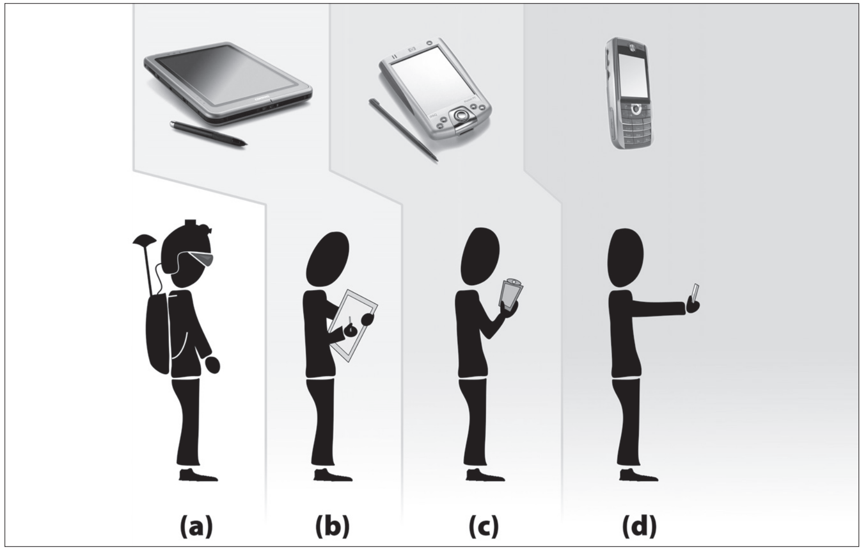

Fig. 1. The evolution and miniaturization of mobile AR: (a) Backpack with HMD, (b) Tablet PC, (c) handheld, (d) Mobile phone

in graphics quality and performance with the high standards set by desktop and console games, and need to provide other sources of play value than just through compelling graphics alone.

Pose Tracking. Registration of real and virtual objects by means of pose tracking is a distinguishing feature of Augmented Reality. Any self-contained mobile AR setup should be capable of determining its own pose using its own sensors. The built-in camera available on most handhelds naturally lends itself to computer vision approaches. Low-powered devices such as cell phones can only run very simple vision algorithms, such as pixel flow or color blob detection, putting severe constraints on the type of AR applications possible on these devices. The quality of computer vision tracking is also strongly influenced by camera and image sensor characteristics, such as frame size, update rate, color depth or lens distortion, which tend to be rather poor on low-end devices. Combination with other sensors, such as inertial measurement units or GPS dramatically enhance the capabilities of handheld tracking. Today only few such devices equipped with hybrid sensors exist, but emerging commercial applications such as pedestrian navigation systems give reason to believe that this situation will improve over time.

Processing Performance. 3D graphics rendering (especially with a software rasterizer) and computer vision algorithms for pose tracking can impose high demands on the processing power of a handheld. Both of these tasks make ample use of floating-point operations, which is not available natively on current embedded processors. Whenever software emulation of floating point arithmetic is too expensive, these devices must resort to performing time-critical calculations using fixed-point operations, which rules out certain types of algorithms.

Networking. Multi-player games generally mandate networking capabilities. The most common communication standards available on consumer handhelds are Bluetooth, GSM/3G, and Wireless LAN. Of these standards, Bluetooth provides only short range and bandwidth, but is ideal for spontaneous setups. GSM/3G suffers from high latency and hefty service fees, which currently leaves WiFi (usually IEEE 801.11b) as the preferred communication option for middle to wide range games. However, depending on commercial development, 3G services may soon be an alternative to WiFi and Bluetooth.

Usability: Besides the basic need for an appropriately sized display and adequate user-input capabilities, the use of the handheld must be ergonomically satisfactory for mobile users. Tablet PCs are generally too heavy and bulky to be used casually or for extended periods of time away from a desk. Handheld and smart phone devices are available in various form factors competing for the perfect trade-off between screen size and weight. Handheld devices with a touch screen have a significant advantage over keyboard-centric devices in terms of designing any kind of graphical user interface, but touch screens are still restricted to more expensive products.

Overall, handhelds are characterized by an unusual mixture of constrained performance and exciting new possibilities such as unprecedented mobility and connectedness. The distinguishing factor of AR games over ordinary mobile games is the magic lens metaphor, which we will examine closer in the next section.

3 Physical Design Implications of the Magic Lens Metaphor

The magic lens metaphor afforded by handhelds imposes very specific constraints to interaction design. The device must be held at a distance of about 50cm, with the camera normally tilted downwards, to allow for prolonged use without significant fatigue and also to let the user focus on the screen. The field of view defined by the small handheld screen is therefore very limited. This means that the amount

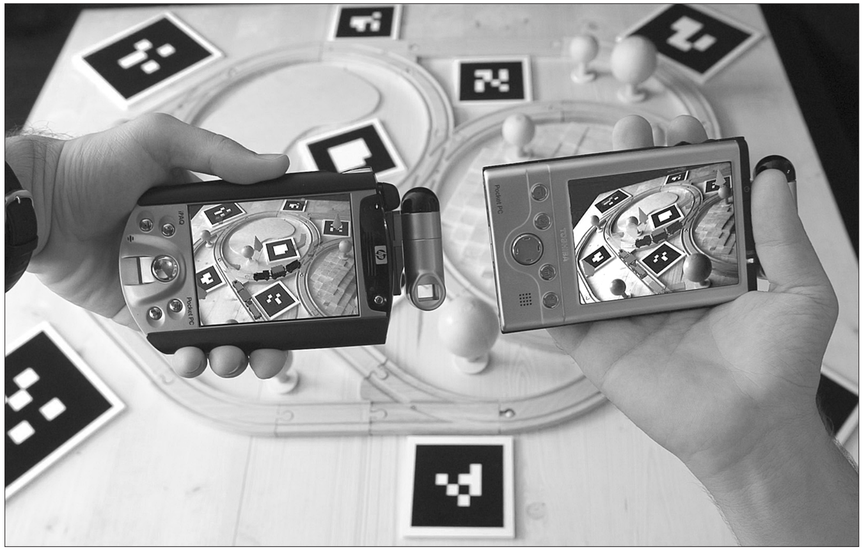

Fig. 2. Invisible Train is a collaborative game casting users in the role of engineers in control of virtual trains on a real wooden miniature railway track. Players can interact with the game environment by operating track switches and adjusting the speed of their virtual trains using the handheld's touchscreen. The current state of the game is synchronized between all participants via WiFi. The common goal of the game is to prevent the virtual trains from colliding. The touchscreen is very instrumental in operating the game, since it lets users select game elements such as junctions which are not in the center of the view. The game still requires a fair amount of physical movement, which has been reported to be an essential ingredient of the play value. However, the use of the touchscreen avoids excessive movements since users can overview and manipulate a sufficiently large part of the playfield at once.

of content that can be displayed - both world-registered and screen-registered - is rather constrained.

It also implies that in order to observe a physically large environment, the device needs to be frequently moved or rotated. Ergonomic constraints and the necessity to keep a line of sight to the display limit the type and amount of possible movements of the handheld. While rotation and movement with the supporting arm are quick, moving the device through physical walking is more disrupting since it is often difficult to keep the screen in view while physically navigating the environment.

Many game designs will therefore aim to minimize such physical movements. For example, devices that feature a touchscreen can be held still while interacting with the environment using the stylus. A similar approach may be taken using

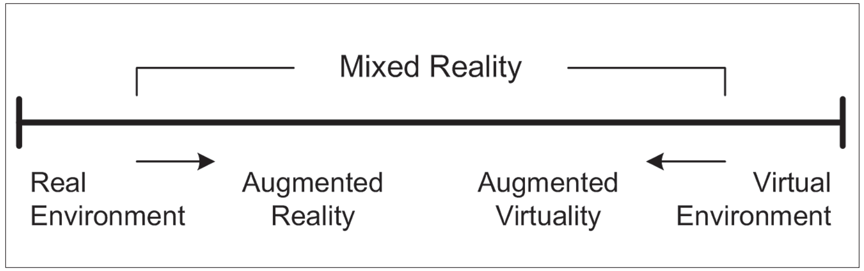

Fig. 3. Milgram's reality-virtuality continuum.

the miniature joysticks often found on cell phones. However, we have observed that the enjoyment of physically navigating the environment is one of the key contributions to the appeal of handheld AR games. Of course a part of this success must be attributed to the fact that a larger, navigable environment must be specifically prepared to support the gameplay. We will return to the issue of complex infrastructure below.

4 Handhelds in the Virtuality Continuum

In order to further examine design issues, we first need to understand the preliminaries of the medium we are designing for, AR. The most accepted definition of AR is suggested by Azuma [1] and lists three requirements for AR: combine the real and virtual, registered in the real world, interactively in real time. According to the older Virtuality continuum proposed by Milgram [11] (see Fig. 3), AR is just one possible manifestation of Mixed Reality (MR), which brings together real and virtual within a single display. The Virtuality continuum juxtaposes AR and Augmented Virtuality (AV). AR is mostly grounded in the real world, with a limited set of virtual objects mixed in. The inverse concept, AV, is conceived as a Virtual Environment with some real aspects – a recurring example for AV are video-textured avatars within a Virtual Environment. The boundary between AR and AV is not strictly defined.

The handhelds' small field of view introduces some ambiguity when trying to assess AR games with respect to the Virtuality continuum: A user will typically focus on the handheld's screen, but simultaneously perceive context from the real environment around the handheld. The handheld is so small that it can be

Fig. 4: Penalty Kick [12] is a simple example for a game of category (1). It uses a coarsely registered 3D marker, which can be printed on a poster or product package. The aim of the game is to shot a soccer ball into a goal printed on the product package. The player can aim where to shot the ball by rotating and tilting the phone. The virtual goal keeper will then try to hold the ball.

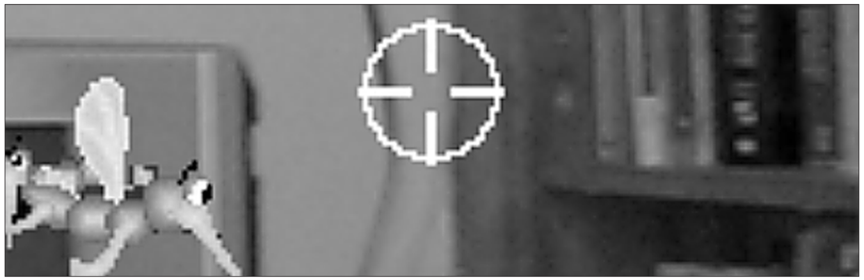

Fig. 5: Mosquito Hunt challenges the player to shoot mosquitos. The gun is pointed at the mosquitos by moving the phone in space. A simple pixel flow detection algorithm makes the mosquitos stay fixed relative to the environment. The world is captured by the build in camera acts as a backdrop for the game, while the mosquitos are rendered as 2D sprites on top of that background. The game only measures orientation, so that actually only the orientation of the device matters, while the position is irrelevant.

interpreted as a kind of "cursor" into the physical environment. Therefore, there are two possible interpretations of "mixed reality display":

- The screen of the handheld represents the AR display. This interpretation is most meaningful if the handheld displays superimposes computer graphics on top of a video stream from the built-in camera. In this case the physical environment is duplicated in miniature format on the display, and becomes a conceptual part of the MR game. A handheld or Tablet PC with a slightly larger display and a stylus is likely to strongly bind the user's attention to the device, while diminishing the user's perception of the surrounding.
- The handheld itself represents the AR display (in this case, more an MR display). The handheld display shows exclusively virtual content, but this content is still fully registered to the physical environment. Moving the device in reality also moves the position (viewpoint) in the virtual world. In this case the handheld itself is the AR display, since the display content must be interpreted together with the surrounding real world. One could say that the handheld is at the same time an AR display and a tangible interaction device. This definition is more in line with Benford's "shared space" approach towards mixed reality [2] which is much broader than the Virtuality continuum.

Some designs take a relaxed approach concerning registration and utilize only the rotational degrees of freedom from the device pose. This decouples the virtual world from the real world, since the locus of interaction is no longer important and rotational changes are measured incrementally.

Even when the real and virtual worlds are fully registered, the use of the real world may be purely to aid game mechanics, but have nothing to do with the game semantics. A popular approach for instant AR is the placement of a marker on a table, which is then tracked by the handheld's camera. While the game graphics will remain registered to the real world while the handheld is moved, the marker itself has no meaning other than defining a coordinate system for interaction. The location of the marker is arbitrarily chosen by the user and has no influence on the game unless it is moved. An interesting variety of using tracked objects such as markers is that if multiple such objects are used, their identity and placement can be used to define the gameplay. In particular, tracked objects can be moved while the handheld remains relatively stationary.

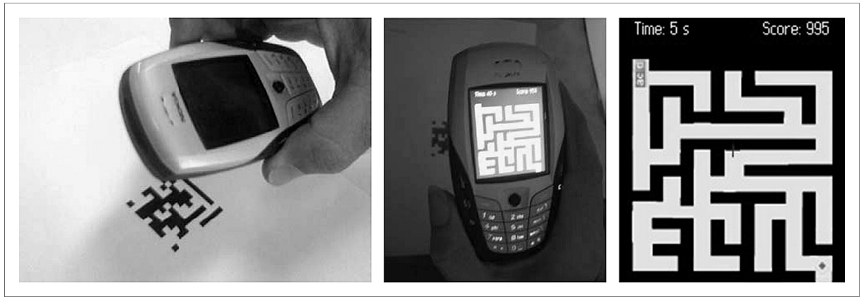

Fig. 6: Mobile Maze [5] goes one step further in the direction of pure VR by turning the handheld device into a purely simulated handheld maze game. The player has to guide a ball through a maze by tilting the physical maze itself. The software visually tracks the phone's orientation using a marker, but does not display any video image.

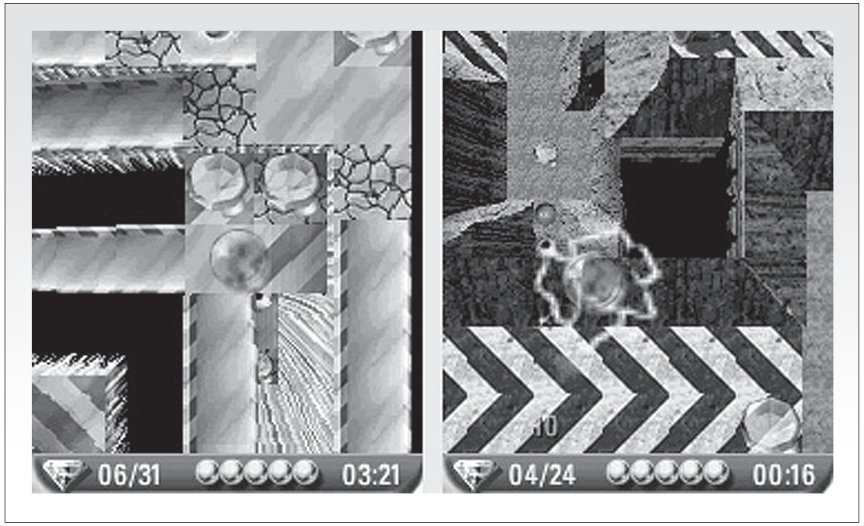

Fig. 7: Mobile Maze displays the whole maze on the screen, so that the impression of a handheld physical maze is suggested. Another variant of the same idea, Marble Revolution always centers on the Marble, while scrolling the game field, which is much larger than the screen. Marble Revolution has a physical interface, but otherwise no aspects that qualify as Mixed Reality. Instead, the player has to navigate a ball through large, scrolling levels by moving and tilting the phone. In contrast to Mobile Maze, Marble Revolution uses pixel flow detection to navigate the ball and does therefore not require fiducial markers.

[1] http://www.bit-side.com/

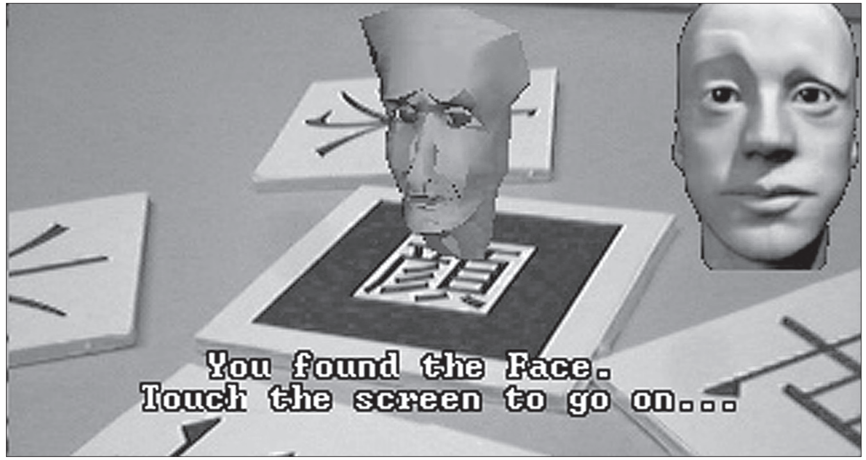

Fig. 8: AR Kanji [14] is a memory card game which asks the player to find the correct Kanji symbols for items depicted graphically on the handheld. The user must search for the right marker, which has the corresponding Kanji character on the back. By turning the chosen marker around, the identification and tracking of the marker is initialized. If the player has chosen the right marker, a 3D representation of the item is shown superimposed on the marker, and the user scores.

Fig. 9: AR Soccer [6] shows a virtual soccer goal and blends in the handheld's video image in the bottom half of the screen, letting a user view his own foot in the soccer environment. The aim of the game is to shot a virtual ball into a virtual goal. To do that, the player has to kick the ball with his foot, which is tracked using an advanced pixel flow detection algorithm. In contrast to simpler pixel flow methods such as used by the Mosquito Hunt game, ARSoccer accurately detects the edge of the moving foot and can thereby calculate the exact speed and direction of the foot hitting the ball.

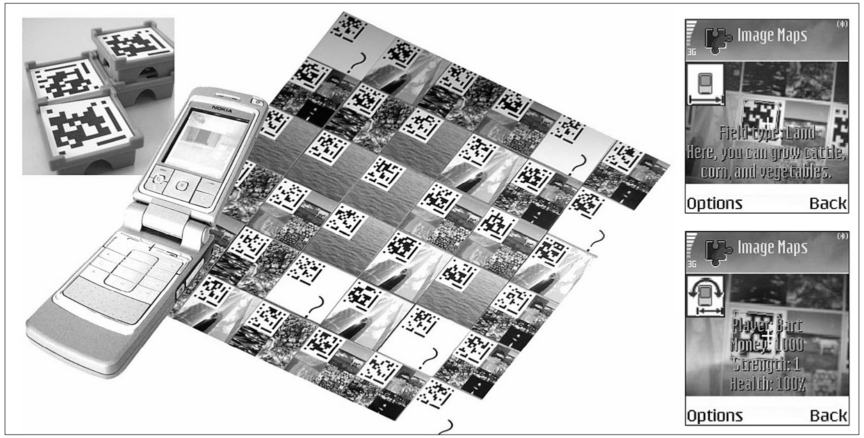

Fig. 10: Impera Visco [12] is a typical turn-based (also called "hot seat") multiplayer strategy game for cell phones that includes many physical elements of classical board games such as dices, pieces and cards. The game uses 36 cards that represent different resources and operations. In each game the cards are arranged differently, requiring the players to scan the game board with the mobile at game start. The mobile phone acts as a game manager rather than a 3D graphics display. Since the game is turn-based, only one phone is required, which can be passed on to the next player.

5 Multiplayer Games

Multiplayer AR games can be categorized by how they share their game space. The simplest form of multiplayer sharing is the sharing of the handheld device itself. While this obviously has the disadvantage that no simultaneous interaction is possible, it suits turn-taking games very well and is also popular in desktop games. Technically, the advantage of device sharing is that only one device with suitable software is required, which obliterates the need for software installation or networking, and is very suitable for instant, casual play.

Simultaneous AR gameplay using multiple networked devices can either be constructed from multiple individual AR spaces, i.e., one per user, or by constructing a shared space jointly observed by the players. Disjoint AR spaces are technically simpler and work for users who are in different locations. A shared space has more stringent requirements concerning technical issues such as tracking accuracy or network latency, but has the unique appeal of combining computer games with physically playing together, being able to engage in a lively conversation and observing the opponent's reactions. We have found these social aspects to be a strong factor of movitation and enjoyment in AR games.

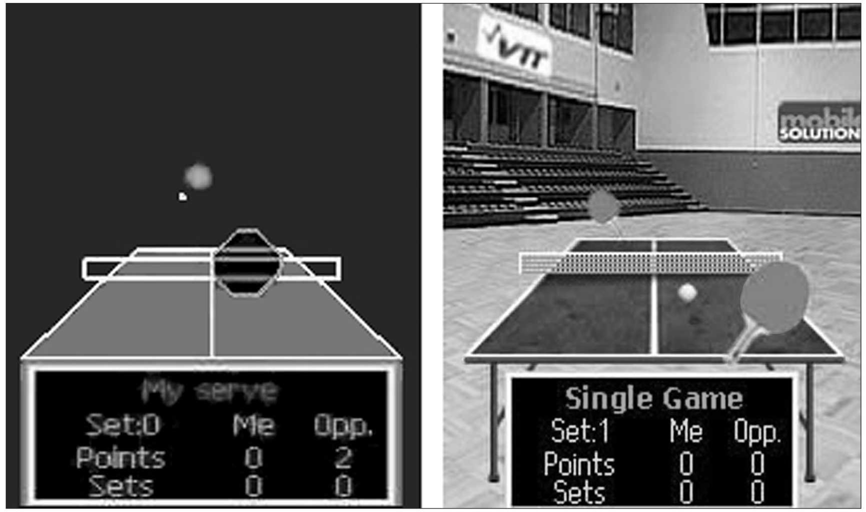

Fig. 11: Symball [7], a multi-player table tennis game for Symbian phones was developed in 2005 by Video Processing Team at VTT (Finland). The game shows a table tennis game from a player's perspective. Although the table and the ball are shared conceptually, no tracking is performed on these and therefore no shared space as described above exists. The game tracks the phones movements by detecting objects of certain color in the camera's video feed. While the table is painted as a static image, the paddle can be moved by tilting the phone. Two players can connect their phones via Bluetooth to compete in a game. The disjoint players' spaces in Symball theoretically enable remotely playing together, but in practice the short range of Bluetooth limits this option.

Fig. 12: AR Tennis [8], developed in 2005 at HIT Lab New Zealand also lets two players share a game of tennis but uses markers to establish a shared space for the players. The phone itself is used as a paddle to hit the ball, which requires a lot of physically movement with the device. Each phone can be fitted with a marker on the back so that it can be detected by the opponent's phone for visual feedback.

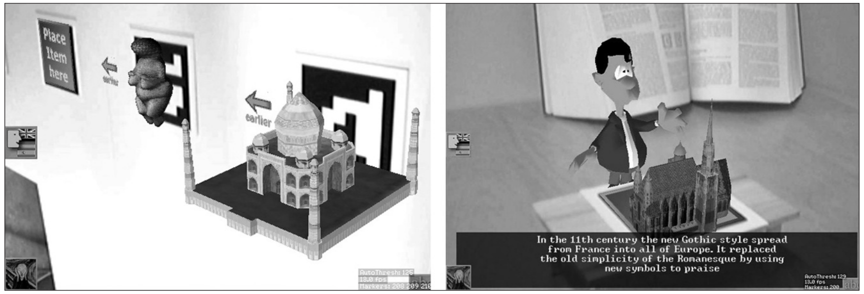

Fig. 13: Virtuoso [15] is a multi-player game for up to 4 players that spans a whole room fitted with a gallery of markers. The game requires the players to cooperate in order to finish the common task of sorting a set of historical items on a timeline (see left picture in the figure above) by their date of creation. Players need to cooperate, since only one item can be carried by a single player. When a player is stuck, she can ask Mr. Virtuoso an animated, virtual arts expert for hints (see right picture in the figure above). Hints are available in various multimedia formats, including multi-lingual narration, text, graphics, audio and video clips.

A shared space can be defined by a generic object such as a marker. In a minimalist setting no further real world aspects are considered. Larger instrumented environments typically have room for multiple players.

6 Complex Environments

In the extreme the game space can encompass a large area (e.g. a campus), supporting both face to face and remote gameplay at the same time. This option is extremely compelling, since the immersion in the "game world" is paid pack in heightened excitement of the players. Nevertheless, one must consider the effort involved in preparing such a larger, navigable environment to support the gameplay, which is definitely not reconcilable with instant, casual gaming. While placing a game board shipped with an AR game on a tabletop may be straightforward, a game that involves physical museum exhibits is only playable in exactly the museum it was designed for.

Such a complex environment will likely be designed for a larger number of concurrent players, and will make the collaboration between the players more complex. For an in-depth treatment of remote collaboration using general mixed reality technology, refer to [2]. We will limit our discussion here to giving an example showcasing the issues pertaining especially to handhelds and their potential for interaction in a complex game environment.

Fig. 14: Museum Augmented Reality Quest (MARQ) is an instance of a collaborative, multi-user edutainment game using handheld AR. It is situated in the permanent exhibition "medien.welten" at Technisches Museum Wien. The theme of this exhibition is the history of media technology. MARQ encompasses a large selection of exhibits and links them into an entertaining story. The objective of the game is to solve a quest composed of puzzles and other tasks associated with the exhibits. The target groups are classes of teenagers at age 12-16. A class is divided into two teams, each given a number of handhelds, which compete for the highest number of tasks solved in a given time.

Tasks vary widely depending on the nature of the exhibit and the kind of knowledge to be mediated. Interactions with mobile AR applications are supplemented by simpler techniques, like displaying classical 2D interfaces on the handheld. This allows integrating classical e-learning methods such as multiple choice questions, which are more rapidly produced.

A noteworthy type of task is interaction with the instrumented hands-on exhibits. These exhibits are tangible interfaces, specifically designed to explain certain technologies: For example, the Morse exhibit allows a user to input a character using an old-style push button, and displays the corresponding letter if one is recognized. These hands-on exhibits are computer controlled and can be set to present a certain task or operating mode when approached by a MARQ player. In that way, the environment is responsible to the player in ways beyond the handheld AR experience.

A prototype of the interaction is set up as an espionage story set in World War II. The exhibits have to be visited by the players in a certain sequence to achieve the game objectives. They start from the checkpoint (see left most picture in figure above), where the quest is introduced and the handhelds are handed out. The screens of the handhelds show a map of the exhibition, highlighting the relevant task locations, the current position of the players and lists already solved and remaining tasks.

Radio finder. The first task is a radio direction finder used at wartime to detect and record radio messages from mobile transceivers. The operator had to manually turn the antenna to home in on the signal and then follow it to record it, guided by characteristic sounds when approaching the exact signal direction. In the radio finder game the handheld has to be physically moved around the exhibit to find and hold the exact signal direction. Through the handheld the players see an AR compass superimposed onto the lower platform of the real exhibit, and hear sounds indicating the deviation from the exact signal direction, depending on the direction and the angle of deviation. Close the exact signal direction the characteristic beeps of a Morse message are played. Once the players have found the exact direction the handheld must stay in it until the entire message has been received (see 2nd picture in figure above).

Morse code. The game story explains that the message was sent in Morse code, and players must proceed to the Morse hands-on exhibit featuring an old-fashioned telegraph pushbutton (see 3rd and 4th pictures in figure above). Players are asked to translate the received Morse code into text. For that purpose the Morse exhibit is automatically switched to input mode: Every character input via the pushbutton is immediately translated into the corresponding letter on the terminal's screen. A Flash application on the handheld shows the previously recorded Morse code. The interface also contains a play button replaying the Morse code, and a virtual keyboard for entering the translation.

Enigma. The players now learn that the translated message is not plain text but must be decrypted by the Enigma machine, another hands-on exhibit. The Enigma was used by the Germans during World War II for encrypted communication. The exhibit shows a real Enigma embedded in a Virtual Showcase [4], a mixed reality display combining real artefacts with projected imagery through mirror optics. When the team arrives the Enigma exhibit automatically switches to free decryption mode (see right-most picture in figure above). The players decrypt the message letter by letter. One player operates the Enigma while another types in the plaintext into the handheld using a virtual keyboard again. This two user operation corresponds to the way an Enigma was actually operated in the field.

Quiz game. Besides the story-driven tasks, MARQ also features a number of multiple choice questions related to real exhibits or AR exhibits, which can be included in the game, but are mostly unrelated to the espionage story. These multiple choice questions are implemented in a Flash application that is data driven and can be configured purely by entering text associated with an exhibit into a database. A marker next to an exhibit triggers the display of the question once observed by the user's handheld.

After solving all assigned tasks or running out of time, the quest game is over and the players return to the checkpoint, where the results of their performance are displayed. The screen shows where mistakes occurred and the percentage of the message that was revealed.

Conclusions

Current technical trends give reason to believe that handheld computers may bring AR interfaces to a mass audience, making them suitable for everyday use. This paper aims to assist future designers of AR game experiences in understanding the design space of this new medium, characterized by small computing capacities, but an outstanding amount of flexibility and mobility.

The most important design aspects of handheld AR games, which are not part of conventional mobile games, are summarized in the following:

- Consider the physical design implications of the magic lens metaphor. Use the physical movement of the handheld device and the information – world registered or otherwise shown on the handhelds screen as an interaction technique.
- Explicitly decide what the AR display is going to be: either just the screen of the device, or the whole device together with its immediate environment. Determine how much real or virtual is going to be shown.
- Decide the circumstances of multiplayer operation. Which aspects of the mixed reality are going to be shared, which not?
- Handheld AR is useful for both casual, instant gameplay and as an interface for interacting with complex physical game environments. Make a suitable decision that has a realistic perspective of deployment, either as a casual game or as location based entertainment.

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