Enhanced Immersion in Augmented Reality Applications

Ellen Häger
Master of Science Thesis in Media Technology

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Abstract

This thesis will examine and evaluate different mechanics that could be used in games using augmented reality. Augmented reality, the technology used to integrate computer-generated images with the real world environment, allows developers to enhance a user’s gaming experience. The different mechanics will focus on immersion and on user engagement and examine which of the two is more important in games. This is examined by implementing the different mechanics in an application for a Google Tango tablet. Immersion is created by letting the environment act on virtual objects, via occlusion culling. The virtual agent interacts with the real world to generate engagement. The different methods are surveyed online, and user tests performed with the application. The results showed how the concept of combining the surveyed methods of generating immersion and engagement using augmented reality was successful.
Acknowledgments

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Linköping, Juni 2017
Ellen Häger
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Augmented reality is used in a wide variety of fields, from entertainment to tourist information. Games with augmented reality (AR) and virtual reality (VR) are becoming more popular, with technologies like the *Oculus Rift* and *Google Cardboard* and games such as *Pokémon Go*. The technology behind augmented reality is expanding, allowing for more advanced methods being used in more accessible ways. As the general knowledge about AR and VR is spreading thanks to the increasing popularity of games featuring AR and VR, the opportunities and demands to create new games are growing. This pushes the technology behind AR further, allowing more advanced concepts to be explored.

Augmented reality and virtual reality share many obvious similarities, yet they utilise the virtual elements in fundamentally different ways. Augmented reality enhances reality by introducing virtual elements. Virtual reality creates a completely computer generated world. In their paper about mixed reality, Milgram, Takemura, Utsumi, and Kishino [14] write about a reality-virtuality continuum, figure 1.1. From left to right, it goes from consisting of all real objects and environments, to the right with all virtual environments with no real objects. Augmented reality introduces some virtual elements on top of the real world. Augmented virtuality consists of virtual objects and environments, but still includes some part of reality, such as the user’s hands which could grab objects or in other ways manipulate the virtual world.

Augmented reality allows the user to observe and interact with the real world, through a window or display that allows for virtual elements to enhance reality. Milgram et al. mention two different categories of augmented reality displays: "see-through" displays and monitor based displays. Monitor based displays are inherently non-immersive and act more as a window. The "see-through" displays lets the user look directly at the world through the medium, such as head-mounted displays (*Google Glass, Hololens*) or panel-mounted displays (used...
in aviation). The device used in this project is a monitor based display, and would be placed on the left side of the mixed reality continuum.

![Mixed Reality Continuum](image)

**Figure 1.1: Mixed reality continuum.**

For a more definite description of augmented reality, Mekni and Lemieux [12] believe the following specifications are required for an AR system:

- It should combine real and virtual
- It should be interactive in real time
- It should be registered in 3D

This definition does not limit the term AR to only the classic head-mounted displays. Instead, includes all types of devices that fulfil the requirements.

Systems used for AR encompass three major parts: tracking and registration, displaying, and rendering in real time. To ensure that the image displayed is believable, it is important that the real world camera maps to the virtual camera such that both images align and match correctly. For applications that allow the user to be in motion, it is especially important to make sure that virtual objects that should be stationary remain fixed in their correct position when the user is moving. The display relates to technical limitations, such as screen resolution, visual limitations, e.g. field of view, and the size of the device. The last part, real-time rendering, is essential to create layers of virtual content that blend in as seamlessly as possible with the real world in a realistic way.

## 1.1 Purpose

The purpose of this thesis is to study what makes an augmented reality game immersive and engaging for a user. The experiment will be carried out using the augmented reality technology platform Tango, developed by Google. An application is developed for the Google Tango development kit tablet. The application features a virtual creature moving around in the real world environment, attempting to hide from the user.

### 1.1.1 Research question/problem statement

- Regarding games using AR technology, is it more immersive to let the environment act upon the virtual agent, or the agent interact with the real world environment?
• What should be the main focus points when developing games for handheld AR systems?

1.1.2 Limitations

The application is developed specifically for the Tango development kit tablet, and will not be adapted to work with the other devices running Tango. Due to time restraints, the creature will only move on the plane it spawned on, and can not climb objects, modify the environment, or fly.

1.2 Related work

In Toward Next-Gen Mobile AR Games[3], Broll et al. analyse the history of mobile AR games and discuss the next generation of mobile augmented reality games. They identified several problems used in previous mobile games, such as the need to carry a laptop around during gameplay. The games developed for handheld systems lacked the desired immersion and presence. Many of the systems used for AR games are simply prototypes, made up from several different hardware components. This in turn locks the systems to specific locations as they require lots of effort to set up and are time-consuming to adapt to different settings. The last problem with these games is the lacking integration with the real world. Since the virtual objects are separated from the real world, the true experience of mixed reality is lost.

Broll et al. identify two different directions for future AR games; simpler games using normal smartphones, and event-based games. The first allows for games to be set up easily without external support. They will grant the user the ability to modify existing games, or create their own. These games are not bound to a certain location, but could be customised to the users local environment. The second type is more complex, depending largely on the gaming location. These games require more advanced technology allowing for better user experience, and must be set up beforehand.

1.2.1 AR Games

The game industry has accepted the technology of augmented reality, as well as virtual reality, and with the popularity of games such as Pokémon Go by Niantic, everyday players have been introduced to the concept of augmented reality games. However, many experts agree that the success of Pokémon Go has little to nothing to do with the so-called AR feature. As such, it is better classified as a location-based game as explained by Walker [16], Dhillon, [4], and Evans [7].

The objective in Pokémon Go is to catch different types of Pokémon, and to find them the player has to travel around in the real world. The player visits Pokéstops to collect items, and is also able to compete against other players in Pokémon gyms. When a Pokémon has been found, the player has the chance to catch them. The application allows for the option to turn on AR during the encounter, which changes the background to the image from the camera. The
AR layer is simply the image from the camera, and the Pokémon does not truly integrate with the environment.

The application eCoology, developed by José A. Mocholi, José M. Esteve, Javier Jaén, Raquel Acosta, and Pierre Louis Xech, introduces emotion agents and emotional pathfinding. In their paper, An Emotional Path Finding Mechanism for Augmented Reality Applications[15], they explain how an agent moves in an environment based on their emotional state.

The application is supposed to be an education game, teaching children about healthy habits and values. The users are supposed to take care of animals, and the animals react and behave differently depending on how the users interact with them. Entities show happiness, or anger, depending on how well their needs are met. The entities might move towards a group of other friendly entities, or move away from potentially dangerous enemies. The most interesting element of the eCoology project is the emotional pathfinding. Since the agents move in an environment that is not continuously defined, the usual method of using graphs for pathfinding is not applicable here. Instead, Mocholi et al. introduce a method using particle systems to explore the environment. The environment is defined by a set of deflectors. The deflectors are objects that the particles collide with, and they have different properties that dictate how the particles react when they collide with the deflectors. The moving agents are defined as particles, and their destination is defined as an attractor. This attractor will attract the particles, and make them move towards it. The deflectors ensure that the agents will not move through walls, see figure 1.2.

The method using particle systems allow for a continuous space to be explored. The movements are refined to make them appear more natural by adding vehicle physics. In addition, the deflectors also act as repellent elements, making the agents want to avoid them if possible, and as occluded elements. By not letting the agents see through the deflectors, a sense of sight is introduced to the agents. Lastly, the entire map is covered by a set of nodes (called buoys) where all the important areas are. However, they are not actually part of the path finding, but rather act as guides for the agents. That is, if the agent cannot see the
goal, the nodes will guide the agent towards the goal, see figure 1.3.

![Figure 1.3: Buoys used to guide the agent.](image)

1.3 Tools

The main tool used for this project is the *Project Tango Tablet Development Kit*, developed and distributed by Google.

The tablet (figure 1.4) has an NVIDIA Tegra K1 192 CUDA cores processor, 4 GB of RAM and 128 GB of internal storage. The screen is a 7.02” 1920x1200 HD IPS display (323 ppi). The tablet is equipped with several sensors, most notably the IR depth sensor and IR projector. There is also a camera used for motion tracking.

![Figure 1.4: Google Tango development kit tablet. Image from https://developers.google.com/tango/hardware/tablet.](image)

1.3.1 Technologies/Libraries/Frameworks

Several libraries and frameworks are used to create the application. The IDE used for this project is Android Studio, as the operating system installed on the tablet used is Android version 4.4 KitKat. The main API is the Tango SDK (Zaniah, released November 2016) for Java. For the 3D graphics and animations, the library *Rajawali 3D Engine* for Android was used. The online survey was created using *Google Forms*. 
This chapter is dedicated to explain the underlying theory for the methods used to develop the application and the design of the surveys.

The first part aims at general information about different types of AR. The second part explains game design and what makes a game fun to play and engaging. This is relevant when designing all types of games, regardless of the technology used. Understanding the gamer is useful when deciding what to include in the game and what mechanics are most important. Different gamers prefer different types of games, and different genres utilise the mechanics and dynamics differently.

### 2.1 Augmented reality

Augmented reality is split into different categories: projection based AR, recognition based AR, location based AR, outlining AR, and superimposed AR [1].

Projection based AR projects virtual objects on physical objects in the real world. Examples of this is projecting a keyboard onto a surface, or projecting a piece of furniture in a room.

Recognition based AR is most commonly used to read QR-codes or bar codes. This type of AR is also used in almost every other category of AR, as the system often has to "see" (recognise) objects to start augment over them. Examples of this include translation applications. These applications recognise written words and translate them to a different language.

Location based AR is used to supply information based on the user's location. This technology is common with smartphones, since they have the possibility to track the user via GPS.

The method of outlining is closely related to projection based AR, as well as recognition based AR. It is most useful in architecture, as it would allow the user
to see a wireframe model of buildings. It is also used in cars, to provide a clear outline of roads in less than ideal weather, such as foggy weather.

Superimposed AR is also using object recognition, and it is used to "alter" the object. This could be used to project an x-ray image on someone’s arm.

There are different types of displays used to achieve augmented reality. Examples are head-mounted displays (HMD), eye glasses, hand-held displays, and spatial displays.

A head-mounted display is a display that the user wears on his/her head. The display is placed in front of the user’s eyes, and supplies images of the physical world as well as virtual elements. The sensors in these systems often allows for six degrees of freedom. The information is aligned with the real world even as the user moves their head. Examples of controlling the interface is hand gestures and voice control. An example of a HDM is the Microsoft HoloLens, shown in figure 2.1. [13].

![Microsoft HoloLens](https://upload.wikimedia.org/wikipedia/commons/0/02/Ramahololens.jpg)

**Figure 2.1:** Microsoft HoloLens. Image source: https://upload.wikimedia.org/wikipedia/commons/0/02/Ramahololens.jpg

Eye glasses (or Smartglasses) are similar to the HMDs, and they resemble ordinary glasses. These displays offer information on what the user sees and where they are.

The hand-held displays are displays that are portable and fits in the user’s hands. This includes smartphones or tablets. The main advantages of these displays is their common nature, as camera phones are commonplace, as well as being portable. A disadvantage compared to the other types of displays is the fact that the user has to hold the device in front of them when using it. Unlike the HDM and glasses, this type is not worn by the user.

Lastly, spatial displays uses AR without ordinary monitors. Instead, the augmented image is projected on to physical surfaces using digital projectors. This separates the system from the "monitor", and allows for multiple users at the same time. Examples of this include virtual tables and shader lamps, where an image is projected on an object to alter the appearance.
2.2 Game design

One of the most well known studies on the topic of game design and game research is the paper by Robin Hunicke, Marc LeBlanc, and Robert Zubek called "MDA: A Formal Approach to Game Design and Game Research" [10]. They introduce the MDA framework, where MDA stands for Mechanics, Dynamics and Aesthetics. With this framework, they wish to further the understanding of game design to help creators achieve their desired goals.

The authors divide the game into three distinctive design pieces: mechanics, dynamics, and aesthetics. The mechanics are the "rules" of the game. They describe how the agents can interact with the world, the relationships between the agents and the objects in the world and how everything behaves. Dynamics are the behaviours and interactions set up by the mechanics during gameplay. The aesthetics are characterised by the desired emotional response by the players when they interact with the game.

The designers and developers create the mechanics, which generate the dynamics, which set up the aesthetics. From the player's perspective, they experience the aesthetics, provided by the dynamics, caused by the mechanics. This is illustrated in figure 2.2

![Figure 2.2: Different perspectives of the mechanics, dynamics and aesthetics.](image)

To further describe the subject of aesthetics, Hunicke et al. move away from general words such as "fun" and "gameplay". Instead, they introduce a different vocabulary to help distinguish the different experiences created by different aesthetic elements. The words they use in their paper are:

- **Sensation**, refers to "game as a sense-pleasure". This means the game lets the player experience something unfamiliar.
- **Fantasy**, "game as make-believe", means the game introduces an imaginary world to the player.
- **Narrative**, or "game as drama", refers to a story that drives the player to return to the game.
- **Challenge**, "game as obstacle course", improves the game's replayability by introducing the player to something to master.
- **Fellowship**, "game as social framework", is most common in multiplayer games and refers to the community the player is a part of.
- **Discovery**, "game as uncharted territory", is the urge to discover and explore the game world.
• Expression, "game as self-discovery", deals with the player’s creativity.

• Submission, "game as pastime", is the connection to the game.

This taxonomy is used as guidelines to create different models for gameplay. Additionally, it helps defining what appeals to different kinds of gamers. This, in turn, helps with the definition of the dynamics and mechanics.

The dynamics work to create the desired aesthetics. To inspire fellowship, a method could be to add objectives that require a team to accomplish. Adding means for a player to influence their world, by constructing buildings or creating characters would allow for expression. Models created for dynamics could be based on feedback systems to determine how changes and states affect the gameplay. Rewarding players who are lagging behind, or increasing the difficulty for players ahead, could keep the distance between players smaller. The content of the game together with the implemented mechanics support the dynamics of the gameplay. Examples of mechanics given are shuffling cards in a card game or spawn points in first-person shooters. Breaking down the game and the game design into these smaller sections helps understanding how they affect each other. This will make it easier to dissect the user experience and make better decisions regarding game design.

Robert Dillon expanded this method with his 6-11 framework [5]. In this framework, Dillon adds emotions and instincts to the MDA framework. These additions further explain and decompose the aesthetics, as this is the most abstract piece in the design puzzle. The emotion he lists are fear, anger, joy, pride, sadness, and excitement. The eleven instincts he lists are survival, self identification, collecting, greed, protection, aggressiveness, revenge, competition, communication, curiosity, and colour appreciation. Dillon propose a network model based on these core emotions. From this network (see fig 2.3) it is a short step to relate the different game dynamics to emotions and how they trigger certain instincts.

2.2.1 Game design for AR

Expanding the concept of game design to incorporate augmented reality requires additional considerations. In a paper by Richard Wetzel, Rod McCall, Anne-Kathrin Braun and Wolfgang Broll, the authors explore and discuss the aspects of designing games for AR devices [17].

The two main systems used for AR games are smaller, handheld systems such as smartphones, and more complex systems using laptops and head-mounted displays. Wetzel et al. compare three different games, each using different technologies and techniques for interaction. For the study, the authors developed two games, TimeWarp and Interface, and compared these with the commercial game The Eye of Judgement, developed for the Sony Playstation 3.

From comparing these different games, the authors have devised guidelines for designing AR games:

• Experience first, technology second: Start by focusing on the experience, then find relevant technologies.
Figure 2.3: A network for an action/adventure game.

- **Stick to the theme**: Technologies should be relevant to the theme of the game.
- **Do not stay digital**: Combine elements from the real world with digital ones.
- **Use the real environment**: Utilise the real world environment.
- **Keep it simple**: Interactions should be easy to understand.
- **Create sharable experiences**: Let other people join the experience by using technologies such as tablets, over HMDs.
- **Use various social elements**: Let the user interact with virtual characters, other players, non-players and actors.
- **Show reality**: Do not let the virtual elements completely obscure the real world.
- **Turn weakness into strength**: When possible, turn technical problems into elements for the game.
• **Do not just convert**: Do not just convert an existing game to an AR game.

• **Create meaningful content**: The virtual components should be interesting to the game.

• **Choose your tracking wisely**: Consider the different methods and their characteristics.

These guidelines complement other areas of game design, such as the ones mentioned in the MDA framework.

### 2.3 Game mechanics

Game mechanics are the "rules" of the game. They describe what the player and the entities can and cannot do. The amount of implemented game mechanics help determine the complexity of the game. With many different game mechanics, a game becomes increasingly difficult to learn. Fewer mechanics will often result in a simpler game that is faster to learn, although not necessarily easier to master.

For this project, the simple route is taken by limiting the game mechanics present in the application. Certain mechanics are necessary to achieve an engaging, interactive gaming experience. The goal of this project is to test the two main aspects of AR, immersiveness and engagement. The main mechanic is the movement and behaviour of the virtual agent. Specifically, to let the virtual agent interact with the environment.

Examples of key game mechanics are movements, such as walking and jumping, and resource management. There are also victory mechanics, and these decide how to win a game. Examples of this include puzzle solving, victory points, and reaching a specific goal, such as **checkmate** in a game of Chess. It is possible to change certain key mechanics by changing the current **game mode**. Game modes are used to configure the game and allow for the players to vary the mechanics and how they behave. Different game modes include **single-player** and **multiplayer** modes, and **sandbox** mode where the goals and progressions are removed.

In computer games, pathfinding is used to allow for the non-player characters to move and behave intelligently in their environment. The movements are decided by different factors in the environment, and ultimately the **A* algorithm** [9] is used to find a suitable path for the agent.

Another mechanic implemented in this project is a simple point-collecting system. Points in games are used to track how well a player is doing, and are supposed to motivate the player to do well. At the end of the game using victory points as the goal mechanic, the player with the most points win.
To find answers to the problems stated in section 1.1.1, an augmented reality application is created. The application is designed to test different methods of achieving immersion and engagement. This application is used to conduct user tests, as well as an online survey.

The project is split into two parts: the augmented reality application, and the online survey. The Android application was created to showcase examples of possible mechanics that are possible with the use of the Google Tango augmented reality framework. The main application has occlusion culling and environment interaction implemented. Two other applications were created from this main application, each with only one mechanic implemented. In this chapter, the method for the main application is described.

The second part of this project is the online survey that was conducted to analyse the different methods and how they are perceived by potential users.

### 3.1 Immersion and engagement in games

The main difference between immersion and engagement, is that immersion is passive and engagement is active. Immersion is achieved by ensuring that the world behaves in a way the user expects it to. Engagement is generated by allowing the player to gain points and engage with the different game elements. Alison McMahan [11] describes different levels of engagement, **deep play** and **shallow play**. Deep play refers to the level of engagement that is near-obsessive, and shallow play is a more casual play style.

By implementing a way of hiding virtual objects when they are placed behind real world objects, they behave in a way that is expected of real objects. That is, they are no longer visible (as long as the obstructing object is not transparent).
The method of generating engagement is a simple point system, as well as letting the user chase the creature as it runs around in the room.

3.2 Application design

To perform the user and online surveys, an application is created to test different methods of integrating virtual elements with the real world.

As mentioned in section 2.2.1, one of the important factors to consider when designing games, or applications in general, for augmented reality systems is to combine the real world with the virtual elements. This will be the main focus for this application, and experimented with in two different ways; letting the environment act upon the virtual agent, and letting the agent interact with the real world environment. The mechanics are supposed to generate the dynamics, which in turn define the aesthetics. This application will focus on trying two different mechanics. These are then used to examined how to create an immersive, interesting gaming experience.

3.2.1 Environment acting upon the agent

The main parts of AR, and what separates it from other media, is the combination of virtual objects and the real world. A problem when designing applications for AR is that when these two world collide, making them integrate is a challenge. One of the obstacles is that the real world cannot change or be modified by the AR system or the virtual agents. However, one way the environment could still "act" upon the agent is by obscuring the virtual elements that are placed behind real world objects. This is done to enhance the feeling of immersion, as an object placed behind another (non-transparent) object is not fully visible (figure 3.1. Different methods to produce occlusion culling in augmented reality are described by Berger [2] and Dong et. al. [6].

![Figure 3.1: The green dots are drawn, as they are not obstructed by other objects, and inside the viewing frustum. The red dot is not drawn at all, as it is occluded by the green dot.](image)

This method is often used, together with frustum culling, to increase rendering speed. It will skip unnecessary polygons and only render the objects that are
3.2 Application design

visible to the camera. However, in this project it will be used to increase immersion, by occluding the virtual objects behind real world objects.

The Google Tango tablet has sensors and cameras that allow it to reconstruct a mesh of the area surrounding it. This is in turn used to achieve culling of the virtual elements.

![Figure 3.2: Reconstructed mesh and virtual creature hiding behind an object.](image)

The mesh is reconstructed and it hides the virtual elements. However, this hides the real world, as the mesh is reconstructed, see figure 3.2. This is avoided by not drawing the mesh, and instead only keeping the depth information gathered by the system. The occlusion rely only on these values. Using this method, the virtual elements are still occluded behind the objects picked up by the sensors on the Tango. However, the mesh will not obscure the view of the real world.

3.2.2 Agent interacting with the environment

Games require interaction, and this is no different when it comes to AR. In contrast to games using VR headsets, the user playing augmented reality games using portable devices is encouraged to move around. This is integrated into this application game by letting the virtual agents move around, encouraging the user to move around after them. The interaction implemented in this application is letting the virtual creature move away from the user, without running through walls or other objects.

The virtual agent has to be aware of its surroundings to know where it can and cannot move to. As the agent explores the area, it creates a 2D grid representation mapping to the real world environment, hereafter called a floor plan, see figure 3.3. It will then make decisions from this information on where to move next.

As the creature is exploring and moving around, a data tree of positions is generated. This data tree is a representation of the floor plan on which the creature can freely move. Whenever the creature has moved to a new position, it will
Figure 3.3: The virtual agent (purple) avoiding the user (blue), and exploring the room. The green parts are the visited places, the grey is obstacles (walls).

examine its surrounding environment. All the points in the data tree receive a certain weight based upon the environment. The creature wants to avoid the player, so points near the player are heavier than points farther away. To ensure the creature will not get stuck in a corner, points near multiple obstacles and previously visited points also receive a higher weight. Walls or points that are completely unreachable receive an infinitely high weight. To find the most suitable point, the A* algorithm is applied on the data tree. The starting position is the current position of the agent, and the goal is the point with the lowest weight.

Figure 3.4: The agent investigates its surrounding area.

For this application, the agent moving around in the real world is used to inspire the player to chase after it. This will in turn make the agent explore more of the area and mapping a larger part of the environment. The player is further engaged by the ability to throw projectiles at the creature. If the player hits the creature, the player receives one point. The projectiles have a limited
range, so the user has to move close to the creature to be able to hit it. There is no leader board or tracking system implemented to save the scores, and they are lost whenever the application is closed.

### 3.3 User Testing

An online survey was conducted to explore how users would rank the different game mechanics. Videos showing the mechanics were shown to the participants, and questions about which mechanic they prefer was asked.

The survey was aimed towards gamers, as the questionnaire contained questions about games and gaming in general, but the survey was open for everyone. It was shared on the social platforms Facebook and Reddit, to get as many participants as possible.

The survey was split into three parts. The first part asked about whether or not the partaker had any experience playing games using AR, VR or motion controllers.

The second part included videos showing different versions of the application. The first version, **version A**, showed the mechanics of occlusion culling, with short clips of the creature hiding behind a box. The second version, **version B**, showed the creature moving around in a room, on the floor, avoiding walls and large obstacles. The final version combined both of these mechanics, **version C**. The questions in this part regarded immersion and which technique the answerer preferred to see in an AR game.

The last part focused on genres and what the responder likes to see in games in terms of graphics (realistic or stylised) and what they think is most important for immersion.

![Figure 3.5: Stylised graphics vs realistic graphics.](image_url)

Figure 3.5 illustrates some of the different styles presented in recent games. The left side shows more stylised graphics, and the right side shows more of a realistic style.

In figure 3.6 a similar situation is presented. The right side shows the style presented in the application, with the real world being shown through a normal camera. The left side of the image depict an example of how using stylised graphics in augmented reality might look.
# Online questionnaire

## Part 1

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Have you played any augmented reality games?&quot;</td>
<td>• Yes</td>
</tr>
<tr>
<td></td>
<td>• No</td>
</tr>
<tr>
<td></td>
<td>• I don’t know</td>
</tr>
<tr>
<td>&quot;Have you played any virtual reality games?&quot;</td>
<td>• Yes</td>
</tr>
<tr>
<td></td>
<td>• No</td>
</tr>
<tr>
<td></td>
<td>• I don’t know</td>
</tr>
<tr>
<td>&quot;Have you played any games using motion controllers?&quot;</td>
<td>• Yes</td>
</tr>
<tr>
<td></td>
<td>• No</td>
</tr>
<tr>
<td></td>
<td>• I don’t know</td>
</tr>
</tbody>
</table>

## Part 2

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Of these two mechanics, which one would you consider to be more immersive?&quot;</td>
<td>• The environment acting on the bunny</td>
</tr>
<tr>
<td></td>
<td>• The bunny interacting with the environment</td>
</tr>
<tr>
<td>&quot;Which one of the two mechanics would you most like to see in an augmented reality game?&quot;</td>
<td>• The environment acting on the bunny</td>
</tr>
<tr>
<td></td>
<td>• The bunny interacting with the environment</td>
</tr>
<tr>
<td>&quot;Would you prefer to see both mechanics together in an augmented reality game, or would you prefer to see only one of them implemented?&quot;</td>
<td>• Both mechanics together</td>
</tr>
<tr>
<td></td>
<td>• Only the environment acting on the bunny</td>
</tr>
<tr>
<td></td>
<td>• Only the bunny interacting with the environment</td>
</tr>
<tr>
<td></td>
<td>• Other</td>
</tr>
</tbody>
</table>

## Part 3

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;What genres of games do you enjoy playing?&quot;</td>
<td>• Action</td>
</tr>
<tr>
<td>(Multiple answers allowed)</td>
<td>• Action-Adventure</td>
</tr>
<tr>
<td></td>
<td>• Adventure</td>
</tr>
<tr>
<td></td>
<td>• Role-playing</td>
</tr>
<tr>
<td></td>
<td>• Simulation</td>
</tr>
<tr>
<td></td>
<td>• Strategy</td>
</tr>
<tr>
<td></td>
<td>• Sports/Racing</td>
</tr>
<tr>
<td></td>
<td>• Other</td>
</tr>
<tr>
<td>&quot;What kind of aesthetics do you prefer in a 3D video game?&quot;</td>
<td>• Realism</td>
</tr>
<tr>
<td>(Multiple answers allowed)</td>
<td>• Stylised</td>
</tr>
<tr>
<td>&quot;What are the most important factors for you regarding immersion in a video game?&quot;</td>
<td>• Good sound design</td>
</tr>
<tr>
<td>(Multiple answers allowed)</td>
<td>• Good animations</td>
</tr>
<tr>
<td></td>
<td>• Good resolution</td>
</tr>
<tr>
<td></td>
<td>• Good lighting</td>
</tr>
<tr>
<td></td>
<td>• Stable framerate</td>
</tr>
<tr>
<td></td>
<td>• Consistent aesthetics</td>
</tr>
<tr>
<td></td>
<td>• Story/writing</td>
</tr>
<tr>
<td></td>
<td>• Other</td>
</tr>
<tr>
<td>&quot;In augmented reality games, would you prefer a stylised look for everything, or would you want the real world to look real?&quot;</td>
<td>• Realism</td>
</tr>
<tr>
<td></td>
<td>• Stylised</td>
</tr>
<tr>
<td></td>
<td>• It doesn’t matter</td>
</tr>
<tr>
<td>&quot;What type of games would you most like to play using augmented reality?&quot;</td>
<td>• Action</td>
</tr>
<tr>
<td>(Multiple answers allowed)</td>
<td>• Strategy</td>
</tr>
<tr>
<td></td>
<td>• Location-based games</td>
</tr>
<tr>
<td></td>
<td>• Building/creating</td>
</tr>
<tr>
<td></td>
<td>• Learning</td>
</tr>
<tr>
<td></td>
<td>• Other</td>
</tr>
</tbody>
</table>
3.3 User Testing

In addition to the online survey, four people user-tested the different applications in person. The results of these user tests helped shape the online survey, as well as give a view of how the application worked when used. These tests were more in-depth, and allowed for a broader discussion.

For the user tests, four versions of the applications were compared. The first application simply had the creature floating in front of the user when they start the application. This is referred to version 0. In this version, the agent does not move or interact with anything. The second application is version A described previously. The third application is version B, and the last one is version C.

The test person compared version 0 with version A, and after that, version 0 with version B. Next, they compared version A and B. Lastly, they got to test the fourth and final version, C, before answering questions about the concept of AR gaming and gaming in general. The amount of time spent on each application was recorded, as well as any comments they had after testing all of the applications.

3.3.1 Potential problems with the user surveys

A major downside for the user survey is that it tests engagement and immersion without actually letting the person answering the survey test the application. An attempt to minimise these problems, a separate user test was conducted. Unfortunately, only a limited number of participants could perform these tests due to time restrictions.

Words used in the survey are subjective, as "immersive" and "engaging" could have different meaning for different people. The genres used in the survey are also broad and comprise several different types of games. For example, regarding the genres, no mention of "multiplayer" or "single-player" is made, as this would result in a long list of possible answers.
In this chapter, the results from the online surveys and interviews are presented. The final application is also presented, showing screen shots from the application in use.

4.1 Final application

The final application is a game where the player is looking for, and chasing after, a magenta-coloured bunny, see figure 4.1 and 4.2. It is possible for the user to throw yellow spheres at the bunny. When the user is looking at the bunny, it will try to escape from the player.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure4_1.png}
\caption{Virtual creature placed in the real world.}
\end{figure}
4.2 User tests and online survey

A small user test/interview was done with four different individuals. The comments and results from this smaller user test laid the foundation of the online survey. As this was an in-person interview, where the participants had the opportunity to try the applications in person, feedback regarding the experience was collected from each participant. None of the participants found the tablet difficult to use, and they did not experience any physical limitations when using it. The main complaint was the lag. Suggestions of improvements were centred around improving the stability as well as adding better feedback from the application. The participants were also asked about how the application could be improved by adding more gaming content and what kind of game they would like to play using a similar system. The ideas that were mentioned were ghost hunting games and bringing strategy board games to life.

During the user tests, some participants placed the bunny on a table instead of the intended floor. This caused some problems where the bunny moved from the table surface, floating in the air. The applications also frequently crashed, and the device got increasingly hotter during the tests.

Table 4.1: Time each user spent on each app

<table>
<thead>
<tr>
<th></th>
<th>App 1</th>
<th>App 2</th>
<th>App 3</th>
<th>App 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person 1</td>
<td>50s</td>
<td>2min 53s</td>
<td>31s</td>
<td>1min 35s</td>
</tr>
<tr>
<td>Person 2</td>
<td>1min</td>
<td>1 min 51s</td>
<td>1min 29s</td>
<td>2min</td>
</tr>
<tr>
<td>Person 3</td>
<td>2min 6s</td>
<td>1min 37s</td>
<td>2min 32s</td>
<td>2min 30s</td>
</tr>
<tr>
<td>Person 4</td>
<td>1min 48s</td>
<td>2min 8s</td>
<td>3min 28s</td>
<td>4min 14s</td>
</tr>
</tbody>
</table>
The online survey got 35 recorded answers. The results from the online survey showed that the majority of the people answering found version A more immersive than version B. However, version B was more popular than version A in regards to which they would prefer to see in a game. When asked if they wanted to see both mechanics together, only 8.6% said they wanted only version A or version B. The reason given for preferring version B was that the mesh for the bunny appeared broken or incomplete. This would therefore lessen the overall experience. No motivation for preferring only version A was given.

There were two questions regarding aesthetics in video games; one asking generally about 3D video games, and another specifically about aesthetics in AR games. For 3D games in general, the results showed an even distribution, with 60% saying they preferred realism, and 62.9% preferring stylised.
Have you played any games using motion controllers? (35 responses)

- Yes: 85.7%
- No: 14.3%
- I don't know: 0%

Of these two mechanics, which one would you consider to be more immersive? (35 responses)

- The environment acting on the bunny: 62.9%
- The bunny interacting with the environment: 37.1%

Which one of the two mechanics would you most like to see in an augmented reality game? (35 responses)

- The environment acting on the bunny: 65.7%
- The bunny interacting with the environment: 34.3%
4.2 User tests and online survey

Would you prefer to see both mechanics together in an augmented reality game (as shown in the video above), or would you prefer to see only one of them implemented? (35 responses)

- Both mechanics together: 91.4%
- Only the environment acting on the bunny
- Only the bunny interacting with the environment
- Other

What genres of games do you enjoy playing? (35 responses)

- Action
- Action-adventure
- Adventure
- Role-playing
- Simulation
- Strategy
- Sports / racing
- Other

What kind of aesthetics do you prefer in a 3D video game? (35 responses)

- Realism: 80%
- Stylised: 62%

What are the most important factors for you regarding immersion in a video game? (35 responses)

- Good sound...
- Good animation...
- Good resolution...
- Good lighting...
- Stable frame...
- Consistent animation...
- Story / writing...
- Other
In augmented reality games, would you prefer a stylised look for everything, or would you want the real world to look real?

(35 responses)

- Stylised: 40%
- Real: 37.1%
- It doesn't matter: 22.9%

What type of games would you most like to play using augmented reality?

(35 responses)

- Adventure (for...): 28 (80%)
- Strategy (for...): 17 (48.6%)
- Location-based: 13 (37.1%)
- Building/area: 13 (37.1%)
- Learning (for...): -9 (25.7%)
- Other: -2 (5.7%)
4.3 Future Work

The next step for this project would be to implement more gameplay elements, add animations, and change the creature model to something more engaging. To expand the current mechanics, a next step would be to allow the creature to move in three dimensions. Although the application might run on different types of Tango systems, the application is not tested, or developed, for other systems. This could also be interesting for future work, as there are currently more devices available that can run Tango applications [8], than just the development kit tablet used for this project.
Discussion and conclusions

This chapter will present some discussion about the application and the results.

5.1 Application

The application discussed here is the final version, version C, as it has all of the mechanics implemented. The mechanics in the application are compared to works mentioned in section 1.2.

The A* algorithm was chosen because it is one of the most commonly used pathfinding algorithms for games. There is a lot of information about it, and it is very well documented and relatively easy to implement. For the purpose of this project, A* was deemed sufficient.

The pathfinding is different from the method used by Mocholi et al. in their application eCoology. In eCoology, the environment is partly specified, with the deflectors and nodes already defined in the world. The pathfinding used in this project works without any previous knowledge of the environment. This negatively affects the precision of the pathfinding, but it works in any indoor environment. This gives more freedom to use the application without preparation, as the pathfinding will work directly after launch.

The simple point collecting system was implemented to let the user directly interact with the agent. The ability to throw projectiles at the virtual creature is similar to throwing Pokéballs in Pokémon GO. Due to time constrains and the late implementation of the projectiles, it is not fully developed. There is no system to keep track of points, nor is it possible to catch the creature.

The guidelines devised by Wetzel et al. (explained in 2.2.1) mention turning weakness into strength. This is a main component in this project, as the game idea is to use exploration of an unknown environment and turning it into an engaging experience for the player. A problem for AR applications is managing the
unknown environment, and to incorporate it into the game is one approach. This also utilises the real world environment, and due to not requiring any preparation to use, it is simultaneously kept simple.

For the occlusion culling, it is possible to show the mesh the Tango creates, allowing the user see what the creature sees. The mesh is not shown in the application, as this would obscure more of the real world. This would help increase the feeling that the virtual elements were in fact in the real world. This is also mentioned as one of the guidelines; to show the real world and not let the virtual elements take over.

Some of the guidelines are not applicable to the application created, due to the nature of the project. Only one device was considered for this project. Instead of considering different tracking methods or finding the most relevant technology, the application and its themes were designed based around the Tango tablet.

The sharability/social aspect of the game is restricted due to not including any multiplayer features. The small size of the tablet is a restriction; multiple people may watch the same screen, but there is no possibility of allowing more than one user at a time per tablet. Social elements within the application are restricted to only interactions with the virtual agent.

As the game is limited to only incorporate one virtual agent, it is critical that this agent is interesting enough to keep the user entertained. There is no other content implemented to distract the user from this agent, aside for the different types of interactions.

### 5.1.1 Limitations and technical issues

During the development of the application, certain limitations of the tablet became apparent. The most prominent of these was the frequent crashes when using the applications. These crashes were caused due to high RAM usage during the mesh building used for occlusion. The colour camera would occasionally stop working, requiring a reboot of the system.

Another issue occurring during runtime when using the mesh building is artefacts appearing in flashes on the screen, shown in figure 5.1.

![Visible artefacts from the depth sensor when creating a mesh.](figure5_1.png)

*Figure 5.1: Visible artefacts from the depth sensor when creating a mesh.*
These issues will likely be solved with further updates of the Tango software, and improved hardware with more stable depth perception.

5.2 Survey results

The user tests were done to find what the most interesting parts of the applications were, and to see if there were any major obstacles in using the system. The test persons tested four different versions, instead of just the three presented in the online survey. The first version, version 0, was not included in the online survey as none of the participants found it very interesting. To keep the online survey more compact, and the reduce the time it would take to complete, that version was not included.

An online survey was conducted to understand the opinions of potential users of AR games and applications. The survey was geared heavily towards gamers, as the mechanics were developed with games in mind. The questions were asked to find which of the main mechanics developed would be preferred in games, and to find if immersion is more important than gameplay. The technology of augmented reality allows for deeper immersion by combining real world elements and the virtual (game) elements.

The vast majority, 91.4%, said they would prefer to see both mechanics implemented in a game. However, comments showed that the bugs and artefacts in the method for occlusion removed some of the immersion. Comments also showed that some people wanted to see only the agent interacting with the environment. This is also shown in the questions about which mechanic would be preferred in a game, where the majority, 65.7%, said they preferred version B over A. On the other hand, when asked about immersion, version A was more popular, with 62.9% of the votes.

Regarding what makes a game immersive, the most popular factor was story/writing, with stable frame rate as the second most important factor. Sound, animation, and consistent aesthetics were also popular. As for what kind of aesthetics was most popular, both realism and stylised were equally popular, with only one vote difference. This is reflected in the answers to the question touching on aesthetics for AR games, as there is not a significant difference between these answers either.

Popular genres were adventure and strategy, both in general and for AR games specifically. During the user tests, ideas about games within these genres were brought up. Strategy games are suitable for AR, as it is possible to augment board games by introducing virtual pieces and bring them to life. With such a game, the pieces would move on a table surface and adapt to the environment design by real world objects. In this example, the virtual elements would have to know how the environment looks.

An adventure game could be based around chasing entities, such as ghosts, that are only visible through a display. Perhaps the entities could move through objects, but doing so will still occlude them. This type of game would not require the virtual agents to be aware of the environment, but rather only let the
environment passively act on them.

5.3 Conclusions

According to the survey results, it is more important to focus on creating engaging content over immersive experiences. A game is an interactive medium, and should therefore focus on engaging the gamer. The immersive parts of the application has the potential to both enhance and ruin the experience. If the graphics are mediocre and leave the virtual elements broken, this will eliminate the sense of immersion rather than enhance it. However, disregarding the flaws in the occlusion, the combination of the environment acting upon the agent and the agent interacting with the environment proved to be a successful concept.
Bibliography


