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Computer games are continuously improving graphics capabilities and game play, but the market demands show that more compelling gaming applications are required. In this article, the requirements of modern gaming applications are investigated and a classification of the most significant game design issues is presented. To understand the issues related to video and virtual reality gaming, an interactive game engine is designed and, as a case study, a traditional two-dimensional arcade game, called Breakout, is ported. Collision detection is supported between the graphics components of the application based on Newtonian laws of physics. To test the effectiveness of our approach, a tangible platform for playing interactive three-dimensional games using video see-through augmented reality techniques is proposed. To evaluate the effectiveness of each application, a pilot study was performed and the initial results of this study are presented.

KEYWORDS: *3D games; augmented reality; computer graphics; human computer interaction; interactive interfaces; virtual reality*

Entertainment plays a central role in modern society and it is not surprising that gaming applications are evolving very fast to keep up with the pace of the digital era in which we are living. During the past decade, the gaming industry invested into audio-visual simulation and interactive 3D graphics to provide more compelling games. Developers have designed a number of customized game engines that can support high quality real-time gamming applications and be easily used to develop different scenarios. The latest developments in popular game consoles like the Sony Playstation and the Xbox have demonstrated superb graphics capabilities and game play. However, in most of the cases, interaction is limited to the capabilities of external interaction devices such as joy-pads and steering wheels with force feedback. On the other hand, handheld gaming solutions offered by PlayStation Portable (PSP), third-generation (3G) mobile phones, and personal digital assistants (PDAs) have the obvious advantage of being mobile but they lack other important issues like speed, realism, display size, and compatibility with external devices.

A promising technology, which nowadays has the technical capabilities of superimposing digital information into the user's perception, is known as augmented

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reality (AR). Since its appearance in the past decade, AR has proven that it has great potential to many application domains including military, manufacturing and design, archaeology, education, entertainment, and many more. In technical terms, it is referred to as the merging of computer-generated information with images captured from the real environment in real-time performance.

AR applications usually relate to various research areas ranging from computer vision, computer graphics, and human-computer interaction that operate in conjunction with the aim of presenting an enhanced reality as well as allowing the user(s) to interact with it in a natural way. Hence, AR seems to be able to provide more support to the interaction issues existing in current real-time gaming systems and also seems to provide a unique visualization experience for future game players.

In the past, a few AR gaming prototypes had been developed illustrating the possibilities of the technology, targeting either indoor (Kim et al., 2005; Metaxas et al., 2005; Nilsen & Looser, 2005; Poupyrev, Billinghurst, Kato, & May, 2000; Starner et al., 2000; Woodward & HonKamaa, 2003) or outdoor environments (Henrysson, Billinghurst, & Ollila, 2005; Thomas et al., 2000; Wagner, Pintaric, Ledermann, & Schmalstieg, 2005). Evaluation studies have shown that the concept of AR gaming is feasible and they gave input for further development (Andersen, Kristensen, Nielsen, & Grønbæk, 2004; Nilsen, Linton, & Looser, 2004).

In addition, the design and implementation of software user interfaces that will produce a robust AR interface are interrelated with the use of human-computer interaction techniques developed in offering greater autonomy when compared with traditional windows-style interfaces. The integration of such interfaces into AR systems can reduce the complexity of the human-computer interaction using implicit contextual input information (Rekimoto & Nagao, 1995). Nevertheless, the design and implementation of an effective AR gaming platform is a nontrivial task and an area of continuous research.

Moreover, universities and research organizations have begun to investigate how video game technology can be used to change the way people learn (Shaffer, Squire, Halverson, & Gee, 2005) or adopted into virtual reality (VR) and used for educational and training purposes (Zyda, 2005). The U.S. Army paid more than $5 million to design a video game based on the Xbox platform to train troops in urban combat (Korris, 2004).

Furthermore, the MR for Military Operations in Urban Terrain project (MR OUT) is installed at the U.S. Army's Research Development and Engineering Command and focuses on a layered representation of combat reality (Hughes et al., 2005). The application uses an extreme and complex layered representation of combat reality, using all the simulation domains such as live, virtual, and constructive by applying advanced video see-through mixed reality (MR) technologies.

The goal of this work is to explore whether AR gaming can provide an alternative way of playing games. To avoid the risks of evaluating an AR system that has not undergone rigorous testing of perceptual design and application utility (Livingston, 2005), user performance is tested by combining some features of video games into a VR gaming application and extending them to a tangible experience of video see-through

AR. To identify the key characteristics of video games, a computer graphics engine has been implemented based on OpenGL and C++ that can support standard visualization functionality (i.e., lighting, culling, and texturing) as well as a physics engine (i.e., collision detection). Based on this, a simple 2D arcade game called Breakout is designed and implemented in a VR environment and then ported into an interactive AR interface, which controls both the visualization and interactions performed during the game.

Background work

There are a few experimental AR gaming applications, and this section will cover only a sample of the most characteristic examples. One of the earliest experimental applications for indoor environments is a multiuser AR gaming system for board games that maintains social communication and provides private space to allow individualism (Szalavári, Eckstein, & Gervautz, 1998). The concept was applied through the development of the Mah-Jongg game to test the setup and interaction techniques.

Another early approach is the Shared Space interface (Poupyrev et al., 2000) that investigated whether the combination of AR with physical and spatial 3D interfaces can be used to create face-to-face gaming. CamBall (Woodward & HonKamaa, 2003) is an interactive augmented virtual table tennis environment using low-cost hardware. Users can play the game over local area network (LAN) or over the Internet using real rackets and web cameras. Another attractive feature of this latter application is that it allows a network audience to view the game. BattleBoard 3D (Andersen et al., 2004) is an AR-based game prototype especially designed for children. The game makes use of LEGO for the physical and digital pieces to support effective interaction, but initial studies with a group of 13-year-old children showed problems in collaboration.

Nilsen and Looser (2005) implemented and evaluated a prototype AR game called AR Tankwar to discuss the role of social interaction in both tabletop and computer gaming. Metaxas et al. (2005) proposed an MR game, called SCORPIODROME, for groups of 3 to 4 children aged 11 to 14 years old, aiming at exploring social gaming. The work reports on some of the lessons learned from this design process and how SCORPIODROME paves the way toward the development of a whole class of MR games. Moreover, Starner et al. (2000) discussed some of the potential for the application of AR gaming through a developing test-bed called WARPING.

Two game implementations that engage multiple players in several different roles demonstrated how users can interact with the mobile and stationary platforms through gestures, voice, head movement, location, and physical objects. ARPushPush (Kim et al., 2005) is another indoor AR game that uses vision-based tracking (based on two cameras) and users' hand gestures to allow a user to work in a wide area and to collaborate with other users. The first camera detects markers attached on the ceiling and the second camera detects markers attached to the back of the user's hand for visualization and interaction.

A few prototypes exist for outdoor environments, with the most significant being ARQuake (Thomas et al., 2000), which is an AR version of the popular Quake game. The setup requires a head-mounted display, a mobile computer, a head tracker, and a GPS system to provide inputs to walk around in the real world and play Quake against virtual monsters.

Mobile gaming is an emerging area, although it currently has many limitations. An early prototype is the Invisible Train project, where users control augmented trains on a real wooden miniature railroad track (Wagner et al., 2005). The architecture of Invisible Train is focused on mobile computing and PDAs, which restrict the user's field of view to the limited resolution of current PDA technology. Henrysson et al. (2005) demonstrated a face-to-face collaborative AR tennis game that operates on 3G phones. However, although initial user studies showed that mobile AR can be used to enhance collaboration, the prototype game achieved a maximum rendering speed of seven frames per second.

ELMO is an optical see-through AR display developed for multiuser co-located collaboration (Kiyokawa, Billinghurst, Campbell, & Woods, 2003). Based on ELMO, a collaborative AR Breakout application was implemented and some initial evaluation of the user experience was performed. However, the application presented is a kind of "breakout" game and the game design is completely different from the work presented in this article. In addition, ELMO focuses on display and collaboration issues, whereas this work pays attention to game design experiences including the graphics and physics engine and also compares gaming experiences in both VR and AR environments.

Game design issues

Important issues in game design include a combination of aesthetic, technical, social, and cultural perspectives. Konzack (2002) described a method to analyze all of the above issues in computer games based on seven different layers, including hardware, program code, functionality, game play, meaning, referentiality, and socioculture. On the contrary, video games define all the aspects of the game including the rules as well as the appearance and the interactions.

However, the interaction cannot be performed in a direct way (Andersen et al., 2004) but through the use of I/O devices such as the keyboard, joystick, mouse, and so on. Similar to video games, VR prototypes seem to follow most of their characteristics (Manninen, 2002), with the only difference of offering, in some cases, a greater level of immersion. Based on the above classifications, an extended categorization, this time addressed to AR gaming, is proposed. The most important features include technical characteristics; interactivity; social, cultural, and pedagogical issues; collaboration; and game scenarios and are summarized in Table 1.

In the remainder of this section, a brief overview of the strengths and weaknesses of video, VR, and AR games as well as the potential of applying AR technology into gaming are theoretically explored.

TABLE 1: Game Design Issues for Video and Augmented Reality Games

Game Design Issues	*Video Games*	*VR Games*	*AR Games*
Technical characteristics	standard visualization and interaction; high resolution and photo-realism	advanced visualization; medium resolution and usually high level of immersion	advanced visualization and interaction; adaptability and usability issues
Interactivity	limited to standard interaction devices	advanced using computer sensors	advanced using computer sensors and natural methods
Social, cultural, and pedagogical issues	not well supported (indirect)	not well supported (indirect)	can be direct and indirect
Collaboration	based on network capabilities (indirect)	based on network and system (indirect)	can be direct and/or indirect
Game scenarios	usually synthetic and unreal	synthetic and unreal	more pragmatic; need to merge scenario with real world

NOTE: VR = virtual reality; AR = augmented reality.

Technical characteristics

Technical characteristics in a gaming environment refer to all the aspects that relate to the technological characteristics of computer games. These include both the software and hardware components that are used in conjunction to form the game. In some cases, the success of a game is analogous to the complexity of the technical characteristics, but this is not always the case. Some characteristic examples relate to the rendering effectiveness of the visualization (i.e., level of detail, photorealism), the rendering speed (i.e., fast updates on frame rates per second), or even the hardware devices used for the visualization (i.e., television, computer monitor, or HMD) and interaction tasks required. In VR games, players can make use of more sophisticated hardware devices to perceive and interact with the gaming environment. For example, a custom VR configuration would require the use of optical or video see-through HMDs for the visualization side and sophisticated sensor devices for six degrees-of-freedom (DOF) interaction such as 3D mouse and sensor gloves.

However, the greatest limitation is the high cost of the hardware setup, although some manufacturers have lowered the prices over the past few years. Another important limitation is the usability issues of sophisticated devices as well as the adaptability of the gaming community. Although AR games make use of the same hardware as VR does, the complexity is increased due to the fact that more elements (i.e., computer vision, image processing, and pattern recognition) come into play. In addition, calibration (i.e., video camera, HMD) and latency are two important issues that have been minimized when an application is designed but before it is implemented. However, depending on the gaming application, sometimes the real environment can play a significant role in the AR game (i.e., ARQuake), thus reducing the graphics requirements.

Interactivity

Interactivity refers to all types of interactions a computer game can support. A successful game must allow single or multiple players to interact in the easiest and most natural way, but not all games require a high level of interaction. For example, a strategy game is focused more on the game play rather than on the interactions between the gaming environment and the players. Most computer games existing nowadays suffer from a low degree of interactivity, mainly due to the complexity and high cost of associated hardware devices. Typical devices used in video game platforms include standard I/O devices (i.e., keyboard and mouse) and cheap interaction and force-feedback controls (i.e., joypads and joysticks).

One of the main aims of virtual gaming environments is to provide an immersive experience to players. A number of sensors and interaction devices exist nowadays that can be easily integrated into VR games, such as position trackers (i.e., magnetic, acoustic, inertial, and GPS), 3D mice (i.e., SpaceMouse, Trackball), and pointing devices (i.e., Wanda and pitch gloves). However, although these devices have the potential to improve the overall immersion of the game and can be used fairly simply by VR experts, it is not so straightforward to be adopted by the majority of the gaming community.

In contrast, AR technology offers a unique solution to the limitations of video and VR games because it can support all interaction devices that current VR and gaming systems do, as well as tangible interaction mechanisms. The spatial relationship between the players and the game can play an important role in the immersion and thus the overall entertainment of the players. Depending on the type and scenario of a game, different spatial relationships are required. For outdoor gaming environments, the spatial relationships can vary in the range of a few meters to hundreds of meters and usually the tracking requirements are not very high. Typically, errors in the range of a few meters (i.e., up to 50 meters) are usually acceptable. On the contrary, in indoor gaming systems, the range of operation varies between a few centimeters and a few meters, but the accuracy of the tracking is substantially higher.

Social, cultural, and pedagogical issues

Social and cultural issues cover a wide range of aspects that can occur during a game. Social interaction refers to the collective communication between the players during and after the game. The role of social interaction in both traditional and computer gaming has been previously discussed by Nilsen and Looser (2005). A considerable new form of social interactions of video games can be considered to be the Internet. Cultural interactions depend on the characteristics of the player(s) such as ethnology and cultural identity. Players from different countries have different ways of reacting and communicating throughout a game, but in a video game, it is very difficult to express these feelings. Furthermore, pedagogical issues could be of great benefit if the aim of the game is to educate and train in addition to the educational aspects of it. During the past few years, a lot of progress has been made on the pedagogical aspects of video and VR games in an educational context, but there are still adaptability and interoperability issues that remain unsolved.

In AR games, social and cultural interactions can be handled in a way that is very similar to the way players react in traditional games. The underlying reason behind this is because AR attempts to enhance the real environment with virtual information and not to replace it. If the enhancement of the real world with spatial audio-visual information is performed effectively, it can trigger not only the normal reactions of the players but also unusual reactions that are otherwise impossible to test. Finally, as far as pedagogical issues are concerned, AR gaming seems to be able to provide a much better audio-visual sense of the gaming environment, thus increasing the level of perception. Although extensive studies need to be performed in perception issues and AR gaming, initial observations have shown that 3D and spatial augmentations can provide an exciting and challenging platform for extending current learning approaches (Liarokapis et al., 2005; Liarokapis, White, & Lister, 2004).

Collaboration

Collaboration between players is an essential aspect of any type of game including traditional, video, VR, and AR. Nowadays, most video games offer network capabilities and thus players have the advantage of collaborating indirectly through the different types of networks (WAN, LAN, TCP/IP, wireless, etc.). The negative side of collaboration in video games is that when players try to collaborate using direct means, they often get distracted from the game. In VR gaming, the same rules can apply with the difference that virtual representations of humans (also known as avatars) can be used to generate collaborative virtual worlds. However, even if the physical characteristics of avatars can be realistically modeled, it is not possible to model accurately the social, cultural, and behavioral characteristics.

On the contrary, in AR environments, it seems much easier to have direct collaboration as well as indirect. In the past, a few experimental collaborative gaming applications had been proposed (Henrysson et al., 2005; Kim et al., 2005; Szalavári et al., 1998), but up to now, collaboration has not reached a satisfactory level of physical communication. The ultimate goal in AR would be to replicate the way we collaborate in real life and not restrict it to just vision but expand it to other senses like aural and smell.

Game scenarios

Game scenarios are perhaps the most important aspects of most types of games and possibly the most difficult to implement because they are linked to the overall satisfaction and enjoyment of the players. A poor scenario will discourage players to try out a game even if the issues discussed above are well designed and implemented. In video and VR games, the scenarios can be more complex because the environment is completely synthetic.

For AR gaming, the effective designing of game scenarios involves extra consideration. The development of AR scenarios should be user-centered to match the user experiences of video and classical games as well as the requirements of all the technological enhancements. Thus, it is considered a compelling and difficult task, and more research has to be carried out on user studies to determine the ideal scenarios. In the next section, the requirements used in the specification of Breakout are illustrated. Furthermore, the software and hardware components used in this work are briefly presented.

Specification and architecture

To illustrate how AR can combine the game design issues described above and solve some of the limitations of current video games, a traditional 2D video game is implemented first in VR and then transformed into AR. The traditional 2D Breakout is one of the first interactive video games available on personal computers. The main idea is to knock down a set of 2D bricks using a 2D racket and a ball moving at constant speed. As soon as the ball collides with a brick, it vanishes. The goal of the game is to make all the bricks disappear from the game arena. To increase the level of difficulty and game play, later versions make use of multiple rackets and balls and vary the speed of the ball.

For the VR and AR Breakout, the basic principles remain the same, but there are a few differences in the underlying geometry and physics (used for calculating collisions). The first is that the VR variant Breakout, a cylindrical wall made up of 3D bricks, exists in the middle of the simulation area. A single player controls three curved bats, each positioned at an angle of 120 degrees to each other. The bats can move clockwise or counter-clockwise using the keyboard arrow keys (or mouse if preferred) as input. The cylindrical wall is situated in the middle of the circle and is constructed with 12 bricks in such a way that it looks like a shaft (see Figure 1a).

The objective for a single player is to knock the bricks down using a small ball as illustrated in Figure 1b. A brick vanishes when struck by the ball and any bricks above it fall under gravity force until they reach the ground. When all the bricks vanish, then a new wall appears in the same position as the previous one. Also, to enhance the functionality of the game, the shaft may contain some gold bricks. When a gold brick is struck, it vanishes, but two extra balls appear in the play areas. Finally, an account of the scope for the player is kept and displayed on the screen.

Breakout elements

In this section, the most important game elements of Breakout are briefly explained to provide an understanding of the game.

Bricks. Players have to bring down all the bricks of the well to gain points. Each brick counts as 1 point, but bonus bricks also exist that give 3 points.

Collision angle. To increase the level of excitement, a special case is implemented in ball-well collision aimed at bringing down all the vertical bricks of the well.

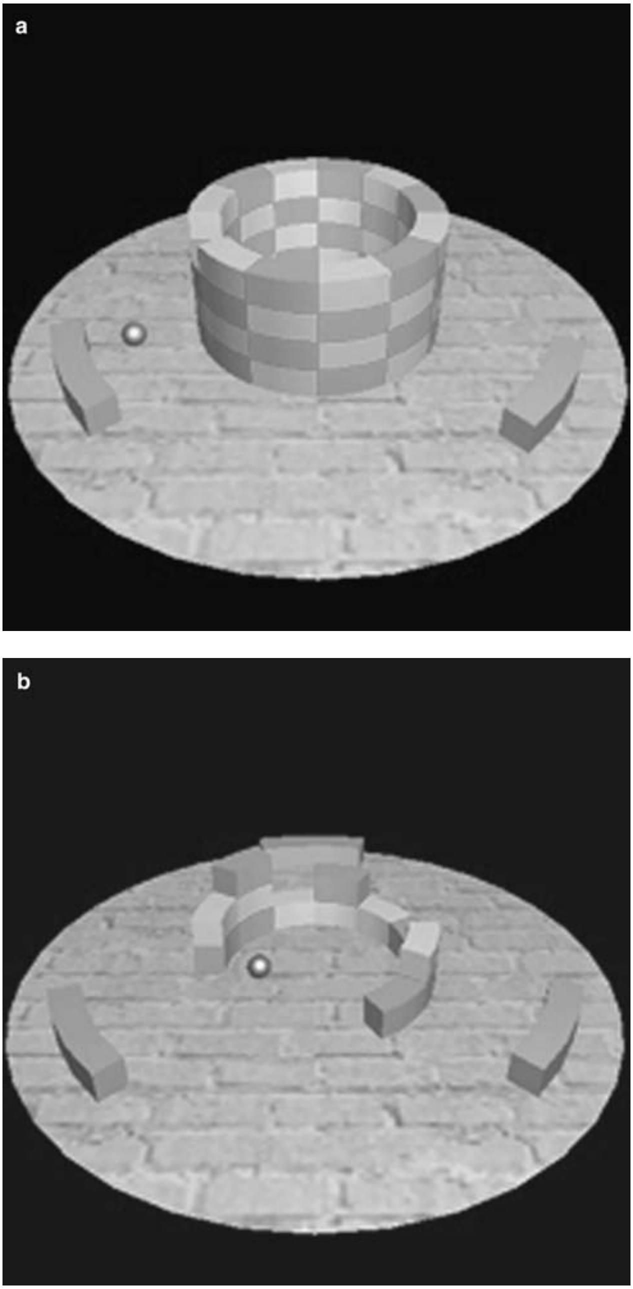

FIGURE 1: Breakout Simulation at (a) Start of the Game and (b) During the Game

Multiple balls. To increase the level of difficulty of the game, up to five balls can be inserted simultaneously into the game. To make the game easier, the starting point for the balls is the same position for all balls, thus, not all five balls can start simultaneously.

Reset. Players can reset the game at anytime if they are not happy with their progress.

Help and tips. Help can be provided to the players before and during the game by pressing "h" on the keyboard.

Implementation

The software components are based on a custom-based C++ graphics library that is capable of performing gaming operations such as interactive camera switching, interactive lighting, standard and environmental texture mapping, sounds, and collision detection. The AR environment was designed based on the implementation of the VR Breakout as well as on the experiences gained from past experimental AR interfaces (Liarokapis et al., 2005; Liarokapis et al., 2004), which are built on top of ARToolKit's vision libraries (Poupyrev et al., 2000).

The hardware configuration is based on a Toshiba laptop, equipped with a 2.0 GHz m-processor, 1 MB of RAM memory and NVIDIA GeForce FX Go5200, a USB Logitech Web-camera, and a set of predefined black-and-white marker cards. The camera supports 640 × 480 image resolution with 30 frames per second (fps) and 1.3 MP, and the size of the marker cards is set to 80mm × 80mm, 100mm × 100mm, and 160mm × 160mm, providing different ranges of operation.

Physics simulation

In the real world, time is considered to be continuous, but in computer simulation, time is discrete (Bergen, 2004). The object transformations can be defined as discrete sampled instances of time. However, when collision detection calculations are applied for these discrete sample instances of time, missed or late collisions can appear. For example, an object traveling at a high speed at a sampled time is likely to traverse far without performing any collision with the surrounding objects (i.e., the ball would pass through the wall in Figure 2). A solution to this is to use an increased sampling rate, which has the disadvantage of increasing the computational load of the simulation.

However, for a simple gaming application like 3D Breakout, it would not add much more to the game play. The behavior of the ball was modeled using Newtonian mechanics and behaves in a realistic manner apart from that we have assumed no loss of energy. Therefore, all collisions are considered pure elastic. Also, it is assumed that all 3D objects (ball, wall, bats, and bricks) are made up of the same material. This as well as the elasticity of the collisions automatically reduce the realism of the simulation. The simulation is controlled by a virtual timer, which is

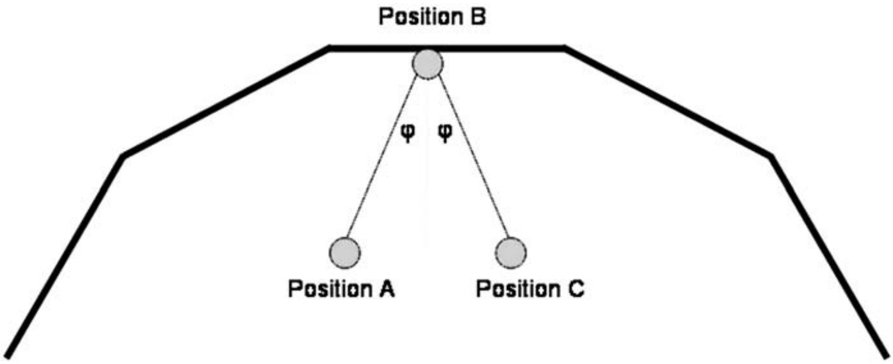

FIGURE 2: Ball-Wall Collision Detection

responsible for all motion calculations of the game. The velocity of the ball (defined as v) as well as the distance (defined as s) traveled during the game play were modeled based on the Newtonian laws that describe the following equations:

$$v = v_0 + \alpha t \text{ and } s = s_0 + vt \tag{1}$$

where v_0 is the initial velocity, α represents the acceleration, s_0 the initial distance, and t the time. The collision detection algorithm calculates whether two objects intersect during the simulation. Based on the virtual timer, if intersection is found, then the location and time of collision are stored. However, to avoid exhaustive comparison of the objects, which would be very expensive, the objects are organized into collision groups (Eberly, 2001). Three different collision groups have been carefully designed including ball-wall, ball-well, and ball-bats. To simplify the game, for the first two cases, the detection collision uses the same algorithm, whereas extra work has been done for the third case. In the simplest scenarios (first two cases), the ball makes a collision with an invisible vertical wall as illustrated in Figure 2.

Because the collision is considered pure elastic, the velocity of the ball remains unchanged at positions A and B (see Figure 2). Therefore, the direction of the ball in the above-mentioned positions needs to be calculated in a frequent timescale using the Newtonian laws. Next, the collision detection between the ball and the wall in the joints is considered. The advantage of designing all major objects (bricks, wall, and bats) using primitive objects (rectangular) is that it allows for a generic approach in some parts of the collisions that have occurred. For example, the bats and the bricks have similar joint sections to the wall and thus will be examined once. In the case of the bats, collision detection is the most difficult to deal with and thus it is described in detail. Special care is taken in the collisions that occurred in the edges and in the joints of the bats. Collisions in the joints of the bats in 3D Breakout can occur either in the inside or the outside area, as shown in Figure 3.

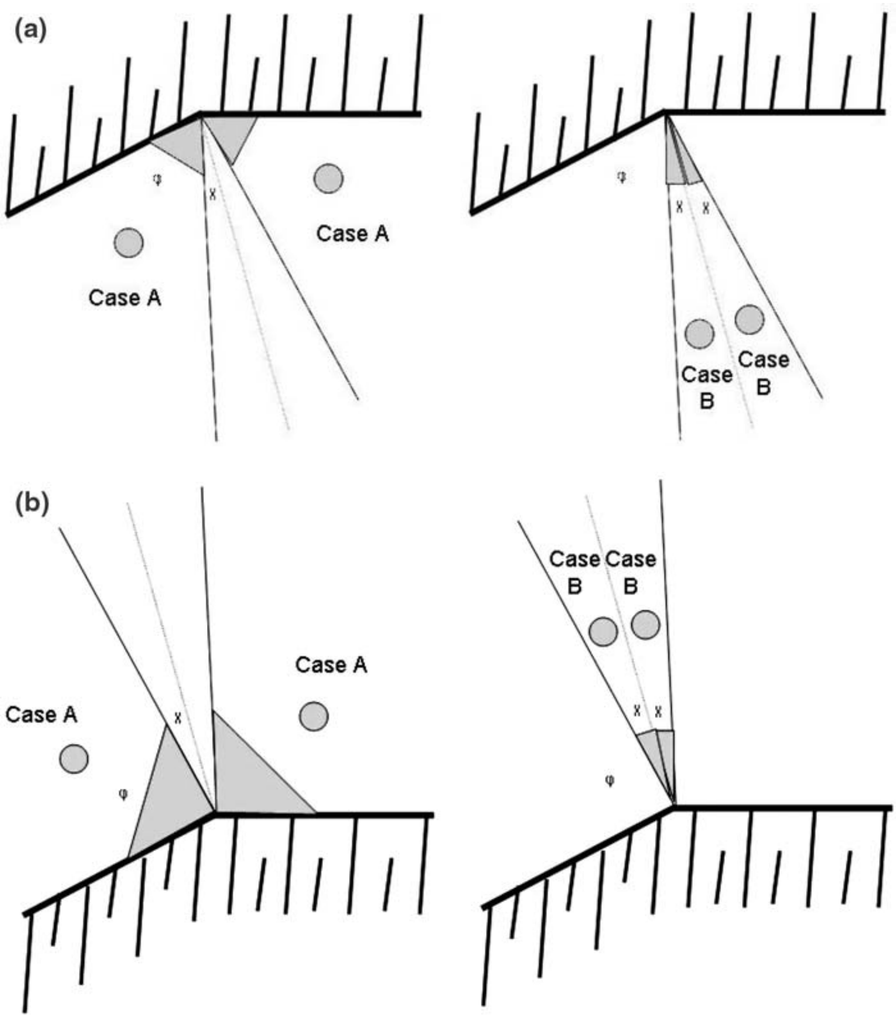

FIGURE 3: Collision Cases in the Joints of the Bats: (a) Collision in the Inside Area of the Bats and (b) Collision in the Outside Area of the Bats

To calculate the collisions when the ball hits the joints of the inside bat, two cases have been identified. In the first case, collision occurred in the inside area of the bat (see Figure 3a), whereas in the second case, it occurred in the outside area of the bat (see Figure 3b). The only difference between the above cases is the angle of operation. As far as the edges are concerned, to simulate realistic collisions, three different cases were implemented (see Figure 4).

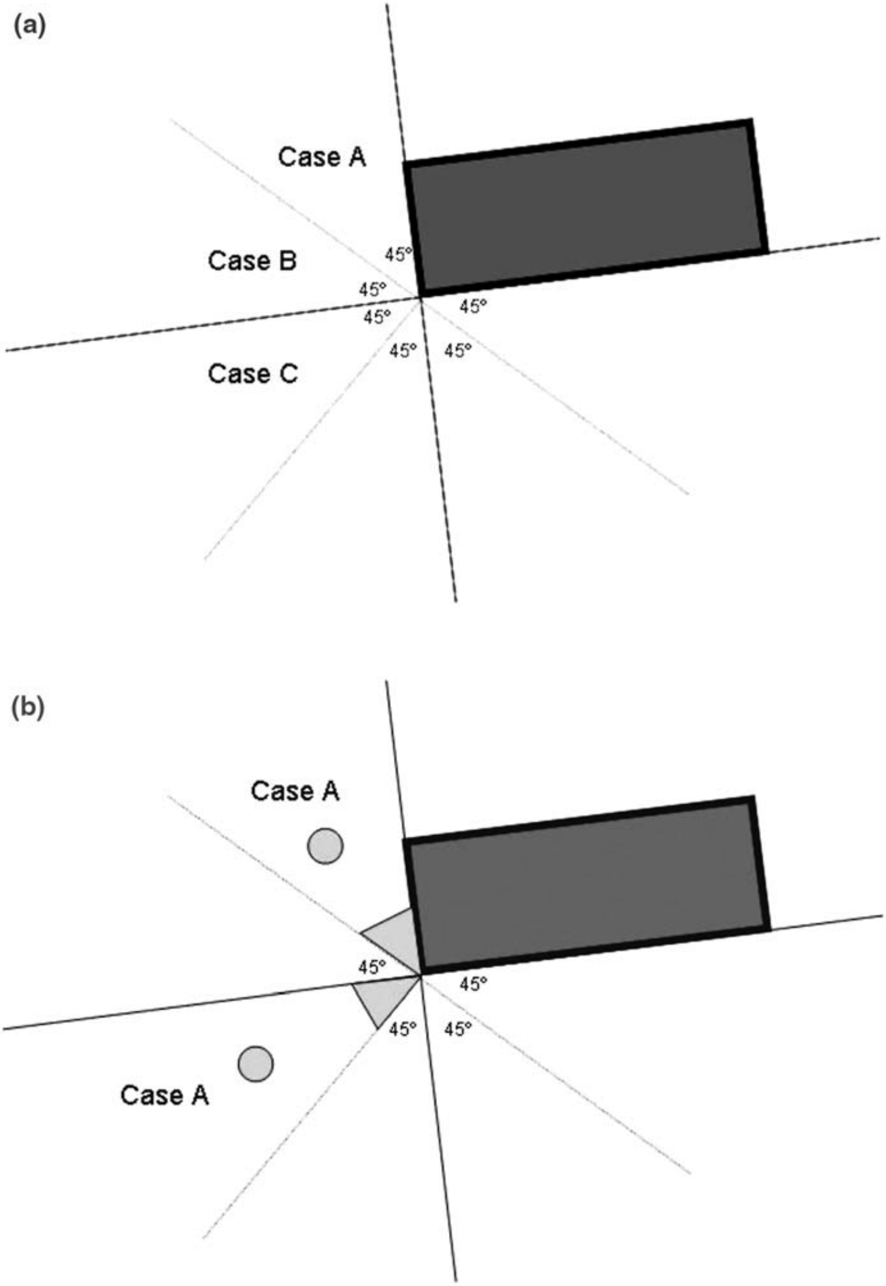

FIGURE 4: Bat-Ball Collision Detection: (a) Ball-Bat Edge Collision Detection Cases, (b) Collision in Case A, (c) Collision in Case B, and (d) Collision in Case C

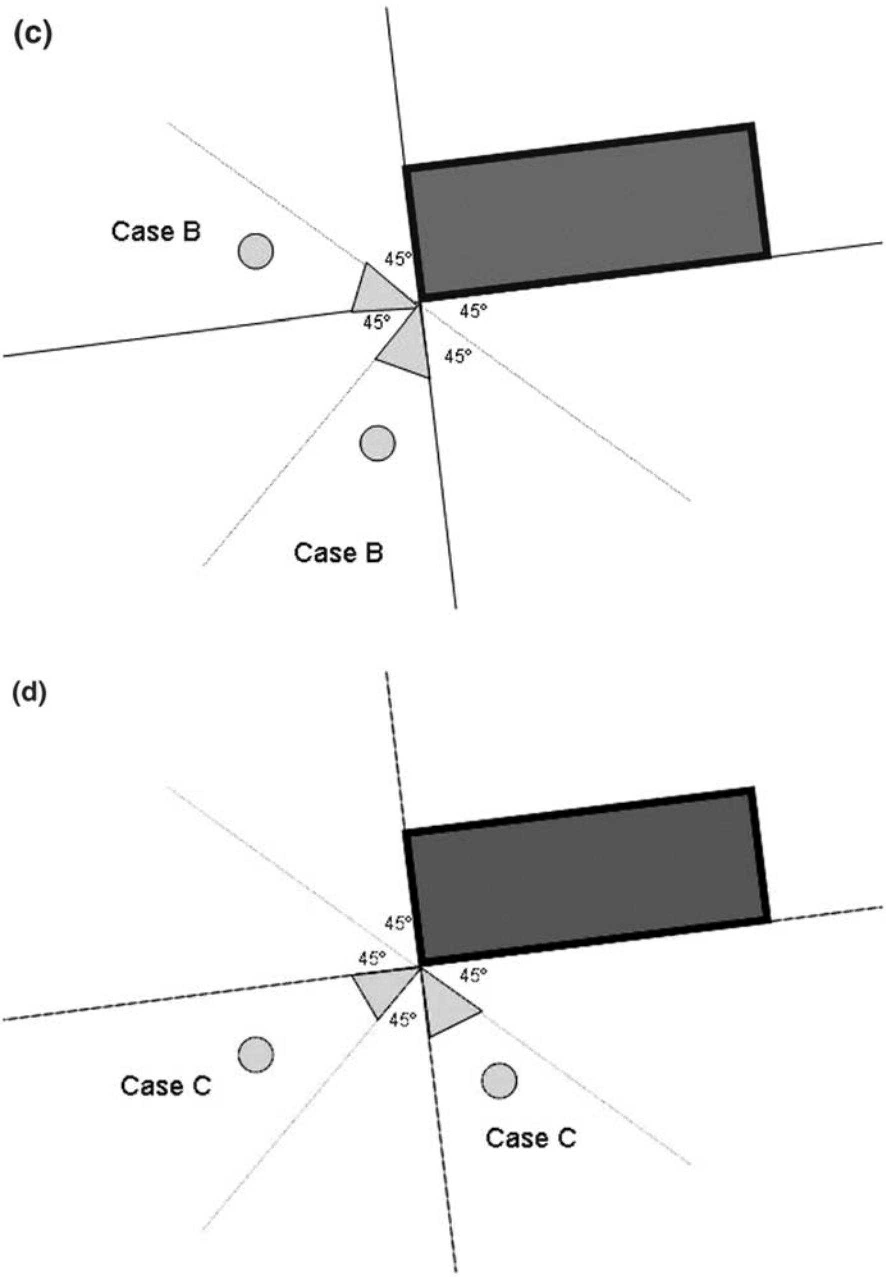

FIGURE 4: (continued)

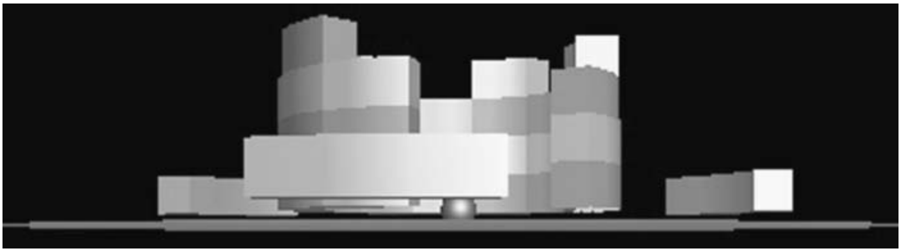

FIGURE 5: Virtual Reality (VR) Breakout Player's View

Figure 4a illustrates how three different cases were identified for the area of interest around the corner of the bat (covering 270°). To simulate realistic edge collision detections, for each of the cases illustrated in Figure 4b, 4c, and 4d, the ball hits the edge of the bat but makes a different reflection. Each case covers a 90° area, and during the game, the ball will either be in the first 45° or in the second 45°.

Virtual reality Breakout

The VR Breakout aims at incorporating some of the most significant characteristics of traditional and video games including standard visualization, interaction, and scenario to provide a simple but fully functional game. In the visualization side, players can enjoy playing the game in a number of different displays including cathode-ray tubes (CRTs), liquid-crystal displays (LCDs), plasma screens, and in some cases, 3D displays (i.e., shutter glasses, stereo glasses, and HMDs). As far as the human-computer interaction is concerned, standard devices such as the keyboard and the mouse are currently used for simplicity, but more sophisticated interaction devices may be easily integrated including a 3D mouse (i.e., SpaceMouse, Trackball), inertia sensors (i.e., inertia Cube), and pinch gloves. An example screenshot of the VR Breakout during game play is illustrated in Figure 5.

Furthermore, in contrast to other popular and commercial games, the scenario implemented in VR Breakout is kept as simple as possible. Complex functionalities for the players, such as the manipulation of the camera, have been eliminated. Although using a simplified game scenario, one could argue that it could restrict the players' satisfaction, the advantage offered is that players can adapt as fast as possible to the game.

Players can manipulate the game scene (perform rotations, translations, and scaling) and change some parameters of the game such as the appearance of the ground, the velocity of the ball, and the switch between various predefined camera positions. The interactive camera switching is one of the most impressive features of the VR version of the application (see Figure 13). Players can switch the virtual camera viewport by pressing predefined keys on the keyboard and obtain different views such as perspective view, fish-eye view, and ball view. Two example screenshots of the fish-eye and ball views are illustrated in Figure 6.

The advantage of interactively switching viewpoints is that it allows the player to use the best view possible to play the game effectively. Besides, some views can be useful when the HMD is employed instead of a monitor. For example, the ball view, Figure 6b, provides an immersive view of the game, whereas the fish-eye view, Figure 6a, seems more useful for standard displays (i.e., LCD and CRT). Moreover, the ball view is useful to increase the difficulty level of the game because it provides an egocentric view. On the other hand, it is worth mentioning that the fish-eye view is not a "real" orthographic view because in the latter case, the player can visualize the game arena in 2D instead of 3D. To overcome this problem, the camera was set at an angle of approximately 90°. Thus, players get the feeling that they perceive the game in an orthographic view but in 3D instead of 2D.

Augmented reality Breakout

The AR Breakout aims at presenting a more exciting way of playing video games. To achieve this goal, it offers some extra features in terms of visualization as well as interaction experiences. Although the AR Breakout uses exactly the same digital content as the VR Breakout, there are a few differences in the configuration setup as well as the resulting functionality. First of all, the AR Breakout requires a video camera (or Web camera) to feed live video-streaming into the processing unit (which could be a desktop computer, a laptop, or a tabloid pc) and a physical marker card that acts as a reference point to the real world. In terms of software infrastructure, the game engine was extended to operate in conjunction with the tracking libraries of ARToolKit (Poupyrev et al., 2000).

From the visualization, or augmentation, point of view, the game can be inserted anywhere in the real environment with the help of some manual input from the player. The player then uses the camera and a reference point (marker card in this case) to register the application into it and perceive the augmented scene either in a monitor display (CRT or LCD) or in an HMD. Thus, the camera switching techniques discussed are no longer applicable in the AR Breakout because only one real camera is used and it is the Web camera.

In case a computer monitor or TV display is used, then multiple users can participate, providing a simple form of collaboration between players, but the level of immersion will stay low. On the contrary, if HMDs are used instead, the level of immersion will drastically increase but psychological problems may appear such as motion sickness and nausea. Using a video splitter, multiple displays can be combined so that the best visualization is achieved. An obvious advantage of the AR visualization technique is that it makes the users feel more immersed into the gaming scenario and promotes collaboration between multiple users.

As far as the interaction techniques are concerned, players can manipulate the gaming environment using standard I/O devices (such as wireless keyboard, mouse, and

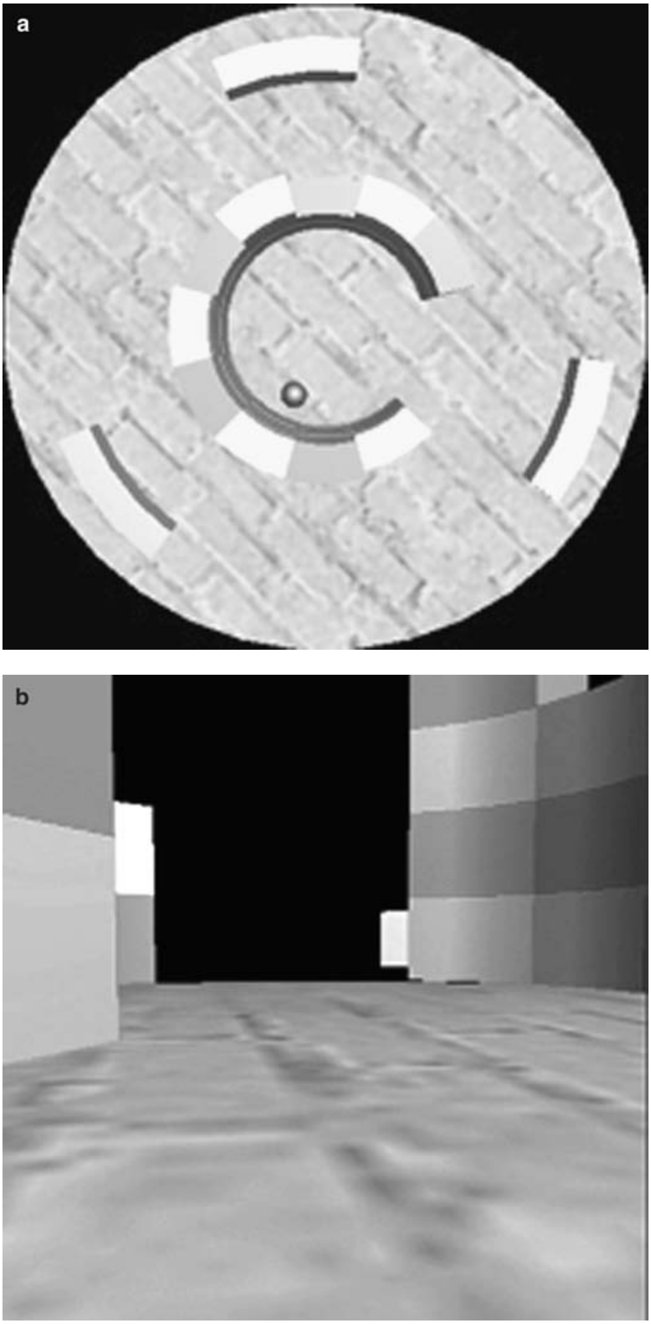

FIGURE 6: Camera Switching: (a) Fish-Eye View and (b) Ball View

joysticks), sophisticated sensor devices, like the Magellan SpaceMouse (Liarokapis et al., 2004), or physical means such as physical marker cards (Poupyrev et al., 2000). Figure 7 illustrates how a user can rotate the Breakout simulation using his or her hand to physically rotate the marker cards. This allows getting the best viewpoint in a natural and realistic manner. Similarly, the player can move the scene closer to the camera (and vice-versa) to zoom into the scene (instead of scaling the graphics).

Pilot study

When investigating human factors in AR systems, there are many difficulties to overcome (Livingston, 2005). Some of the most characteristic limitations include deficiencies in the hardware configuration such as the visualization display (i.e., standard displays, small area displays, large area displays, and HMDs), the tracking system (i.e., latency and accuracy), and the ergonomics of the device used as well as the software configuration including usability of the interface, occlusions between real and virtual information, and human-computer interactions. The focus of this study is to test the overall effectiveness of the AR game compared with the VR version, which is similar to the video game version. The assessment method used is through the dissemination of a user-centered questionnaire made up of both qualitative and quantitative questions.

Procedure

To evaluate the effectiveness of each system, a pilot study with 10 users aged 25 to 35 took place in a university laboratory environment. The players were given both the VR and AR Breakout and spent some time familiarizing themselves with the game. Then, they first played the VR Breakout and then the AR Breakout for the same amount of time. When players were happy with the testing, they were asked to complete a three-page questionnaire made up of four sections. The first section investigates the relationship between games and individuals and attempts to understand their preferences. The second and third sections attempt to assess the effectives of the visualization and interaction of the virtual and augmented reality systems, respectively. The last section focuses on the final impressions of the players in the form of written feedback.

Qualitative results

The first part of the questionnaire included general purpose questions aimed at understanding the perceptions of users toward all types of games including traditional and video games. It is worth mentioning that there is a whole generation of people that has grown up using digital media and computer games, thus, they are expected to be more positive in their feedback. On the other hand, those for whom computer games are not part of their lives are expected to provide more negative feedback. The findings from this study are summarized in Table 2.

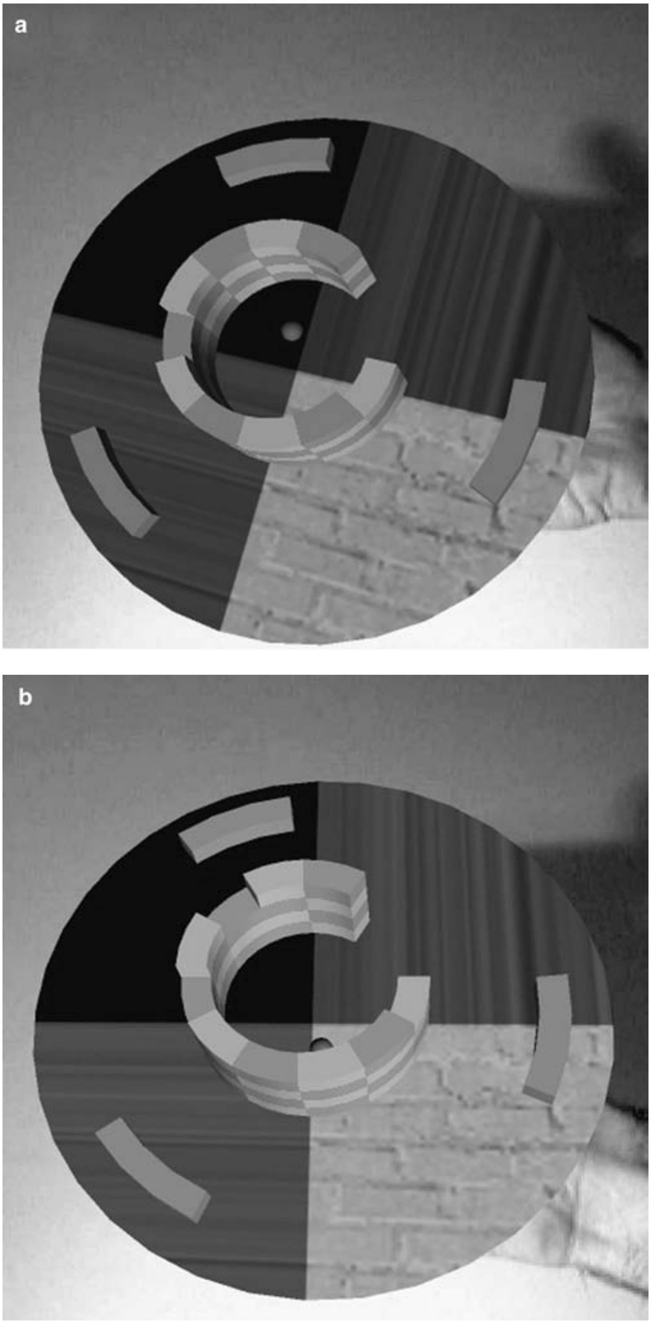

FIGURE 7: Scene Manipulation Using Natural Methods

TABLE 2: Game Design Issues for Video and Augmented Reality (AR) Games

General Question	M *(max = 5)*	SD *(yEr±)*
Play traditional games?	4	1.05409
Frequency of playing games?	2.7	1.33749
Use computer for games?	3.5	0.97183
How often play video games?	3.1	1.44914

Table 2 clearly illustrates that 80% of the users like playing traditional games and 70% of them like playing computer games. It is interesting that only 54% play traditional games often, whereas 62% prefer video games. This is a very important observation because although we live in a society that video games seem to dominate, users still prefer traditional games. However, due to a number of issues (i.e., price, excitement, availability, and special effects), most players prefer video games. Undoubtedly, AR seems to offer an alternative solution to the needs of users, offering a combination of traditional and video games.

Next, the effectiveness of the visualization and interaction of the VR and AR versions was quantitatively measured. The camera-switching technique was one of the features of the VR application that gained most of the attention of the players. The majority agreed that it helps to keep the excitement of the game high but, on the contrary, some particular views are not very easy to use effectively. For example, the ball view was argued, on one hand, to provide an imaginary but exciting view for the player but, on the other hand, to be very hard to play because the whole scene could not be viewed. On the contrary, the best view was agreed to be the perspective and orthographic. To overcome this problem, some players proposed to use multiple windows with different views.

The scene manipulation using natural methods was commented to be the most impressive aspect of the AR version of the game. In particular, most players agreed that it is extremely promising to manipulate the augmented viewport. They commented that the natural rotations of the gaming scene are much easier to perform in contradiction with the VR version. It is surprising that the augmented zooming (moving the scene close to the camera) did not receive very positive feedback by all players. Specifically, two users mentioned that it is distracting to orient the marker toward the camera, whereas the others felt that the camera viewport should be wider.

Quantitative results

To quantitatively evaluate the VR and AR Breakout, six important issues were compared, including efficiency, usefulness, realism, learning, interaction, and camera movement. A brief analysis of the findings for each comparison is illustrated below.

The first comparison concerns efficiency in terms of processing power of the two experimental applications. Figure 8 clearly illustrates that the user response considers the VR Breakout (M = 4.4, SD = 0.96609, SE = 0.30551) to be much more efficient

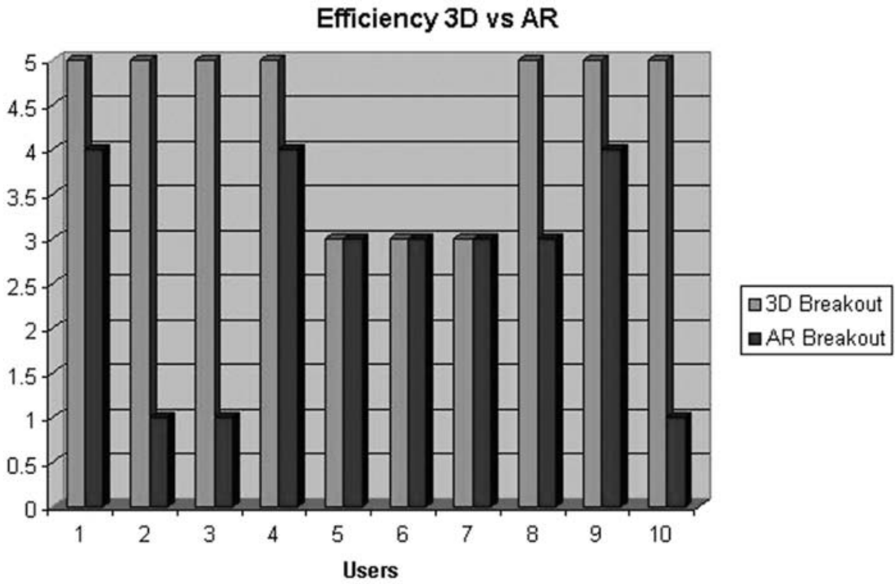

FIGURE 8: Efficiency of Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

compared with the AR Breakout (*M* = 2.7, *SD* = 1.25167, *SE* = 0.39581). This result was expected because the 3D Breakout is less processing intensive, whereas the AR Breakout consumes much more power due to the video and image processing operations such as the video capturing and video merging.

The second comparison aims at testing the overall usefulness of the two prototypes to determine which one is more useful to play. Figure 9 shows that there is no clear preference in user responses between the VR Breakout (*M* = 4.0, *SD* = 0.66667, *SE* = 0.21082) and the AR Breakout (*M* = 4.0, *SD* = 1.41421, *SE* = 0.44721). It is worth mentioning that five users preferred the AR application, two users the VR Breakout, and three users did not find any difference.

Next, the level of realism in terms of graphics was measured as shown in Figure 10. In this case, most users preferred the classic way of presenting graphics even if both systems used the same computer graphics engine. Specifically, the VR Breakout (*M* = 3.4, *SD* = 0.96609, *SE* = 0.30551) received a higher score compared with the AR Breakout (*M* = 3.0, *SD* = 0.94281, *SE* = 0.29814), but only marginal. The main reason behind this is that the AR Breakout application mixes the computer graphics scene with a sequence of images taken from a Web camera with limited resolution (640 × 480, 1.3 MP). The merging operation greatly reduces the realism of the graphics presented in the AR scene, but if a high-resolution video camera is used, then this will be improved.

The results of the fourth measurement, presented in Figure 11, aim at comparing the ability of participants in learning how to play the Breakout game. Although both

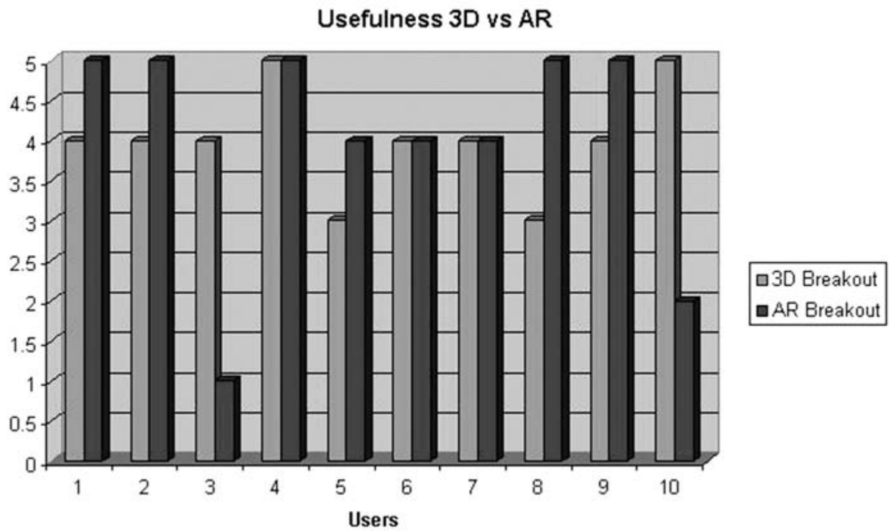

FIGURE 9: Usefulness of Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

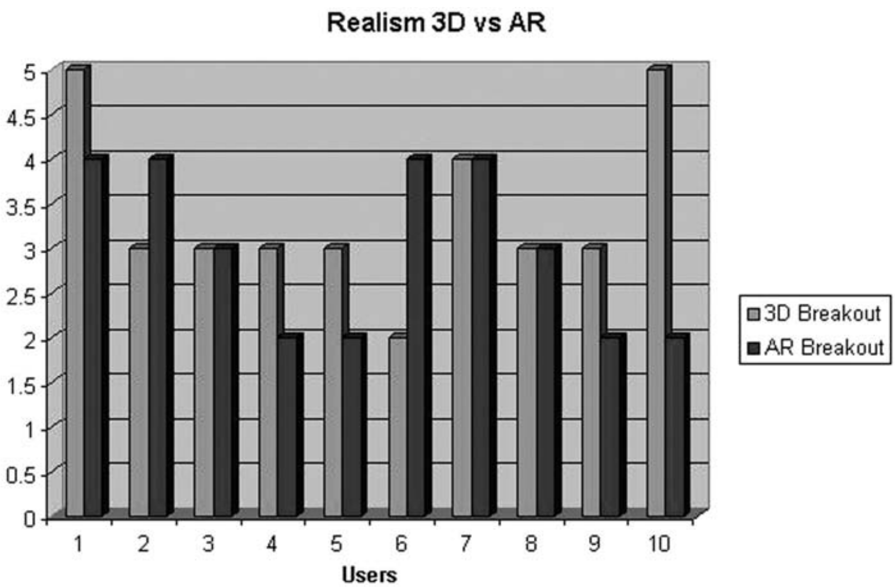

FIGURE 10: Realism of Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

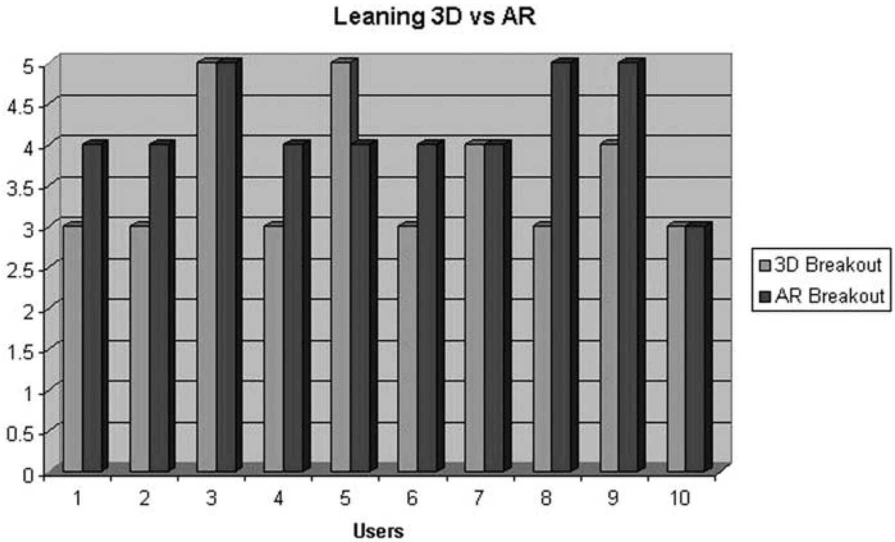

FIGURE 11: Learning in Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

systems are not regarded as educational games, users can acquire different skills and knowledge on how to play the game. It is surprising that most users agreed that in the AR Breakout (*M* = 4.2, *SD* = 0.63246, *SE* = 0.2), it is much easier to familiarize with the game and adapt to the game play than the VR Breakout (*M* = 3.6, *SD* = 0.84327, *SE* = 0.26667). It is worth mentioning that a recent survey performed with surgeons has shown that they have much better reactions when they have played a computer game 30 minutes before an operation. This implies that there are some hidden learning benefits from playing games, which should be explored further through extensive user studies.

Furthermore, human-computer interaction techniques of both VR and AR gaming were measured as shown in Figure 12. Again, the AR Breakout (*M* = 4.2, *SD* = 1.0328, *SE* = 0.3266) received a much better score compared with the VR Breakout (*M* = 3.1, *SD* = 1.59513, *SE* = 0.50442). The obvious reason for this is that the AR Breakout allows for tangible manipulations, making use of a combination of standard I/O devices like the keyboard and mouse and physical interfaces like black-and-white marker cards. On the contrary, interaction within the VR Breakout is limited to standard I/O interactions.

Finally, the movement of the camera was compared and the results are illustrated in Figure 13. In the VR Breakout, the camera can be manipulated using predefined keyboard keys and positioned anywhere in the virtual space. On the other hand, in the AR Breakout, users have to physically move the Web camera in the real environment. As expected, the camera manipulation techniques in the VR Breakout (*M* = 3.8,

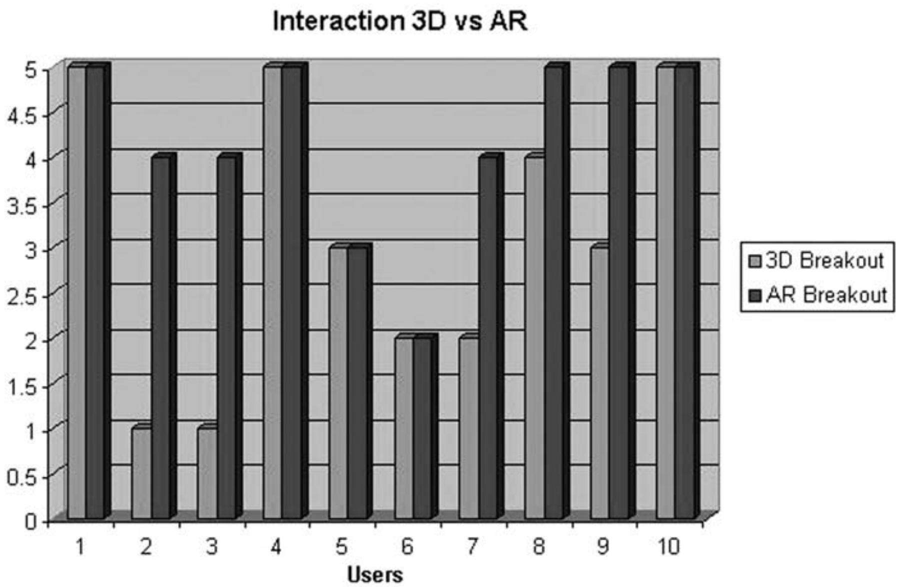

FIGURE 12: Interaction in Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

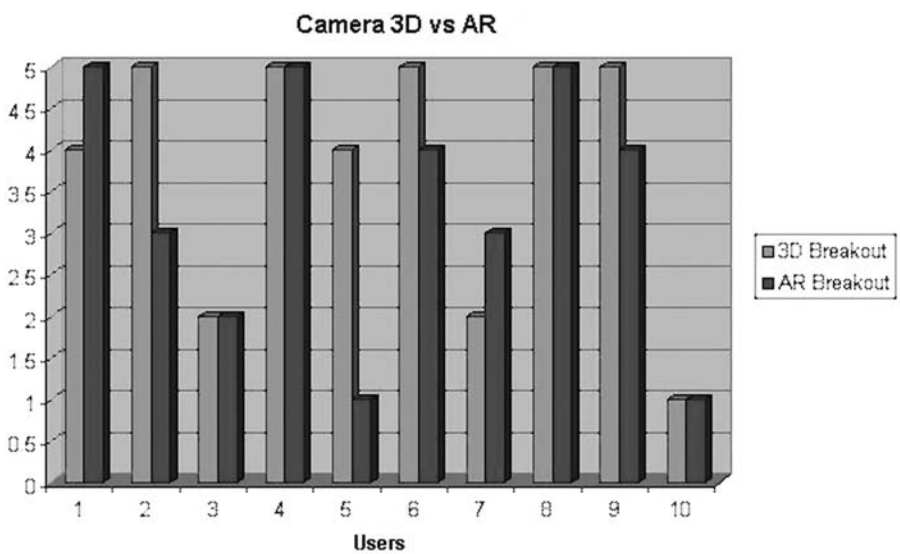

FIGURE 13: Camera Movement of Virtual Reality (3D) Versus Augmented Reality (AR) Breakout

SD = 1.54919, *SE* = 0.4899) seem much more user-friendly compared with the AR Breakout (*M* = 3.3, *SD* = 1.56702, *SE* = 0.49554), mainly because most users were accustomed to using the keyboard rather than moving a physical Web camera. However, most video cameras have zoom functions embedded and, in theory, this could be controlled by the AR game.

Virtual reality improvements

Most players were influenced by recent developments in dominant gaming consoles such as Xbox and Playstation and made direct comparisons. A characteristic example was a player who proposed to port the VR application into both consoles and provide support for multiplayer features. However, this was out of the scope of this research because the main aim was to test the effectiveness of the same game applied in two different platforms. In general, most players agreed that the VR game is a complete 3D game but the graphics could be significantly improved, providing support for multitexturing, advanced lighting, shadows, and other computer graphics techniques.

Furthermore, two users suggested providing access to the cyberspace so that they can play the game remotely either in stand-alone mode or in multiplayer mode. With the evolution of network technologies, this is a really important point that can boost the interest of the gaming community, and it is not only restricted to the VR version but can also be applied to the AR Breakout. Besides, some players proposed to implement more scenarios including different levels of difficulty for beginners and advanced users. Features could help this, such as changing the size of the game components (i.e., well, bat, and ball), the speed of the simulation, and the number of wells. Finally, a player suggested including “cheat buttons” and saving high scores to increase the competition.

Augmented reality improvements

Although the AR Breakout received much more positive feedback compared with the VR version, some players proposed a few improvements. Most players argued that the effectiveness of the application is not as high as it is in the VR version, and this is the only factor that limits the overall user satisfaction. In practice, the VR application (35~40 fps) runs almost twice as fast as the AR application (10~20 fps), but this is expected due to the real-time tracking and merging between the graphics and the live video feed.

Extra optimizations have to be performed in the future to reduce the computational cost of tracking. Moreover, a player suggested using better quality Web cameras or video cameras to increase the field-of-view and thus the robustness of the visualization and the immersion of the players. However, this would significantly increase the cost of the application and, therefore, is not considered at this stage of this research. Another player proposed making use of different spatial sounds when the ball collides with the components of Breakout (i.e., wall, bat, and well).

Conclusions

In this article, some of the visualization and interaction research challenges imposed by the Breakout game were presented. The VR system is made up of a graphics and physics engine to perform a realistic simulation, whereas the latter is based on a tangible AR platform that includes most of the VR functionality but also provides new forms of interaction. To access the visualization and interaction issues of each game, a preliminary evaluation was performed with 10 users. Initial results illustrated that players preferred the VR Breakout in terms of efficiency and the AR Breakout in terms of game play and ease of interactions. Overall, the AR version seems to have all the necessary potentials to become an alternative platform for future gaming applications, but certain aspects have to be improved such as the efficiency. In addition, more user studies need to be performed with larger samples to get user feedback concerning social, cultural, and pedagogical issues.

In the future, the vision-tracking component of the AR platform will be optimized so that the overall efficiency of the application is improved. In addition, alternative methods of interacting will be investigated including gestures and voice recognition. Finally, the next step is to implement more games based on the same 3D engine and port them into both the VR and AR platforms so that a more complete evaluation with more players can be performed.

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