Toward Next-Gen Mobile AR Games

Wolfgang Broll, Irma Lindt, Iris Herbst, Jan Ohlenburg, Anne-Kathrin Braun, and Richard Wetzel
Fraunhofer Institute for Applied Information Technology (FIT), Germany

Mobile augmented reality games offer a new and rich game experience allowing players to move and interact in their physical environment with 3D content. The authors review existing approaches to mobile AR games and identify two major trends: small, user-modifiable AR games and larger-scale, event-based AR games that are interwoven with their physical environment.

Digital games employ digital technology as part of the game experience. In contrast to noncomputer games, digital games "facilitate the play of games that would be too complicated in a noncomputerized context."[1] Game developers can create rich, interactive virtual worlds that real people can inhabit. Through digital technology and the possibility of representing complex behavior, computer games can deliver new and intense experiences to players.

Mobile or pervasive games reach beyond desktop- or console-based gaming. They overcome spatial, temporal, and social boundaries of conventional computer games by making the real environment intrinsic.[2] They bridge the gap between traditional noncomputer games and existing video games by offering direct social interaction.[3] Thus, mobile games integrate social components of traditional games into digital games, extending them into our everyday activities.

Location-based or -aware games emphasize these aspects of pervasive games.[4] The game content and the player's interaction opportunities depend on the player's current real-world location. The user's local environment (including buildings, plants, people, and so on) might contain items relevant for gameplay. Moreover, interaction with some of these items might be part of the game. This interaction extends to other players who might compete against one another or cooperate as part of the game when sharing a certain area—similar to common real-world activities.

Finally, pervasive or mobile augmented reality (AR) games[5] represent distinctive location-aware pervasive games—that is, they use AR technology to enhance or modify the players' real environment with virtual content (see the "Augmented Reality" sidebar). Instead of being represented by an avatar like in many traditional computer games, players are their own avatar moving in the game world by moving in their real environment. Most pervasive AR games are purely outdoor. However, some of them facilitate combined indoor and outdoor activities. Pervasive AR games typically combine real and virtual content, storytelling, and the user's imagination to create a new type of entertainment experience. Such systems have the potential to create an ultimate gaming experience.[6]

Here, we identify major future trends as well as requirements and challenges in mobile AR games.

Lessons learned from previous AR games

Looking at existing pervasive AR games (see the sidebar "A Short History of Mobile AR Games"), we observe that while they're successful with respect to the delivered gaming experience several obstacles prevent their widespread adoption.

In previous games such as NetAttack or Epidemic Menace, users found solutions based on head-mounted apparatus—such as an additional backpack for the computer equipment—rather disturbing. In contrast, handheld solutions were less obtrusive but engendered strong feelings of immersion or presence. Furthermore, few approaches based on integrated hardware exist. Typically, prototypes are assembled from a large set of individual hardware components. Consequently, the

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Augumented Reality

Augmented reality (AR)[1-3] refers to the extension of the user's real environment by synthetic (virtual) content. This content might use various media, including but not limited to text, audio, images, and 3D objects. While all virtual content extends physical locations or objects, thus providing location-based information, 3D objects are precisely registered to their physical environment regarding their geometry (position and orientation) and ideally, their photometry. Registration requires appropriate additional technologies for tracking such information. The visual extension is typically done using optical or video see-through augmentation. Optical see-through augmentation is based on semitransparent head-mounted displays, superimposing the real environment using semitransparent mirrors while video see-through displays show a captured video image superimposed by the virtual content. The latter also applies to AR on handheld devices such as tablet PCs, ultramobile PCs, and mobile handheld devices such as PDAs and smart phones.

Paul Milgram[4] introduced the mixed reality (MR) continuum stretching from reality via AR, and augmented virtuality to virtual reality. Augmented virtuality refers to the extension of virtual worlds by real-world content (such as real persons in a virtual studio application). More recent publications suggest that additional dimensions such as ubiquity might be needed.[5] With respect to the number of concurrent users and the overall multiplicity of MR applications, a 3D taxonomy using the dimensions immersion, ubiquity, and multiplicity can be applied (see Figure A). Thus, immersion refers to the original Milgram continuum, while ubiquity refers to how and where such MR systems might be actually used, and multiplicity refers to the degree of usage by concurrent users.

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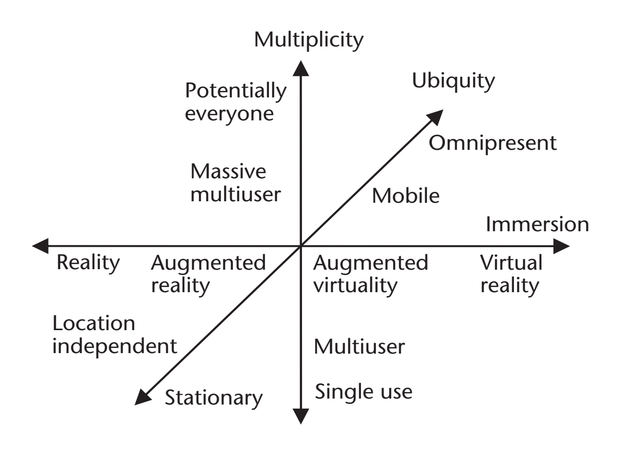

Figure A. Three-dimensional taxonomy for mixed reality environments extending the mixed reality continuum to ubiquity and multiplicity.

software runs on prototypic systems. Both result in a large effort to set up an AR game. One major reason for this is the lack of general orchestration and supervision tools. As a result, most existing location-based AR games such as ARQuake or Epidemic Menace are restricted to a specific local environment and their adaptation to another location requires a high degree of effort. Due to this fact the number of participants is usually rather small (for example, 6 to 10 players per session in Epidemic Menace).

Finally, despite the fact that they're restricted to a specific environment, most existing AR games lack integration with the real world. This often shows in virtual game objects appearing to be separate and not connected to aspects of the underlying environment (such as in Human Pacman). Thus, players concentrate on either the virtual or the real aspects of the game space, which prevents them from having a real mixed game experience.

Future mobile AR games will need to provide a nonobtrusive but immersive view, more robust hardware and software technology platforms, general orchestration and supervision tools, and better integration of virtual game artifacts with the physical environment.

Current developments

Based on the lessons learned we can identify two major directions for future mobile AR games that overcome some of the drawbacks of previous games.

The first is covered by small, simple AR games that use standard hardware components such as ultramobile PCs (UMPCs) or smart phones and built-in devices (such as cameras, GPS sensors, touch screens, touch pads, and so on). These

A Short History of Mobile AR Games

A pioneering work in mobile AR gaming was ARQuake,[1] developed in 2002. ARQuake is the AR version of the famous first-person shooter Quake. The aim is identical to the desktop version where the player shoots monsters and collects items. In the AR version, the players wear AR systems consisting of a laptop (in a backpack) attached to several sensors for tracking position such as differential GPS for the orientation and a camera for marker-based computer vision tracking.

In 2004, another AR variant of a famous computer game was developed. The story of Human Pacman[2] is the same as that of the original arcade game Pacman: Pacman (represented by one player) has to collect all the cookies in the world before he is caught by a ghost (represented by another player). The game's system consists of a central server, the wearable client system, a Bluetooth device, and a helper laptop. The client and server communicate via WiFi, and the client is connected to the physical devices via Bluetooth. The user's viewing orientation is tracked by a 3-degrees-of-freedom orientation sensor built into the helmet and the position is determined via GPS. A special sensor detects whether the player is touched by the enemy player.

NetAttack,[3] also developed in 2004, is a scavenger hunt game. The basic idea and technique of ARQuake was enhanced by having outdoor as well as indoor gameplay. The outdoor player wears a mobile AR system and is tracked by GPS and marker-based computer vision tracking. The outdoor player is supported by an indoor player. The partner inside, sitting at a desktop-based survey system, communicates via Wi-Fi with the outdoor player, guides him, and helps him find game items.

In 2004, AR Soccer[4]—the first handheld-based AR game—appeared. AR Soccer is a computer vision-based smart phone game. Players shoot a penalty by kicking a virtual ball into a virtual goal with their real feet. The smart phone's camera tracks the player's foot. Instead of an optical flow algorithm, the foot is detected and tracked using a 2D edge-extraction approach.

In 2005, AR Tennis[5] and The Invisible Train[6] were developed as marker-based games on handheld devices.

AR Tennis is a multiuser-supported smart phone game that also uses computer vision-based tracking. In AR Tennis, the smart phones are equipped with markers, which can be detected by the cameras of the other players' phones. The tracking data is transmitted via a peer-to-peer Bluetooth connection, thus enabling the two players to play tennis virtually with their smart phones.

The aim of the multiuser game The Invisible Train is to steer a train over a wooden railroad track. The player can interact over the touch screen by changing the speed of the trains and the switches. The Invisible Train is a synchronized multiuser game in which PDAs are connected via Wi-Fi. The tracking is realized by a marker-based computer vision approach.

In Capture the Flag,[7] developed in 2006, a team catches the opponent's flag, which is presented by a small wooden box. This box is equipped with a Bluetooth device and a touch sensor. The touch sensor tracks whether the participants pick or move the box. The box and the smart phone are connected via Bluetooth.

Mr. Virtuoso is an educational game played as video-see-through AR on a PDA.[8] The objective is to sort artwork according to their date of creation along a timeline. The timeline consists of fiducial markers. Each marker carries one artwork. The virtual expert Mr. Virtuoso provides information to the artworks. The PDAs are synchronized via Wi-Fi using a server.

In 2007, Epidemic Menace,[9] the successor of NetAttack, was developed. Epidemic Menace uses multiple devices including PDAs and smart phones. It also takes place indoors and outdoors, and the players communicate via smart phones. The smart phones display a small map of the game area and the user's current position. The PDA supports position tracking. The outdoor players are optionally equipped with mobile AR systems.

devices support several types of mobile connectivity (Wi-Fi, EDGE/3G, Bluetooth) and are optionally complemented by standard interaction devices such as wireless mice. The software typically uses well-established components (such as ARToolkit[4] for fiducial tracking or the NMEA [National Marine Electronics Association] protocol 0183 for GPS) and standard interaction techniques based on markers, mice, or built-in buttons to facilitate immediate use without training. This allows out-of-the-box AR games that can be set up and used without additional support. Such games let users extend or modify existing games, add game levels, or even create their own game within a certain game type predefined by the equipment. While the game will be independent of a specific environment, gamers can adapt their game and couple it more closely to their real local environment. Based on the robustness and widespread availability of the hardware and the easy setup (independent of specific locations), these AR games can be made commercially available in the near future.

The second type of AR games is event-based and far more complex, but it also allows a much more intense user experience. All types of hardware or combinations of hardware, several device types, and a wide range of software components are typical for such AR games. While the overall game story and technologies might be independent of the particular location, the game content and infrastructure setup usually depend heavily on the actual gaming location. This extends to aspects such as tracking and communication technology as well as real-world game items or the provision and setup of base stations. Besides the advanced hardware, such games often use sophisticated interaction techniques. The event-based games require a team of experts to prepare the location, set up the game, train the participants in hardware and interface mechanisms, and support and supervise the gameplay. These games often attract spectators in addition to the game players and supervisors. To achieve a high degree of presence, the real world and the virtual content must be closely coupled. Closely coupled AR games must consider blocking real objects when displaying virtual content or extend and modify existing real-world content such as buildings. Immersive output devices such as head-worn displays and location-based spatial sound support such AR games.

Figure 1. Ultramobile PC used as a Magic Lens in the game The Alchemists. The Magic Lens augments the real environment by applying virtual objects to fiducial markers.

Sample games

Here we present two games we recently developed that are representative of the two major types of emerging AR games.

The Alchemists

The Alchemists is a small and easy-to-set-up AR game about alchemy and magic potions. In the game, players become alchemists. They need to find and collect suitable ingredients for their potions. The game is typically played by two to four players over 1 or 2 hours. The player who gains a certain number of points wins. The game is played on standard hardware: two Sony Vaio UX 180P UMPCs with integrated cameras used for marker-based tracking (ARToolkit).[7]

The UMPC is a Magic Lens for the players (see Figure 1); the screen contains a video feed from the webcam on the back of the device. When the camera detects a marker, a 3D object superimposed on the video stream creates the illusion of looking through the UMPC into the augmented game space.

A marker can either represent an ingredient, a bag, or a cauldron. To set up the game, the players (or a designated game master) distribute and attach the ingredient and the cauldron markers to fixed positions in the environment. Each player carries the bag marker together with the UMPC.

During the game, the players search for the ingredients hidden in the environment. When they find one and inspect it, they have to consider whether this ingredient is valuable for the recipe they are going to brew. The players have a choice of three different potions to brew: love, fear, and power. They have the recipes for the different potions, but these

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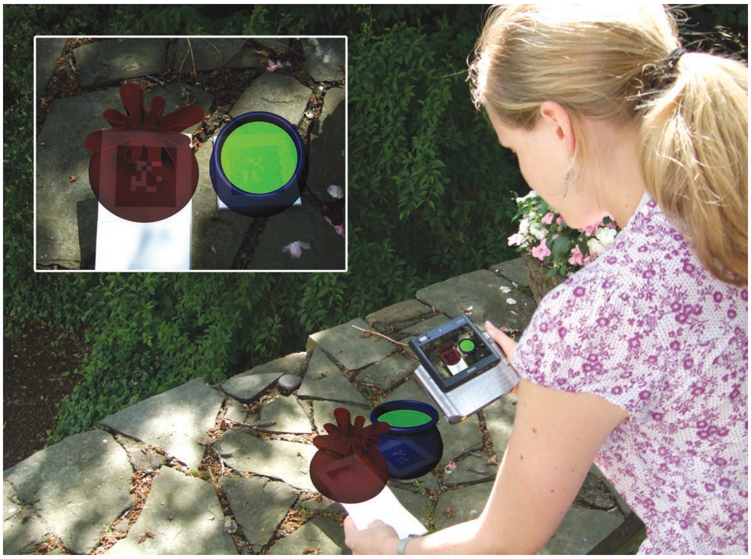

Figure 2. Augmented view of a basic interaction technique: putting two markers next to each other in the game The Alchemists.

are vague and don't name specific ingredients. Instead, the recipes refer to mythical or intrinsic attributes needed for the potion. Good ingredients for love potions are commonly connected to romantic gestures or are seen as aphrodisiacs. The players must consider fairy tales, legends of the past and present, common sense, and whatever else could help them interpret a certain ingredient's value.

To use an ingredient for a potion, the players have to collect it with their alchemist's bag and then go back to their cauldron and drop it into the brew. With enough ingredients, a potion is finally brewed. Which potion depends on the ingredients used. If all have strong values for fear (for example, a spider or syringe) then together they will create a masterful fear potion. If the ingredients do not quite fit, it could still be a mediocre potion or a complete failure that costs points.

Uncertainty is an important aspect of the game design. It's easy to implement but keeps the players discussing best options and second-guessing their choices while their actions are based on real-world knowledge and experiences.

Interaction techniques employed are deliberately straightforward: To pick up an ingredient, the player puts the bag marker next to the marker representing the ingredient. This moves the ingredient into the bag. To move the ingredient from the bag into the cauldron, the player puts the bag marker next to the cauldron marker. The ingredient is then put into the cauldron and the player receives text and audio feedback about the type and grade of potion (see Figure 2).

We designed the Alchemists as a simple game for three main reasons. First, we wanted to create a game that can be easily set up by players themselves. Second, the gameplay and the interaction techniques should be easily understandable so they don't require a lot of instructions. The game can be played almost instantly without a steep learning curve. Furthermore, we wanted to create a game that inspires players to create additional games employing the same technology. For the latter reason, we developed an XML-based format that contains the complete game description including the game artifacts and game rules. The game description can be created using a Web-based authoring tool developed by our project partner, the Interactive Institute in Sweden (www.tii.se).

Players can start with the Alchemist game description and modify it by using different 3D models or by gaining more points for specific potions. Starting with these small modifications, players can also come up with their own games, defining their own game rules and artifacts.

We evaluated the game with the help of several focus groups ranging from digital media students and game design students to members of a role-playing game association. Players easily grasped the game mechanics and quickly became engaged in the game. As we expected, team members discussed the potential usefulness of the ingredients they found. The players thought this aspect was appealing, leading many of them to recommend the game for situations where they would like to get to know each other (for example, kickoff meetings, student weekends, and company parties). The focus groups didn't rate the game's replayability very high because of the lack of mystery in later sessions as the best combinations of ingredients would then already be known to them. However, players made many suggestions on how to increase the game's longevity (for example, using the brewed potions to defeat a vicious dragon). As discussed before, this was an intentional part of the game design: to motivate players to use the authoring system and enhance the game experience.

We also play-tested the game with a small group of schoolchildren between 9 and 10 years old. They had no problems with the interaction techniques and greatly enjoyed the experience. Their style of playing was much faster compared to the older students. They were equally adept at figuring out the needed ingredients for their desired potion.

We foresee that this type of small and easy-to-set-up game can push the success of AR games because it uses inexpensive and robust hardware, doesn't require nonplayers and expensive events to stage the game, and is suitable for creating communities around the sharing and testing of player-created games.

TimeWarp

TimeWarp is an outdoor edutainment game that lets players explore a city's history using AR and mobile devices. The game is based on a tale about

Figure 3. A challenge in TimeWarp where the user selects the correct code of arms for Cologne.

Figure 4. The TimeWarp mobile AR system including an AR jacket, a PDA, headphones, and a head-mounted optical see-through display.

Figure 5. Real world (small picture) and augmentation seen through a head-mounted display in the game TimeWarp.

small elves called *Heinzelmännchen* who helped the citizens of Cologne, Germany, during the night (although no one had actually seen the elves). The elves disappeared one evening when a tailor's wife tried to trap them. TimeWarp extends this legend by spreading the rumor that the elves never left Cologne but fell into time holes and are still in the city, trapped in different time periods.

The game's goal is to find the elves in the city within specific time periods by using time travel. The players have to rescue them by solving small challenges requiring knowledge about the city and its history (see Figure 3). Players are equipped with a "magical technical" system that enables them to see the elves and to travel to different epochs—Roman, medieval, New Age, and even to the future.

The player's system consists of two mobile systems: a mobile AR system (see Figure 4) that augments the real environment with graphics and sound (see Figure 5) and a handheld information terminal that provides an overview on the game area and status. The TimeWarp application is based on our Morgan AR/VR framework and uses our AR/VR viewer Marvin for 3D visualization and audio. The authoring and orchestration tool AuthOr (which we discuss later) displays maps on the PDA.

In the course of a game, the players arrive at a base station. Here they get an introduction to the story and the system. Then the players master a training scenario to learn major interaction techniques. After they have familiarized themselves with the system, they go in search of the elves. The effort to organize such an event is enormous. A caretaker is required for each player or group of players. An additional organizer takes care of the players at a support station.

The interaction design for TimeWarp considers the requirements for this type of game because it takes place in a public, uncontrolled, and unrestricted space (see Figure 6, next page). TimeWarp implements socially acceptable controls and contributes to the overall AR experience. GPS, inertia tracking, and a feature-based computer vision carry out the ubiquitous tracking. We incorporated physical objects into the gameplay and used CityGML data for Cologne to achieve object occlusion for rendering. CityGML (www.citygml.org) is an XML-based exchange format for modeling 3D urban objects. Furthermore, user control should contribute to the overall AR experience. Thus, we avoided 2D control widgets such as menus or sliders. Besides using physical proximity as an interaction control, we implemented two core interaction controls:

- focus, action, and feedback
- placing

The location of TimeWarp is the old town of Cologne, an area of about 1.5 square miles. Within this area players have to find game-relevant locations. As

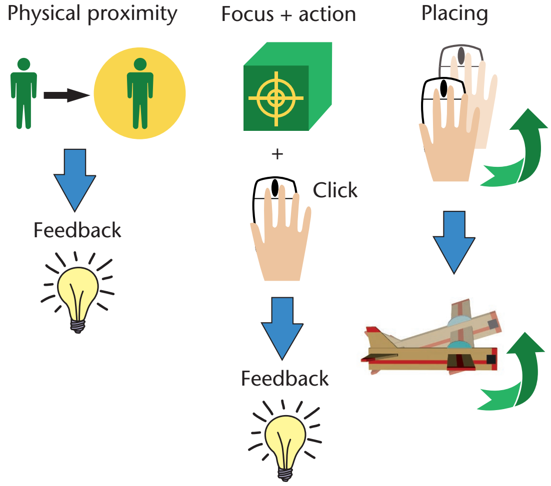

Figure 6. Overview of the three implemented interaction techniques in the game TimeWarp: proximity, focus/action/feedback, and placing.

the player's position is tracked, the system reacts to the player's physical proximity to a location. TimeWarp distinguishes between three levels of proximity: outside, near, and at a game location. The system reacts to this input depending on the player's physical proximity to a specific position. Time travel and interaction with time portals are examples for this type of control. As players approach the game location of a time portal (near), they hear the mysterious sound of wind chimes. If they get closer to the portal and enter it (at), then they travel in time automatically and immediately. Thunder accompanies this interaction and a view-related label denotes the new time period.

The remaining interaction controls require additional hardware to generate click events. Focus, action, and feedback is based on focus and click events. Focus is controlled with either a gaze-based view pointer, a view-related crosshair, or by stepping through selectable items in a predefined order using the mouse wheel. Actions and feedback associated with a click might consist of various elements—for example, items appear on the PDA interface and disappear in the AR augmentation (such as when a player buys an item). Actions and feedback associated with a click can be complex as well, depending on the individual needs of the designed challenge.

Placing was inspired by the Wii remote controller: Movements with a gyroscopic mouse in midair control the heading of a flying item. The interface designer specifies a target sphere the item must hit to finish the interaction task.

In contrast to The Alchemists, extending or modifying TimeWarp using new challenges or markets requires significant effort. According to the task and time period, individual 3D models (including extensions or modifications to existing buildings) and appropriate sounds must be provided. During the game design's initial stage, we interviewed city guides and historians about topics relevant for gameplay and spent several days in the relevant area to identify problematic places such as narrow alleys or busy roads. We also discussed the best setup for the game.

We evaluated TimeWarp through several user tests. More than 20 people between the ages of 15 and 40 played the game in Cologne. We collected data with video observation, questionnaires, and interviews.

We observed that people felt more engaged with virtual rather than real elements. Conversely they felt more present in the real environment than in the game. This effect might be reduced by providing more game content and a continuous gameplay. Therefore, the player is constantly within a mixed-reality environment. We also discovered that the interaction techniques have to be as simple as possible to avoid the players paying too much attention to technological aspects instead of the game.

Because of the complex and sophisticated technology, this kind of AR game provides an intensive user experience. We are convinced that such games, closely coupled to the real environment, will offer new opportunities in entertainment.

Enabling tools and technologies

Realizing AR games requires an appropriate framework allowing AR-specific rendering. To minimize effort for the developers, such a framework should be available on all platforms involved. Such frameworks must support individual input and output devices, including access to tracking technology.

For the game development, we use our Morgan AR/VR Framework[8] and Morgan Light, a lightweight version for handheld devices. While Morgan is a fully featured framework for various aspects of AR and VR developments that includes a render engine, streaming functionality, and access to different input and output devices, Morgan Light is designed for specific hardware and I/O capabilities of handheld devices. Both provide similar functionality through the same interfaces. This enables AR game developers targeting different platforms to concentrate on the game design rather than on platform-specific issues. Several abstraction layers achieve this functionality, including one layer for abstracting from graphics library access with implementations for OpenGL and Direct3D and their mobile versions OpenGL ES and Direct3DMobile. This lets the render engine be independent from the graphics subsystem.

Adapting game content to individual platforms

In traditional computer games, game designers manually optimize their games for each individual target platform. Usually this results in incompatible versions that can't interoperate; for example, online multiplayer games allow for online gaming only between versions of the same platform, although the

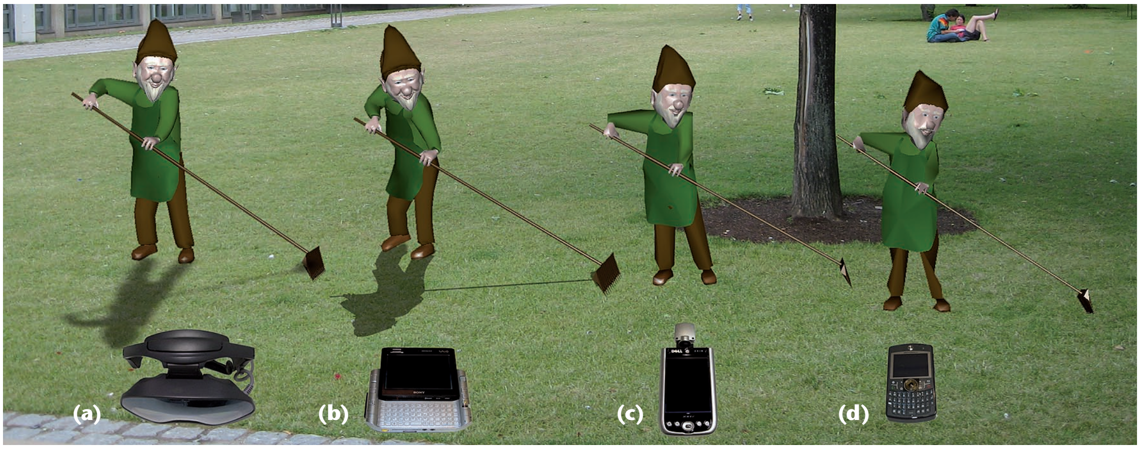

Figure 7. Different devices result in different render quality. (a) Head-mounted display plus laptop: high polygon count, smooth shadows; (b) Ultramobile PC: high polygon count, hard shadows; (c) PDA: medium polygon count, no shadows; (d) Smart phone: low polygon count, no shadows.

target platforms share similar functionality and processing power (such as Sony Playstation 3 or Microsoft Xbox 360). We follow a different approach for supporting the interoperation of various mobile AR systems. For player-generated games, players should be able to participate in the game using devices available to them. For both scenarios, this means the same game session can be shared by players using a mobile laptop-based system, a UMPC-based system, or even a handheld system (see Figure 7). Automated downscaling of the AR game content is required to adapt the output to the systems' individual capabilities. This lets game designers create AR game content without specific knowledge of the final target platform. This is even more important for player-created games because nonprofessional game designers usually don't have the tools and knowledge to adapt the game content to individual platforms.

In our framework, we support automatic downscaling of game content and rendering effects to achieve the best visual result on the target platform. This includes automatically generating levels of detail for 3D meshes, letting the game developer use the same high-quality models for all platforms without slowing down the rendering process on UMPCs or handheld devices. Additionally, while desktop AR systems or laptop-based AR systems can be quite powerful, advanced effects such as soft shadows or reflections can be used. These effects are turned off or the quality is reduced if the platform can't render them in real time.

Another important building block of our framework is support for Collada (Collaborative Design Activity for establishing an interchange file format for 3D applications, www.collada.org), which has become the quasistandard for digital content creation in games. Different content creation tools (such as Autodesk 3ds Max or Adobe Photoshop) can use Collada throughout the complete design cycle. In this content description format, it's possible to define different profiles. Hence, platforms that can't support a specific profile can ignore them and choose a more appropriate one. This way, different levels of visualization quality can be defined for different target platforms.

Supporting user interface development

Because mobile AR games of the second type (like the edutainment game TimeWarp) require the content to be coupled to the game environment, we need appropriate orchestration and setup tools to support this coupling.

Therefore, we developed a tool called AuthOr (see Figure 8) that supports the authoring and orchestration of mobile AR games and provides a map interface for the game developer where game elements can be placed directly within the game area. The same tool can also be used as part of a game interface itself. The map serves as an orientation aid for the players and allows the display of game elements on top of the map. AuthOr can augment arbitrary maps, including stylized maps of the area, topographic maps, and maps supplied by Google Earth, Google Maps, and Virtual Earth map tiles. Therefore, the effort to adapt a game session to a new location becomes reasonable.

Figure 8. The mobile information terminal of the TimeWarp game. (a) The game status is displayed. (b) AuthOr shows the user's environment, including game-related items.

Mobile AR games have the potential to facilitate the ultimate game experience by immersing players in a physical and virtual game world. Further work in this field will need to focus on high-quality displays that support an unobtrusive view and on more advanced tools that support development of different mobile target platforms as well as the orchestration and supervision of AR games, thus lowering overall development costs.

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Wolfgang Broll *is head of the Collaborative Virtual and Augmented Environments Department at Fraunhofer FIT and a lecturer at Aachen University of Technology (RWTH). He has been doing research in the area of mixed reality and 3D user interfaces since 1993. Broll received a PhD in computer science from the University of Tübingen. Contact him at wolfgang.broll@fit.fraunhofer.de.*

Irma Lindt *is a research associate and project manager at Fraunhofer FIT. Her research interests include adaptive user interfaces, interaction authoring, and pervasive gaming. Lindt received an MS in computer science from Eastern Michigan University and is a PhD candidate at the University of Koblenz-Landau. Contact her at irma.lindt@web.de.*

Iris Herbst *worked as a research associate in the Collaborative and Augmented Environments Department at Fraunhofer FIT and is a senior software engineer at Hocoma AG. Her research interests include wearable mixed reality systems, human–computer interaction, and multimodal interfaces. Herbst received a diploma in mathematics and computer science from Leibniz University Hannover. Contact her at iris.herbst@hocoma.com.*

Jan Ohlenburg *was the lead system architect of the Morgan AR/VR Framework and Morgan Light during his time at Fraunhofer FIT. He is a senior software engineer at Realtime Technology (RTT) AG. His research interests include computer graphics and scene graph management as well as AR on handheld devices. Ohlenburg received a diploma in computer science from Aachen University of Technology (RWTH). Contact him at jan.ohlenburg@rtt.ag.*

Anne-Kathrin Braun *works as a research associate in the Collaborative and Augmented Environments Department at Fraunhofer FIT. Her research interests include tracking and localization technologies and pervasive gaming. She received her diploma in computer science from the University of Koblenz-Landau and is currently working toward a PhD in computer science at the University of Koblenz-Landau. Contact her at anne-kathrin.braun@fit.fraunhofer.de.*

Richard Wetzel *is a research associate in the Collaborative and Augmented Environments Department at Fraunhofer FIT. His research interests include pervasive gaming, innovative learning environments, and mixed reality art. He received an MA in virtual realities from the National College of Art and Design in Dublin. Contact him at richard.wetzel@fit.fraunhofer.de.*