AUGMENTED REALITY GAMES: A REVIEW

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ABSTRACT

This paper presents a review of the state of the art in Augmented Reality (AR) games. Distinguished advancements in terms of entertainment and serious games from both the research and industry are presented. These works are then analyzed across metrics like technology usage, game genre and chronology. Via this analysis, trends are extracted and novel insights into promising domains are eventually concluded, in both the perspectives of research and commercial development.

INTRODUCTION

Augmented Reality (AR) generally refers to a synthesized perspective of the real physical environment using computer-generated imagery. Additionally it is also commonly accepted to be interactive in real-time and registered in three dimensions (3D) [2].

Games are often recognized as the best application of AR technologies. Games are well-known for bringing new technology to the masses (like the popularization of the graphics processing unit), and the game industry is a huge and expanding industry that attracts an enormous number of consumers [1]. Hence a vast majority of work in both AR research and industry are focused in making games, and this paper aims to provide a review of the state of the art in this domain.

To define the domain clearly, the works referenced in this paper only includes games that are complete games. Moreover, the works are listed only if they are research work that have been published or commercial work that have been publicized on the internet. AR is also commonly confused with Virtual Reality (VR) which performs somewhat the reverse of AR. VR actually places the human in the real world into a completely virtual world, instead of placing virtual objects into the real world. This paper is about the latter and does not include VR games.

To the best of knowledge, there are no formal reviews done in the domain of AR games. There was however a paper that reviewed the AR domain in general, way back in 1997 [2]. In that paper, various applications of AR were presented but games were not in that list. Although a large number of work has been performed in AR games, a consolidation has not been done yet. There was also a case study review [18] that was performed by only describing five AR games separately. Without a thorough holistic view and analysis of current advancements, a lot of overlapping work will surface, especially in research.

Motivated by the lack of a holistic consolidated review of current AR work in the computer games domain, this paper aims to fill that cavity. The goal of this paper is to provide an initial framework for an analysis of the trends in current AR games such that researchers and practitioners are able to have a holistic view of the current state of the art in order to better advance AR game technology as well as make better commercial AR games. This paper by no means tries to cover the complete space of AR games but aims to cover the most high profiled ones.

The contributions in this paper includes

1. a review of state of the art AR games in research and industry, and
2. a trend analysis of these games.

The analysis results shown in this paper serves two purposes. Firstly, researchers will be able to target and work on areas that are currently lacking in terms of technology. Secondly, commercial game developers will be able to determine currently popular technologies to create or enhance their AR games. In terms of commercial viability, they can also use this review to select game genres that are currently lacking in AR games and get the first-movers advantage.

Games can be broadly classified into either entertainment games or serious games. Not surprisingly, AR games also fall into either of these categories. The structure of this paper will be to first describe key advancements in the entertainment games domain in Section , followed by the serious games domain in Section . Then an analysis is provided in Section to cluster and identify common trends and pitfalls in current advancements, as well as provide directions for future AR work. Finally, a conclusion is given in Section .

ENTERTAINMENT GAMES

This paper defines entertainment games as computer games whose sole purpose is to provide entertainment

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to the player. Entertainment or player enjoyment is the original goal computer games were created for. The purpose of having such a definition is more obvious when compared to relatively newer domain of games known as serious games, which will be defined in Section .

This section lists, in reverse chronological order, some of the most prominent entertainment AR games created in both the research and commercial domains.

AR Defender

AR Defender [14] is a commercial casual game that was just recently released on the iPhone, a popular mobile smart phone product by Apple Inc. [13]. It makes use of its proprietary marker pattern printed on a card so that the software can make use of the phone's camera to detect the position and orientation to place a virtual tower. The goal of the game is to defend the tower by moving the camera and shooting various weapons at the enemy units that try to take down the tower. It is claimed to be the first complete and fun AR game on the iPhone [11].

Invizimals

Invizimals [24] is a commercial casual game that was released on the PlayStation Portable (PSP), a handheld gaming device by Sony Computer Entertainment [23]. It requires the player to lay proprietary printed marker patterns in the real-world. These markers are detected by the PSP's camera and rendered as traps in the virtual game world such that virtual animals can be hunted and captured by the players. It has been well received by consumers and received a top ranking in Amazon UK [12].

Art of Defense

Art of Defense [9] is a multi-player AR board game made for research purposes. It makes use of a classical physical board game placed on the tabletop but modified to contain multiple pre-defined marker patterns. Its software is built on a mobile smart phone which it makes use of to detect and track the marker. Virtual towers can then be built by players on these marker positions via the phone. They performed an empirical user study which has shown that players found it enjoyable although they also found it vastly different from traditional non-AR computer games.

AR Quotes

AR Quotes [14] is a commercial casual game that is also on the iPhone. It makes use of its proprietary marker pattern printed on a card so that the software can make use of the phone's camera to detect the position and orientation to place a virtual peg. The goal of the game is to toss virtual rings such that it falls on the peg. Although simplistic, it is the first game on the iPhone to use markers to overlay 3D content onto real-time video.

MyTown

MyTown [3] is a location-based commercial social game based on real-world property ownership released on the iPhone. The game simply makes use of the phone's Global Positioning System (GPS) to find out the player's location, then allow him/her to buy and own that real-world location virtually. The game also enables the player to drop virtual items based on proximity to these real-world locations. The AR technique used here does not actually superimpose the virtual graphics onto a video, but rather conceptually superimposes the virtual items onto the real world using the GPS. With their partnership with H&M and Travel Channel, MyTown served 14 million branded items in apps and drove thousands to their 200 retail stores across the country.

AR Squash

AR Squash [21] is an AR racquet sports game created for research purposes. It uses pre-defined markers, a charged-coupled device (CCD) camera connected to a personal computer, and a motion tracker. Unlike others, the markers in this game are not used to render objects on top of them. Instead, these markers are placed on walls and used to detect the 3D geometry of the real world. The ball is rendered virtually and the player hits the ball using a motion tracker mounted on a racket. The ball then moves realistically according to physics with the geometry estimated using the markers. This work shows an innovative and alternative use of marker-based technology.

Augmented Coliseum

Augmented Coliseum [20] is a mini RTS AR game created for research purposes. It uses pre-defined markers, cameras connected to personal computers and mini robots with movement controllers. The markers are placed on the mini robots such that virtual add-ons like weapons can be rendered on them. The player controls these robots with the movement controllers such that they will attack the other robots in the virtual world using the virtual weapons. Hence, they have demonstrated a deep fusion of both virtual (using weapons to attack) and real-world interactions (collisions) in this game.

CurBall

CurBall [17] is a casual curling-cum-bowling sports game created for research purposes. It uses pre-defined markers, cameras connected to personal computers and a motion detector. The markers are placed on easily movable physical objects which are rendered as obstacles on the screen. The motion detector is placed in a ball which is also rendered on the screen as a ball. The game is a two-player cooperative game. The first player controls the ball and the task is to get the ball to a certain goal position without hitting the virtual ob-

stacles. The first player can see the entire game world with the rendered obstacles and ball. The second player can only see and move the physical obstacles. The two players are physically separated and are only virtually connected thru a network. Hence they have to cooperate and shift the obstacles while rolling the ball to reach the goal. They have hence presented a novel cooperative networked game.

Butterfly Effect

Butterfly Effect [25] is a casual AR game made for research purposes. It uses a head-mounted display (HMD) [2] and a customized rod controller. The aim of the game is to capture all the virtual butterflies that are rendered in front of the player. The rod serves as a device to attract the butterflies and make them move in a regular fashion such that they can be caught easily. Catching butterflies simply means moving the HMD close enough to them. The butterflies are rendered in a 3D volume around the player, so the player has to move and make use of real objects to get to these butterflies. Their game has shown to make good use of the 3D space around the player without using markers.

ARBattleCommander

ARBattleCommander [27] is an AR real-time strategy (RTS) game made for research purposes. It uses a video see-through HMD [2] to both display the virtual objects on the see-through real world as well as obtain inputs from the player via a heads-up display (HUD) menu in the HMD. It also uses a GPS to track position and a motion sensor to track motion. The system also detects a glove worn on the player's hands which allows him/her to issue commands on the HUD using physical hand movements. The player is the commander of a team of units who can then make use of his hands and the HUD to control them like in that of a standard RTS game. The limited field of view also acts like a natural fog-of-war present in RTS games.

ARQuake

ARQuake [5, 28] is an AR version of the popular first-person shooter (FPS) Quake game by id Software [10] made for research purposes. The system uses a video see-through HMD, a GPS, a hybrid magnetic and inertial orientation sensor, a custom made gun controller, and a standard laptop carried on a backpack. A full replica of the real world map is created as a Quake map. The software algorithm's task is hence to constantly perform accurate registrations of the virtual map with the real world. The player then plays the FPS by using the orientation sensitive HMD to aim, and pressing the gun controller to shoot. Though the game has never become commercial, ARQuake was the first fully working outdoors AR game. Hence it has generated substantial interest in the AR community back then.

SERIOUS GAMES

The term "serious games" [35] is generally accepted to mean games with a purpose, going beyond entertainment to deliver engaging learning experiences across a wide range of sectors [34]. Examples are educational games for teaching aids in schools, combat games for military simulations in the army, and advertising games for marketing purposes in commercial companies.

Similar to the previous section, this section lists, in reverse chronological order, some of the most prominent serious AR games across both the research and commercial domains.

Tangible Cubes

Tangible Cubes [15] is an educational AR game to educate children on endangered animals. It uses pre-defined markers that are viewed on a video HMD. It also allowed game administrators to view the augmented scene using web cameras mounted on personal computers and notebooks. The markers are actual numbers and symbols printed on cubes and the task of the child is to turn the cubes to indicate their choice when asked to find a certain animal. The respective animals are virtually rendered on the choice markers. One cube also overlays videos on it to describe the questions. Their results indicate that children found it more enjoyable and preferred playing the AR version rather than the traditional version of the computer game, although they did mention that the AR version is harder.

Learning Words

Learning Words [16] is an educational AR game to help children learn words. This game is done by the same researchers who created Tangible Cubes. It also uses HMDs, markers and cameras. In this game, the child is required to correctly spell words by placing and aligning the markers representing each alphabet in their correct positions. Several markers are also used as user interface menu buttons and video overlay hints. Similar to Tangible Cubes, their study also shows that children liked the AR version of this game more.

Shelf Stack

Shelf Stack [4] is an AR game used for upper-limb stroke rehabilitation. It uses pre-defined markers viewed through cameras on a personal computer. Markers are placed as the game designer wishes on the player's desktop, which then sits a virtual object on top of it in the screen. Many of these objects will be rings. At each stage of the game, one of the rings will be highlighted along with another object (like a teapot). The aim of the game is to keep placing the highlighted item onto the correctly highlighted ring. A time limit is imposed with a scoring mechanism.

AR Racing

AR Racing [22] is a driving AR game that teaches hand coordination, including to people with disabilities. It uses markers, HMDs, pinch gloves and the Wiimote, a motion sensing device by Nintendo [26]. The goal of the game is to move the virtual car around the scene using the Wiimote without colliding with certain virtual obstacles placed on marker positions in the real world. These virtual obstacles can be moved around using the glove. Their results show that multi-modal interaction games are beneficial in the domain of serious games.

Environmental Detectives

Educational Detectives [19] is multi-player educational AR game to support learning in late high school and early college environments. It simply uses a GPS on a smart phone to display the player's current position on a virtual map. The real environment is not shown on the smart phone. Similar to MyTown, this game conceptually superimposes the virtual items onto the real world using the GPS. The goal of the game is to find out the culprits, causes and solutions to a scientific sabotage case by moving to various real-world locations and conducting interviews with virtual persons as well as reading virtual documents. The cases are modeled such that the information to be obtained are related to scientific topics the student players are studying. They have provided case studies of their development process which serves as a good reference in terms of serious AR game design.

GenVirtual

GenVirtual [6] is a musical educational AR game to help people with learning disabilities. It uses pre-defined markers and a camera mounted on a personal computer. Each marker represents a certain musical note and they can be placed according to what the therapist intends to teach. Cube buttons are then rendered on each marker. A musical sequence is then demonstrated at the start of the game, with each button appearing to indicate the musical note correspondence. The goal of the game is to correctly repeat the sequence. The corresponding note is played when the player's hand is placed over the button (marker).

ARVe

ARVe (Augmented Reality applied to the Vegetal field) [29] is an educational AR game for rehabilitation of cognitive disabled children to make proper decisions. It uses pre-defined marker patterns printed on a picture book. The children views the book through a camera mounted on a personal computer, in which virtual plant entities are rendered on the markers. The goal of the game is to place the correct virtual plant entities (by shifting some moveable markers) in the same positions shown on a reference page. For example one task might be to place the flowers, seeds and leaves of pears and strawberries in their correct positions. Their research showed that cognitive disabled children were very enthusiastic and showed a higher motivation to complete the tasks than other children.

THE AR GAME DOMAIN

With a description of all the prominent work performed in AR games, this section aims to consolidate and analyse the current state of AR games. The analysis focuses on the spectrums of technology used and game genre implemented such that insights can be effectively drawn using these spectrums as a basis.

Technology

The current state of technology usage can be summarized in the graph shown in Figure 1. Note that technology is not divided into hardware and software because AR games are currently still primarily dependent on the choice of hardware. The software program is still very much built around the hardware that are chosen. Descriptions of each of the technologies on the y-axis are already given alongside the game descriptions in the previous section on Entertainment Games.

As shown in Figure 1, the work done in earlier years mainly make use of highly specialized hardware like HMDs, gloves and motion sensors. These hardware used are mostly costly lab equipment which is why these work primarily stayed in the lab without being commercialized. In recent years, especially in 2010, it can be seen that marker-driven detection and tracking through a simple web camera or phone camera has become immensely popular. The cost of equipment is simply a cheap camera and some paper to print the marker patterns. This easy accessibility to equipment meant that even hobbyist researchers without funding can investigate AR games, and that game companies can make AR games easily available to the masses. This also coincides with the rapid adoption of smart phones and ultra-portable laptops by consumers. It is noted however that there are still recent work using HMDs [22, 15, 16]. Hence HMDs are not completely obsolete especially when a high level of immersion is required.

Game Genre

The current state of game genres implemented can be summarized in the graph shown in Figure 2. Most of the mainstream game genres are listed on the y-axis, namely First Person Shooters (FPS) [30], Real-Time Strategy (RTS) games [31], Role-Playing Games (RPG) [32], and Sports games [33].

Although there is no obvious trending in terms of chronology, at least it can still be seen from Figure 2 that more AR games are being created as time goes by. It is also seen that in general, AR games tend to deviate from the mainstream game genres. Undoubtedly,

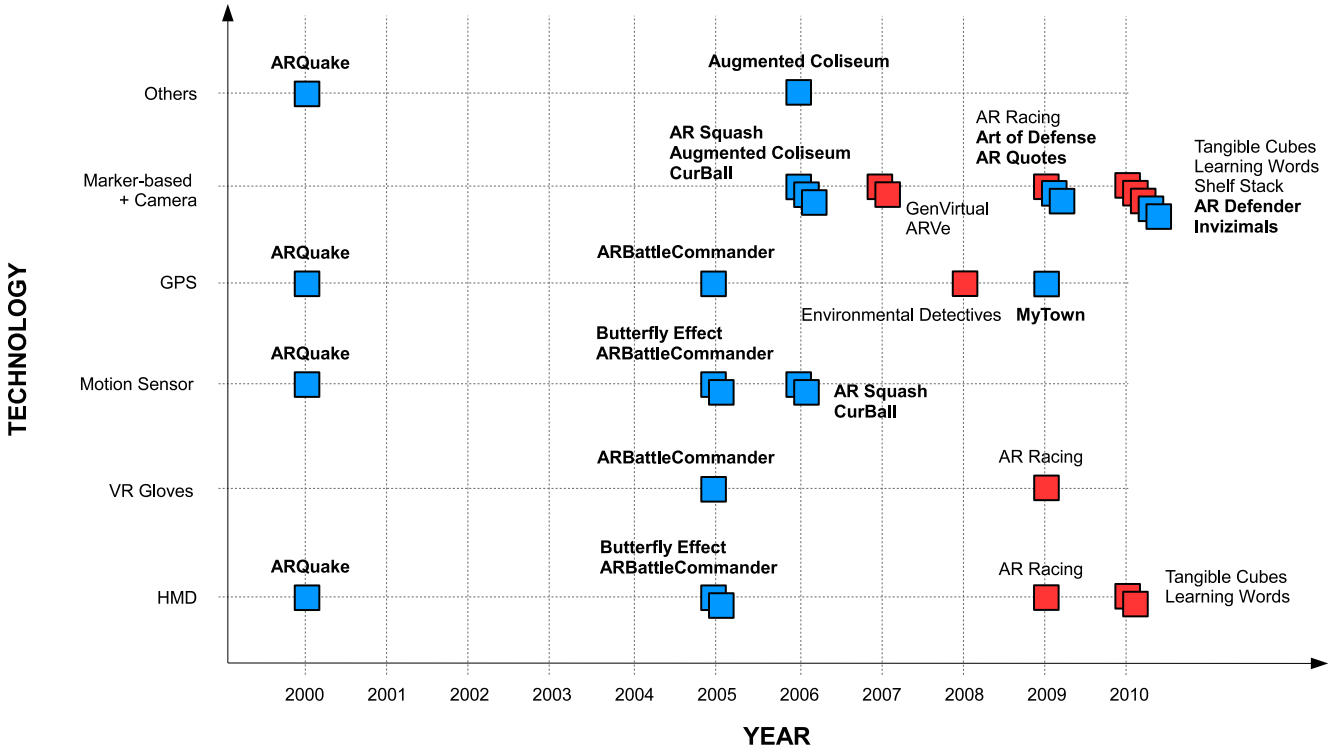

Figure 1: A graph of technology usage versus year of release/publication. Blue color denotes entertainment games while red color denotes serious games. It can be seen that in general, the trend is moving from multi-modal expensive hardware to simply using markers and cameras.

serious games exhibits this trait more obviously as current serious AR games are used mostly for education or medical rehabilitation. If serious AR games are to be created for military or advertising purposes, then probably mainstream serious game genres will be seen more often.

It can also be seen that entertainment RTS AR games, especially the tower defense sub-genre is rather popular. This sub-genre involves defending certain stationary assets by building more assets or shooting the enemies using screen controls. The reason why this is so popular might be that most AR games are moving towards marker-based technology, and the camera do not need to move much in tower defense games.

It also seems like nobody is making RPG AR games. The obvious reason might be that RPG games involve a lot of content, and it is not feasible to place thousands of markers in the real world. This is hence a shortcoming of marker-based AR games.

Insights

From the analysis described, several insights can be drawn for both research and commercial development.

In terms of research, it appears that the AR requirement of current software is very much built around the hardware that is provided. In current games, that means mostly detecting and tracking the markers. This, as mentioned earlier, has a scalability shortcoming. Other than that, designing and printing of markers is also a hassle. Hence a promising direction for research is to look into generic marker-less detection and tracking of generic objects. A good starting point would be to look at mature computer vision domains like face and gesture detection and recognition. There are marker-less AR research [8] that are on-going, just that nobody has applied it successfully in a working game.

Moreover, it is also observed that the serious AR games are mainly applied in the education and healthcare industries. Conventional serious games have been successful in military and advertising industries and hence AR versions of those games would prospectively be more engaging and fun as some of the researchers have shown. This are also areas whereby research work can venture into.

In terms of commercial development, many unchartered domains exist that are yet to be commercially exploited. In commercial products, the first-mover's advantage is important to a product's success. Firstly, AR is not incorporated into any of the mainstream genres yet. Imagine for example Starcraft [7] being played by physically placing game cards on a map. Secondly, it seems like there are no serious AR games on the market currently. Most of the serious games created by the research community are technological demos at best, and it is up to the commercial developers to make these demos into

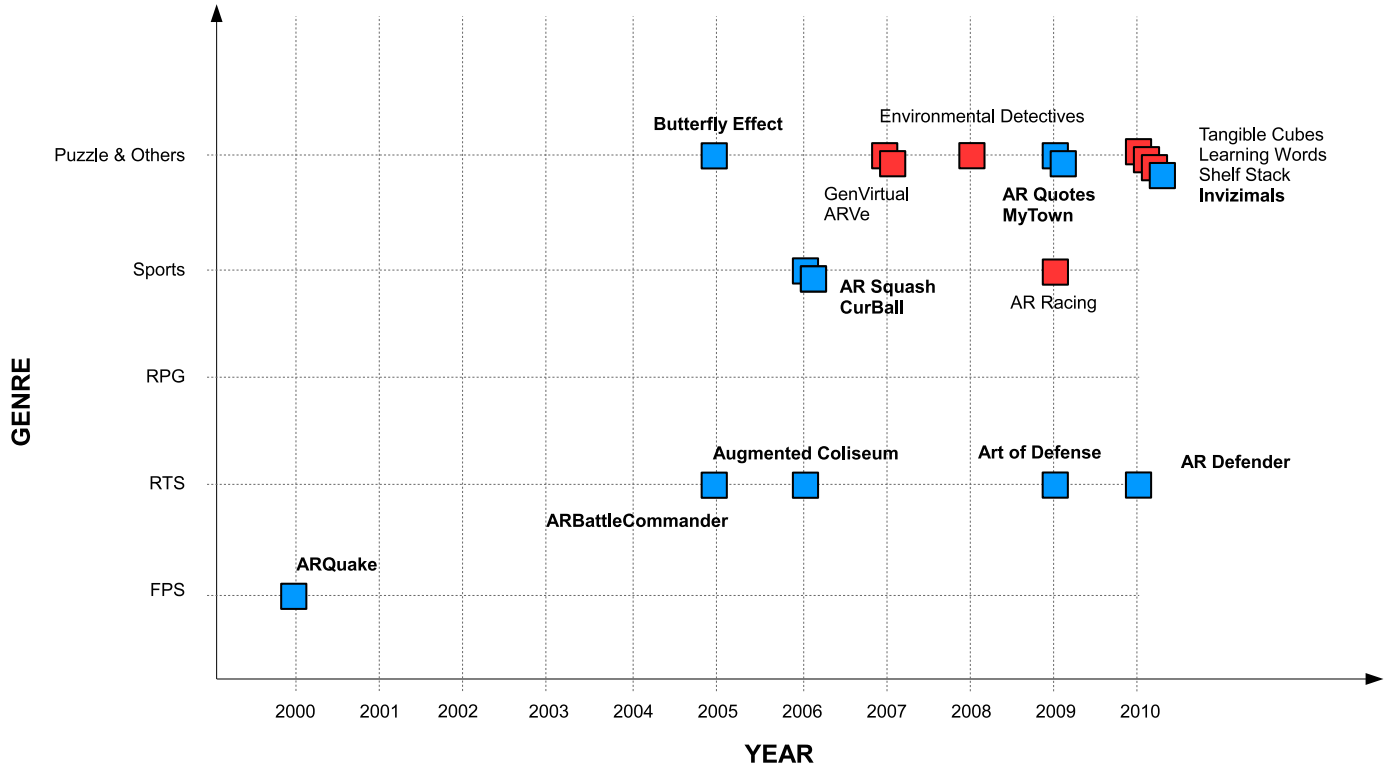

Figure 2: A graph of game genre versus year of release/publication. Blue color denotes entertainment games while red color denotes serious games. It can be seen that in general, AR games are largely non-mainstream genres. The only mainstream genre that is popular is that of tower defense RTS games.

professional solutions such that the society can benefit from them. Moreover, the advent of marker-based technology has made AR so much more accessible to consumers than it was previously, therefore this era would be a good time to make commercial AR games.

CONCLUSION AND FUTURE WORK

This paper has presented an initial effort at analyzing current AR games across various technologies used as well as game genres. The trend graphs show that modern AR games tend to make use of cheap and highly accessible equipment found on popular mobile consumer phones and laptops. They also show many avenues which are lacking in both research and commercial development. Hence researchers and game companies can make use of the review in this paper to better focus their energies in terms of AR games.

Although this paper tries to list most of the current state of the art AR games that have been created, it does not claim to have considered each and every single AR game created so far. This paper can be seen as simply a starting point at trying to consolidating an AR games database. Hence a future work is to create an automated database that people an submit a technological description of their AR games. In doing this, the trend graphs and certain aspects of analysis can also be automatically generated. Moreover, the current spectrum of analysis is currently only technology and game genre, hence more spectrums should be added in the future.

In all, this paper serves as an ignition for a continuous and iterative process of consolidating and analysing AR games in both research and industry, such that researchers and practitioners can advance better with a holistic view of the domain at all times.

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