Augmented Reality as a Potential Tool for Filmmaking

Paul Blachfield
Dublin Institute of Technology

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Augmented Reality as a potential tool for filmmaking

Paul Blanchfield

A dissertation submitted in partial fulfilment of the requirements of Dublin Institute of Technology for the degree of M.Sc. in Computing (Advanced Software Development)

Date: September 2018
Declaration

I certify that this dissertation which I now submit for examination for the award of MSc in Computing (Stream), is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This dissertation was prepared according to the regulations for postgraduate study of the Dublin Institute of Technology and has not been submitted in whole or part for an award in any other Institute or University.

The work reported on in this dissertation conforms to the principles and requirements of the Institute’s guidelines for ethics in research.

Signed: Paul Blanchfield

Date: September 2018
Abstract

Augmented Reality (AR) has been used for a wide variety of industries. The purpose of this study was to determine the suitability of this technology for use in filmmaking. One of the problems on a film set is the time taken to block a scene. Blocking involves the placement of subjects and props within a scene. Different ideas have been used for blocking including previzualisation and Virtual Reality (VR). This study proposed the use of AR as a tool to solve this problem.

Marker-based and Markerless AR were assessed in turn to determine their suitability for addressing the problem. The use of AR markers and QR codes were examined in comparison with the use of Simultaneous Localization and Mapping (SLAM) implementations. The marker-based AR requires a physical object to scan and markerless is done via the mapping of GPS coordinates. Experiments were conducted on the accuracy and code required for each type of AR. These involved calculating the distances from the marker and the code required to create the virtual content.

Surveys and expert interviews were conducted with filmmakers and people working in the AR industry to determine the usability and feasibility of the proposed application. This provided a qualitative approach to the technology as the acceptance of any new system is of equal importance to how it functions.

Keywords: Augmented Reality, Filmmaking, User Experience, Marker-based, Markerless, Field of View, Blocking
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<td>AI</td>
<td>Artificial Intelligence</td>
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<td>AoV</td>
<td>Angle of View</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>CGI</td>
<td>Computer Generated Imagery</td>
</tr>
<tr>
<td>FoV</td>
<td>Field of View</td>
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<tr>
<td>HMD</td>
<td>Head Mounted Display</td>
</tr>
<tr>
<td>IFTN</td>
<td>Irish Film and Television Network</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td>IOT</td>
<td>Internet of Things</td>
</tr>
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<td>MAR</td>
<td>Mobile Augmented Reality</td>
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<tr>
<td>MRLE</td>
<td>Mixed-Reality Learning Environment</td>
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<tr>
<td>SLAM</td>
<td>Simultaneous Localization and Mapping</td>
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<tr>
<td>UX</td>
<td>User Experience</td>
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<td>VR</td>
<td>Virtual Reality</td>
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<tr>
<td>VIO</td>
<td>Visual Inertial Odometer</td>
</tr>
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<td>XR</td>
<td>Cross Reality</td>
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Table 1: List of Acronyms
Chapter 1

Introduction

1.1 Background

*Augmented Reality (AR)* is present on the *X Reality (Cross Reality)* spectrum. Other elements on this spectrum include *Virtual Reality (VR)* and *Mixed Reality (MR)*. Akçayır et al (2016) define AR as a real-world context which is dynamically overlaid with context-sensitive virtual information. Figure 1.1 shows a well known albeit fictional use of AR in the film *Minority Report*. Tom Cruise’s character can manipulate content around a screen without touching it.

![Figure 1.1: Scene from Minority Report (2002)](image)

The current market trend for AR is towards educational or entertainment content. Smart devices with built-in cameras are the main tool for viewing AR content. Since
the release of *Pokémon Go* in 2016, there has been an increase in the popularity of AR. This popularity is present within the entertainment industry [1, 2]. There has been a dynamic shift in the presentation of AR through the use of head mounted devices (HMDs) including smart glasses. This is because of the reduction in the size of the hardware and the improvements in technology. These advancements created a ubiquitous environment for the technology which improves user experience.

### 1.2 Research Project/Problem

The main problem addressed was whether AR could be a tool used for blocking a film scene. Blocking is the filmmaking process describing the interaction between a camera and subject. There are three different subjects to be considered, actor, extra and prop. The ultimate reason for blocking is to visualise the placement of everything within a scene. For example, a camera panning through a crowded room must show certain elements. These elements are key to the story. This is also how product placement occurs on camera. The camera pans down from an advertisement to the action below. Currently blocking is a rule of thumb assumption of what the camera can see. The AD looks towards where the camera is set up and from experience determines the field of view. This can be time intensive and can cause a high level of human error. An application that could present the field of view of the camera could potentially solve this problem. In the world of filmmaking, “time is money” and it is important to get every shot set up in the shortest time possible.

The research question for this dissertation was:

>“Can the use of a Mobile Augmented Reality (MAR) application created using marker or markerless based Augmented Reality (AR) increase the efficiency of camera and subject placement in a filmed scene?”
1.3 Research Objectives

A breakdown of the research objectives for this dissertation are as follows:

- Review the existing literature relating to augmented reality, user experience and filmmaking.

- Create multiple levels of prototypes for an AR application.

- Prepare experiments to test the different components of the application. The three components were *Accuracy, Code*, and *User experience (UX)*.

- Evaluate the results of the experiments and perform an analysis.

- Identify potential research areas for future analysis.

1.4 Research Methodologies

The research methods were a mixture of qualitative and quantitative. This blend allowed for the analysis of the usability and efficiency of the technology. The quantitative data required was the distance required to view virtual content.

Secondary research was the main component of this study. This research was an analysis of the existing material written about AR. This material included research papers and software documentation. The documentation presented the best possible avenues for experimentation within the technology.

Primary research complemented the secondary research to create a more rounded study. This primary research was in the form of surveys and expert interviews. The surveys presented a view of the potential user base. The expert interviews allowed for a deeper understanding of the subject matter and problem. The surveys focused on the Irish film industry. The expert interviews introduced the AR industry into the mix.
1.5 Scope and Limitations

The scope of this research was the design and usability testing of AR applications. This was determined by using of the technology to complete a specific task. The technology was analysed on a smartphone.

The hardware used presented its own limitations. Devices such as HMDs reside outside of the remit for this dissertation but could be analysed as part of future research.

1.6 Document Outline

This dissertation breaks down into the following chapters:

- **Chapter 2** was an analysis of the existing literature relating to AR. A background of the filmmaking process was addressed. The concept of blocking was established as a part of this background and presented in relation to the overall problem. There was some film theory included to justify decisions made during a production. To solve the problem, user experience theories were used for evaluation. This chapter introduced the relevant theories and demonstrated the metrics which were evaluated. Gaps and commonalities between AR, filmmaking and user experience were presented.

- **Chapter 3** described the design process which was chosen for this dissertation. For this research project, prototypes were created to demonstrate the proof of concept of the application. Three experiments were conducted for each of the components being assessed, *Code, Accuracy* and *User Experience (UX)*. Within each experiment section the metrics for measurement were presented and justified.

- **Chapter 4** demonstrated the creation of the prototypes and the results that were gathered from the experiments. The results gathered from each experiment were compared. The languages and software packages that were chosen to conduct
the experiments were presented as well as the product created from each. The order of the experiments was UX, Code and finally Accuracy. The Accuracy experiment was further broken down into marker and markerless experiments.

- **Chapter 5** analysed the results from the experiments. It also evaluated the design process as a whole for the dissertation. Any problems encountered and adjustments made were justified.

- **Chapter 6** presented a conclusion to the overall thesis. Any contributions made to the research of augmented reality within the context of filmmaking were presented. All of the limitations encountered during the process of writing the thesis were presented and addressed. Finally there was an analysis of future work in the area of augmented reality and filmmaking which was outside the scope of this particular research project.
Chapter 2

Literature Review

2.1 Introduction

There are three parts to this literature review.

1. A background to AR technology

2. An introduction to filmmaking concepts

3. An analysis of user experience.

2.2 Augmented Reality

AR was first coined by Tom Caudell and David Mizell in 1992. It made an appearance on Milgram’s *Reality-Virtuality Continuum* shown in Figure 2.1. AR was first developed by Ivan Sutherland in 1968 in tandem with the first VR system. Other key events in AR’s history included the inventions of the tablet (1972) and the laptop computer (1982). (2, 3)
AR is the process of placing virtual information on top of a real-world environment to “augment” the user’s surroundings. This is through the use of a mobile device such as a smartphone or a HMD. Examples of HMDs include the Microsoft HoloLens and Google Glass.

Advancements in technology have benefited the creation of AR. These include GPS (1993), markers (1999) and real-time feature tracking (2006). The release of ARToolKit in 1999 boosted AR development. This spawned numerous software development kits (SDK). These SDKs included ARCore and ARKit.

According to Liu, the goal of AR is to combine the real and virtual in a photorealistic way. This makes it difficult to distinguish between the two. The techniques used can range from tracking and registering features of objects to using projection mapping.

2.2.1 AR Concepts

There are two concepts for the development of mobile AR applications (MAR). These are Marker-based and Markerless. The Field of View (FoV) is relevant to both of these concepts. The dictionary definition for FoV is “the angle between two rays passing through the perspective center (near nodal point) of a camera lens to the two
The FoV for a camera changes depending on the size of the lens. Changing the lens changes the view of the camera as shown in Figure 2.2.

\[ \text{AoV} = 2\arctan\left(\frac{\text{Sensor width}}{2 \times \text{focal length}}\right) \times \left(\frac{180}{\pi}\right) \] (2.1)

Using the result of Equation 2.1, the FoV in Equation 2.2 can be calculated.

\[ \text{FoV} = 2(\tan(\text{Angle of View}/2) \times \text{Distance to Subject}) \] (2.2)

Markers

There are two types of markers used to present virtual information. These are AR markers and QR codes. AR markers are black and white and are only able to track and identify a virtual object. QR codes are square barcodes that store positioning information. Other forms of information are also embedded in the code. QR codes appear in advertising and have become ubiquitous within society. They often appear on tickets and receipts. AR codes appeared as a part of educational courses. Figures 2.3 and 2.4 are examples of AR markers and QR codes.

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CHAPTER 2. LITERATURE REVIEW

Markerless

Markerless is the presentation of virtual imagery without the use of either AR markers or QR codes. There is a separate process which determines this position of the virtual object known as Simultaneous Localization and Mapping (SLAM). It is possible to globally align a virtual object in a real scene using SLAM. For correct initialization there needs to be a baseline established. This is determined by camera pose. Markers set limits to the visibility of AR. Using SLAM, a room can be scanned and objects placed at specific GPS coordinates. For example, objects placed around the room retain their positions even after the camera has moved. When you pan the camera around the room the different items will move on and off the screen. Pokémon Go uses SLAM as a part of its game mechanics. This allows developers to release content at a given location at a set time. These releases have often caused crowds to descend on the selected areas.

2.2.2 Real World Examples

This section analyses the real world applications of AR. Since it is a broad area of research there was a choice of industries. The three chosen were Education & Training; Entertainment & Marketing and Tourism & Navigation. The chosen industries have some overlap in their approach to the technology. Yet, there are some unique uses
which are dependent on the industry.

**Education and Training**

In the realm of education there are two distinct groups of people. This is beyond the scope of the standard teacher and student. These groups are *digital nomads* (teachers) and *digital natives* (students).

There is a gap between the *digital native* and the *digital nomad*. The distinction between the two is usually centered around age. If someone is under the age of 30 they are a *digital native* while those above are *digital nomads*. A *digital native* is someone who has encountered technology for their whole life. *Digital natives* are more adept at the ever changing landscapes. *Digital nomads* are those who had a period of their lives without technology on such a wide scale. They know of a time when technology was not a driving force in everyone’s lives (\(\text{2} \), \(\text{3} \)). Overlap between the two groups appears with older students or younger teachers.

In schools, the emphasis is on *interaction*. Universities focus on *engagement*. The use of AR is the distinction between interaction and engagement. For example, school kids used the technology as a learning aid at a botanical garden (\(\text{2} \), \(\text{3} \)). University students created a “*connection between the theoretical explanations and the laboratory practices*” (\(\text{2} \), \(\text{4} \)). This confinement of the technology to laboratory environments is also present in (\(\text{2} \), \(\text{5} \)) and makes an appearance in (\(\text{2} \), \(\text{6} \)).

The aim of AR in education was to reduce the amount of teacher assistance required within lessons to increase productivity. AR tools are used in situations where students are learning *science, technology, engineering or mathematical (STEM)* subjects. Daas (2018) presented a study describing how AR taught students how to code (\(\text{2} \), \(\text{7} \)). A limitation to the use of AR by teachers is the lack of knowledge that some may have towards the technology. This could be because some of them are *digital nomads*. This limitation in combination with developers lack of creative design education expertise
leads to a stop start embracing of the technology within education systems. AR and MR environments can improve real time communication (\cite{7,8}). They can also be a part of a *Mixed Reality Learning Environment (MRLE)* (\cite{7,8}). MRLE’s present both real and virtual information as educational tools (\cite{7,8}).

There are contradictions between the advantages and disadvantages of using AR for education. There are mixed feelings towards the cost of AR. This could be as a result of the hardware used. The cumbersome nature of the hardware is another disadvantage of AR. Some of the devices used such as *HMDs* can often leave the user tethered to a computer. (\cite{7,8}). An example of a tethered HMD is the *Leap Motion* headset. The *FoV* for this device is *100 degrees*. Except for the lack of movement the device is comfortable. This goes against the research but this it is on the more expensive side for devices.

**Tourism & Navigation**

The use of technology is ubiquitous in the realm of tourism and navigation. Since the invention of the *satnav*, drivers are looking for newer ways to detect what is ahead of them, to find where they are going and to avoid being stuck in traffic. Research is ongoing on the use of AR in relation to *collision detection* while driving. A drawback to this is the possibility of distracting the driver (\cite{7,8}). These distractions could cause an accident. When a driver’s focus is on one threat another could appear. There needs to be exact specifications of what is being detected and how this information is being relayed to the user.

Currently, cars use audible beeps to detect if a collision is about to occur. This could lead to the adoption of *Audio Augmented Reality (AAR)* (\cite{7,8}). With *AAR* a noise transmits when a user enters an area. This would reduce driver distraction and allow them to adapt to situations. In the case of driverless vehicles, an opportunity arises to superimpose information about the surroundings for the passengers to view in real time. Mulloni presented the idea of AR information superimposed over real-world
environments. In the study AR is used to navigate college campuses or unfamiliar areas. (?)

The creation of a unique tourist experience is a concern for historical sites. With the crowded spaces and limited artifacts visible, it can be difficult to engage tourists, who often arrive at a site, grab a selfie or two with the main attractions and move on. There has been some success with the use of VR at historical sites. An example of this is at the *Sforza Castle* in Milan, Italy. A guided tour of the castle grounds with a VR element is one of the tours available. Park demonstrated the creation of AR applications for immersive tourist experiences. (?)

A drawback of using AR or VR applications at historical sites could be the removal of the *tactile* and *human elements*. The human element comes in the form of the tour guide. They have usually lived in the area their whole life and provide a unique tour through the site. The tactile comes in the form of getting lost in a location and the feel of being there. When led through a site by a virtual guided tour or an audio tour the focus is on the story. The tourist feels the need to keep moving instead of absorbing the surroundings. People can reject predefined narratives preferring to make smaller individual decisions. There is a market for this with bespoke experiences or *sandbox* gaming environments. A sandbox environment allows the user to explore an area on their own.

**Entertainment and Marketing**

The entertainment and marketing industries are a growing player in the adoption of AR. Entertainment’s use of AR is in two types, *passive* and *engaged*. Going to the source of the AR determines the type. Musicians and filmmakers use passive AR to add extra elements to their work. Examples of passive AR include applications created by bands such as *Gorillaz* and *U2*. Gorillaz created an AR application called *Lenz*.

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5https://beyondthegate.io/en/homepage/
ahead of the release of their latest album *Humanz*[^6] U2 incorporated AR content as an element of their *eXPERIENCE + iNNOCENCE* world tour[^7]. The users of these apps do not need to do anything other than open the app at the right time to view the material.

AR gaming allows users to move from *passive* to *engaged* interactions. The most well known AR game is *Pokémon Go*. *Pokémon Go* developed by *Niantic* and released in 2016. According to Shea (2017), the game forces players to roam an area using their device’s capabilities. The *Pokémon* avatars within the game are also attached to physical locations. [^?][^?]. The user goes to the different locations to ”*capture*” the *Pokémon*. Since *Pokémon* are fictional versions of animals they share traits such as habitats. For example, you can find water-based *Pokémon* near a river. An image from the game is in Figure 2.5.

![Figure 2.5: Pokémon Go](image)

Nostalgia and ease of use caused a surge in the popularity and level of engagement of *Pokémon Go*. No additional hardware was required to play the game other than having a smart device. The application is *freemium* allowing developers to gain revenue even though the majority of players were using the application for free. *Freemium* means that the core elements of an application are free with extra content available for a small fee.

Two shortcomings of *Pokémon Go* are that it presents a physical danger to the player and also drains device battery. Despite warnings present in the game, some users injure themselves while playing. Others are victims of attack by people taking advantage of distracted players. The other and most noted shortcoming for *Pokémon Go* is the drain on the battery that it causes. While the game is played, GPS and graphical rendering are being used. Both of which can have a detrimental effect on the battery life of the device. Some users disable any AR components on the app and use it with only GPS location and a push notification for when a *Pokémon* is present.

*Pokémon Go* is a markerless AR game. There has been research done on the use of markers for gaming. One such example of this is the trading card game *Stereo Cards*. In this game, the playing cards themselves are the markers that store additional information for the camera (?:). The game environment for *Stereo Cards* is in Figure 2.6.
CHAPTER 2. LITERATURE REVIEW

Marketing corporations have tapped into the potential of AR for *gamification*. The dictionary definition of *gamification* is “The application of typical elements of game playing to other areas of activity to encourage engagement with a product or service.”\(^9\)

Nazri presented an example where an AR game is available to anyone who purchases a brand of chocolate bar. To view the content the customer scans the wrapper with a smart device. The research showed that AR encourages customers to visit a company’s website. This can lead to increased sales and brand exposure. \(^?\)

2.2.3 AR Software Development Kits

The five *SDKs* discussed for of this research project were *ARCore*,\(^{10}\) *ARKit*,\(^{11}\) *AR-ToolKit*,\(^{12}\) *Project Tango*,\(^{13}\) and *Vuforia*.\(^{14}\) There was an even split between the *SDKs* for *Android* and *iOS* operating systems.

---

\(^9\)https://en.oxforddictionaries.com/definition/gamification
\(^{10}\)https://developers.google.com/ar/
\(^{11}\)https://developer.apple.com/arkit/
\(^{12}\)https://github.com/artoolkit
\(^{13}\)https://www.trustedreviews.com/news/what-is-project-tango-2941129
\(^{14}\)https://docs.unity3d.com/Manual/vuforia-sdk-overview.html
ARCore

ARCore is Google’s entry into the AR development market and first appeared in March 2018. Gaming interfaces created using ARCore have appeared in Aultman’s research [2, 3]. ARCore requires Android 7.0 (Nougat) to operate. This is because of the camera capability which is part Nougat’s source code.

ARKit

ARKit is a set of software tools released by Apple in June 2017. Developers used ARKit for creating prototyping platforms [4, 5], educational software [6, 7] and SLAM applications [8, 9]. ARKit utilises a technique called visual inertial odometry (VIO). VIO is a combination of motion from cameras with the measurements from a Inertial Measurement Unit (IMU) [10, 11]. ARKit allows for an absolute camera pose but due to a limited FOV can only work on special devices [12, 13].

ARToolKit & AR.js

ARToolKit is a marker based AR tool for the creation of applications. The main features of ARToolKit include positioning and orientation tracking. The type of AR marker is not important for ARToolKit. This is because it can recognise different marker patterns. Development of other AR platforms used ARToolKit including AR.js.

AR.js[15] is a web based AR tool which runs within a browser. No external applications are required to operate AR.js. Using this web interface AR is visible with either a smart device or via a desktop or laptop computer. Within AR.js the frame rate (45, 50 or 60) is set to increase the stability dependent on the device used. Recalibration in AR.js occurs when the camera moves away from the target and back towards it. Unlike ARKit this AR tool operates on devices older than two years old.

Project Tango

*Project Tango* was the predecessor to *ARCore* released by *Google* in 2014. The three functions of *Project Tango* were *motion tracking*, *depth perception* and *area learning*. Motion tracking uses an *accelerometer* and a *gyroscope* to determine *position* and *orientation*. Depth perception presents the shape of the surroundings. Area learning maps out an area that the devices sees to place virtual objects within an area. *Project Tango* was only available on devices “optimized with extra hardware - such as a barometer, motion tracking camera, and an infrared depth-sensing camera”\(^\text{16}\).

Vuforia

*Vuforia* is a series of plugins and libraries for *Unity*. It was the industry predecessor to *ARCore* and *ARKit*. The main drawback of *Vuforia* packages is the cost. The cost of use per application is too expensive for applications with a small market share.

### 2.2.4 Limitations

The main limitation of AR is the issue of *real-time interactivity*. This means that there are no allowances for developers to define event based interactions with objects.\(^2 \, ?\). As a result of this changes can’t be made to augmented graphics and sounds.

*ARKit* is only available on *iOS* devices released after the iPhone 6. *ARCore* relies on phones which have the *Android 7.0 Nougat*. *Nougat* is only available on phones released within the last two years. There is no way of installing it on earlier models.

A limitation with marker-based AR was the lack of room for external allowance when presenting a model. For example if the marker is a square the maximum shown is the area within the square. This renders it difficult for using a marker to establish a base point.

\(^16\)https://www.digitaltrends.com/mobile/tango-vs-arcore-theunlockr/
2.3 Filmmaking

2.3.1 Background Research

An understanding of two filmmaking concepts are important for the context of this research. The concepts are *blocking* and *in-camera*. *In-camera* is often referred to as in-camera editing to avoid confusion with the legal definition.

Beaver defines *blocking* as an arrangement of characters and objects on a screen to create a sense of the *depth of field* and *compositional depth*. The compositional depth is a more psychological reading of a scene. An example of this is if one character appears to be taller or higher on a screen than another. The viewer perceives that the taller character is more important and has a higher status in the scene. An example of this is in Figure 2.7 a scene from *Silence of the Lambs*. The idea behind the scene is to make Jodie Foster’s character Clarice appear as small as possible. The director achieved this by having everyone else on screen taller than her. The idea of enclosed space comes from the lack of personal space each person has.

![Figure 2.7: Scene from The Silence of the Lambs (1991)](image)

*In-camera editing* refers to having as much visual information captured while filming as possible. This is to alleviate the need for extensive external *computer-generated imagery (CGI)* or additional editing. There is *CGI* in most filmed scenes but it is not always intrusive. The *in-camera* special effects are generally referred to as practical
effects. Two examples of this are the shark from *Jaws* also known as *Bruce* in Figure 2.8 and the models used for *Star Wars* in Figure 2.9.

![Figure 2.8: Bruce from Jaws (1975)](image)

![Figure 2.9: Models used for Star Wars (1977)](image)

### 2.3.2 Production

Figure 2.9 presents an organisational chart for the preproduction of a film. The process of filmmaking is divided into three stages. The first stage is pre production which is concerned with the preparation of the different elements of the film including casting
and finding locations. Production is when the cameras are rolling and the filming is happening. The final stage is post production which involves editing so the raw footage can be moulded into a finished film.

The scope of this research will focus on directors, directors of photography (DP) and assistant directors (AD). These three members of the crew combined are responsible for setting up scenes and shots. A scene is an interaction between multiple actors that progresses the plot of the film. A shot could be for example showing the contents of a bag or someone walking through a door.

The director has the vision for what should happen. The DP sets up the camera and films what is happening. The ADs ensure everything in the background of a scene is where it should be to get the most out of the scene. As for the AD that role breaks down into three separate positions that branch off from each other. The 1st AD assists the director, the 2nd AD deals with the principal actors while the 3rd AD directs the background extras and other tasks. Each AD helps the one above them by taking on extra work to free up people and adjust to any situations on a film set.
2.3.3 AR & Filmmaking

There have been some examples of the use of AR within the filmmaking industry. The most prominent use of AR is the green screen alternative *ARWall*. *ARWall* replaces and renders a computer background in real-time with changes dependent on where the actor is moving. In traditional filmmaking this is usually done with a green screen. A green screen or sometimes a blue screen is the norm because of the ease to remove green or blue colours from an image. Other instances of AR on screen involved pre-rendered computer generated avatars filmed walking around an area.

Spielman presented an idea of having an on-set editing application with a *HMD*. This type of hardware can cause difficulty to some users without a specialized knowledge of 3D imaging. This allows the user to see *previz* information in real-time. *Previz* also known as pre-visualization is an animated render of what a shot or scene is going to look like. An animated storyboard like the one in Figure 2.11 gives filmmakers a sense of what the finished product would look like.

VR has recently become a component of the filmmaking process. This was the process for *Steven Spielberg’s film Ready Player One* (2018). Since the majority of the film takes place within a virtual environment, the actors wore VR headsets while blocking scenes. This was to help them avoid walking straight through virtual objects while
filming.

2.4 User Experience

UX is an analysis of users and user interactions. This analysis creates a framework of who the user is and how an application can suit their needs. The UX analysis framework provides the foundation for this part of the research study. This framework was built on existing UX theories and those manipulated to suit AR needs. An analysis of prototyping and proof of concepts for AR applications concludes this section.

2.4.1 Analysis Framework and UX Theories

The design of all applications needs to comply with a set of heuristics. Heuristics are faster ways for a user to solve a problem. Aultman states that these must include user interface (UI) elements that are easy to identify, clear and consistent, easily distinguished from the surrounding environments and contextually relevant. The UI must always match the user’s viewing angle and provide adequate feedback. In the research done by Pallot, the creation of a UX framework should take into account the Quality of Service (QoS) and Quality of Experience (QoE) combined with existing UX theories.

When creating the UX framework the first aspect to consider is how it aligns with Norman’s Seven Stages of Action Model. The crucial elements of this model are the Gulf of Execution and Gulf of Evaluation. Figure 2.5 shows a graphical representation of these gulfs.
These gulfs are the gaps that can exist between the system and its goals. In the context of AR the *Gulf of Execution* would be the user was not able to present virtual content with an AR enabled device. The *Gulf of Evaluation* is when the virtual model shown is not what was expected. Other theories which were included into this framework were the *Gestalt Laws of Proximity* and *Similarity*. The *Law of Proximity* states that “items are placed near each other to appear to be a group” while the *Law of Similarity* is “similar objects will be counted as the same group”. These two laws align with the concepts of AR because the idea is to present virtual content within an environment so that it appears to belong as part of the surroundings.

The research presented a way of creating such a framework by combining MAR components such as Information content with designable elements like the ability to move 3D content. To conduct an evaluation it was proposed that the validity of the evaluation is clearer when multiple methods are used to confirm the result.

A visual representation of the UX framework from this research study is shown in Table 2.1. The column on the left contains the relevant UX theories taken into consideration. On the right there are the design components required for a MAR to pass this stage of the development. There was some duplication among the design components as they applied to numerous theories. This was inspired by existing frameworks found in the research.
Table 2.1: UX Framework

<table>
<thead>
<tr>
<th>UX Theory</th>
<th>Required design components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Evaluation</td>
<td>adequate feedback, user friendly UI, easy to learn, adaptability</td>
</tr>
<tr>
<td>Gulf of Execution</td>
<td>clear navigation, adequate feedback,</td>
</tr>
<tr>
<td>Law of Proximity</td>
<td>consistent navigation, grouping of elements</td>
</tr>
<tr>
<td>Law of Similarity</td>
<td>consistent navigation, clear navigation</td>
</tr>
<tr>
<td>Quality of Experience</td>
<td>adequate feedback, ability to manipulate content, easy to learn</td>
</tr>
<tr>
<td>Quality of Service</td>
<td>contextually relevant information, user friendly UI, adaptability</td>
</tr>
</tbody>
</table>

2.4.2 Prototyping

For the creation of a MAR prototype three aspects need to be taken into consideration. These are ease of use, cognitive overload and end-user expectations. The UX of an AR application is dependent on the screen size and resolution of the application as well as the potential for the use of smart glasses. The need for context sensitivity and proactive functionality must also be addressed.

It has been difficult to present AR applications in a 2D medium. To counteract this Nebeling demonstrated an alternative using modelling clay. Figure 2.13 shows models which were used to represent the AR content. This gave potential users tangible association with the application. A prototype is presented as a scenario of use rather than the actual presentation of the functionality.
2.4.3 Metrics

When the efficiency component of the research question is taken into account the following metrics needed to be collected and analysed.

- **Time**: There must be a time limit. Unlimited time would reduce efficiency of the evaluation.

- **Marker Size**: The research has shown that marker size as well as screen size are important considerations when dealing with MAR applications.

- **Distance**: For this research the distances were calculated in feet and inches. This was because the pixel conversion were in dots per inch (dpi) which refers to the resolution of the output of an image. Equation 2.3 shows how to calculate the conversion from pixels to inches.

\[
\frac{\text{Pixels}}{\text{DPI}} = \text{Inches} \tag{2.3}
\]

- **UX**: This metric is concerned with the evaluation of the previous determined framework.

- **Static Analysis**: This is separate from the other metrics and happens to the source code before any compilation or execution occurs. The focus of static analysis is on syntax issues such as spacing, declaration of variables and if a variable is overwritten multiple times.

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CHAPTER 2. LITERATURE REVIEW

2.5 Chapter Summary

This chapter began with a background analysis of AR. This analysis included the real world uses for the technology. The areas discussed were Education & Training, Travel & Navigation and Entertainment & Gaming. Other real world examples were up for consideration but the principles remained the same. An introduction to the concepts of filmmaking gave context to the research project. This background allows for ease of presentation of the later ideas throughout the thesis. The final section of the filmmaking analysis is the current intersection of AR and filmmaking. This chapter concluded with a review and analysis of UX in relation to AR and mobile applications.
Chapter 3

Design and methodology

3.1 Introduction

This chapter acts the software design document for the proposed application. A software design document is a description of the planning and implementation of an application. This chapter acts as that document for the creation of any proposed applications. This document starts with an analysis of the functional requirements of AR applications. Threat modelling follows on from this with the focus on the use of applications within the confines of a film set. The different levels of prototyping were next which included the creation of high-level prototypes. The high-level prototypes acted as proofs of concept for marker-based and markerless implementations of AR. The final section of this chapter gives a detailed description of the experiment design to test the applications capabilities.

3.2 Application Design

3.2.1 Aim

The aim of the application for this research is to determine the FoV of a camera. This will let the user know the area seen by the camera. To achieve this a virtual

\[\text{http://ecomputernotes.com/software-engineering/softwaredesign/documentation}\]
representation of the FoV appears over an area as either a model or a measurement grid.

3.2.2 Functional Requirements

With the continuing advancement of AR applications, the Digital Manufacturing and Design Innovation Institute (DMDII) created a list of functional requirements for AR applications. The original requirements are listed in bold, with the corresponding justifications shown below them. The nine chosen functional requirements align closely with this research topic.

1. “The software and content generation tool shall have a user interface that can be learned by non-software literate personnel.”

   - This is an important distinction to address because not all filmmakers are software literate. Some filmmakers are reluctant to the use of technology beyond that necessary for image capture, editing and sound.

2. “The software and content generation tool shall output an application that can be used by AndroidOS, iOS, and Windows OS devices.”

   - The use of ARCore for Windows and ARKit for MAC satisfy this functional requirement as it allows for use on Android and iOS devices. There is a facility in ARKit to make the application work across platforms. AR.js can operate on devices which are over two years old which is the average age of devices being used today.

3. “The software shall NOT require a custom version of OS, for the content to be utilized. The software shall install on a standard OS version for the smart device.”

   - As mentioned in the previous requirement there are tools available for the various operating systems. A standard OS would operate an MAR if the developers had utilized the correct tool in its creation.
4. "The software and content generation tool shall allow the user to select the content by supporting all of the following: Local, Secured Server, Cloud-Based." [2][3].

- Prototyping of the application offered a solution for this requirement. There needs to be a sufficient way of storing camera and lens information. Several devices using the application could link to a central location which is broadcasting the information. This central location would either be a marker or defined location on the set. There could be a cloud storage database for the different lens sizes. This database could be on a public cloud since the size of lenses are not likely to alter significantly between productions.

5. "The software and content generation tool shall NOT require the use of a visual tracking tag if the AR hardware supports other tracking methods (SLAM)" [2][3].

- The aim of this study was to find a solution that did not require a tracking tag. A comparison between marker based and markerless AR with the aid of SLAM tracking forms a component of this study.

6. "The software and content generation tool shall NOT require the use of a specific type or style of visual tracking tag." [2][3].

- The rejection of this requirement could form a part of the analysis. There is the potential for using a visual tracking tag to solve the proposed problem. This would depend on the alternative methods available.

7. "The software and content generation tool shall allow the worker to rotate 3D content." [2][3].

- The term worker relates to anyone interacting with the AR application. This could be ADs or Directors. They would be able to rotate a 3D object using the application. The 3D object would be a virtual representation of the FoV of a camera.
8. “The software and content generation shall support the ability for the workers to take a snapshot of their smart device (wearable and touch display) display. Allowing them to share that snapshot with others.”

- Snapshots could be invaluable when recording the same scene over several days. Another use for snapshots would be in the event of jump-cut montage which is used in music videos. In previous iterations of these videos, directors used tracing paper placed over the viewfinder to track shots.

9. “The software and content generation tool shall provide the ability to link to IoT data to specific locations by creating a ‘localization tags’ through the use of QR Code, Near Field, RFID, and/or Bluetooth tags.”

- This functional requirement links to a potential use of the applications. This use would be for the creation of television shows. In the case of shows such as sitcoms there is a static number of locations. With the revolving door of directors for these shows, camera shots saved in applications like these could act as a shorthand. This shorthand would improve the workflow of the production. New directors could apply their own impression to the available camera placements with instant feedback.

3.2.3 Threat Modeling

When designing any application a threat modeling analysis must take place. The first threat to the application on a film set is the location itself. On any film set there are a lot of hazards that need to be accounted for including the amount of expensive equipment in a small confined area and the number of wires on the ground. If an application used by a member of the crew causes an accident, this could lead to a production being shut down. When a production is shut down the cost involved would be greater than the revenue saved by using the application. Figure 3.1 is a
rough estimation of the layout of a film set at an external location with the threats highlighted.

Table 3.1: Key for Figure 3.1

<table>
<thead>
<tr>
<th>C1 &amp; C2</th>
<th>Cameras</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>Craft Services</td>
</tr>
<tr>
<td>L1 &amp; L2</td>
<td>Lighting</td>
</tr>
<tr>
<td>P</td>
<td>Props</td>
</tr>
<tr>
<td>R</td>
<td>Road</td>
</tr>
<tr>
<td>S</td>
<td>Steps</td>
</tr>
</tbody>
</table>

Figure 3.1: Threats on a film set

The location for the scene in Figure 3.1 is at a monument in a town centre. The first threat is the surrounding roads. The road at the top of the image remains open throughout the production. The other three roads operate on a stop/go process while scenes are being filmed. There are wires on the steps leading up to the monument. If
the film is set in but filmed in early spring, the actors and extras would be wearing coats between shots. These coats could be left on the steps causing an extra threat. There are cameras placed on either side of the monument, with a lighting rig surrounding the principal actors in the middle. A collision with any of these pieces of equipment is a major threat to the production. Some further threats which could be found in this example include scene dependent props and kettles being boiled on the craft services table.

For this scene an AR application would act as a guide for placing extras in their positions on the roads. They should be visible to the camera without causing harm to themselves or the crew. The application must not conceal any real threats. This corresponds with research that states that virtual content should not alter the real objects in such a way that is disorientates the users.\textsuperscript{[?], [?]}. Another threat to the use of technology on a film set, are signals such as WiFi or Bluetooth. On a film set, all mobile devices must be switched off for several reasons. The most obvious threat being the noise created by a phone ringing. All feedback from an application must be silent or cause the device to vibrate. The other disruption caused by mobile devices is from the transmission of signals (the interference noise you hear on a radio before a phone rings). This is also the case with Bluetooth and could affect how the cameras record the footage. A potential solution for this would be to use the GPS settings within the device itself so the application would work while the device is operated in airplane mode.

The use of a public cloud to store data presents its own threats. The first being the privacy of the data stored on the service. There are also issues with the metering of the usage of a public cloud. It could be easy to use more data than available in the subscription. This could cost a lot of money by the end of a production. The final threat with the use of a public cloud is the loss of service. If service is lost and all of the saved snapshots are missing this could delay the blocking process. \textsuperscript{[?], [?]}. A
private cloud could be used to mitigate these threats providing a more secure storage location. Local storage devices could also be used.

3.3 Prototyping

Prototyping is a key step in the design of any application. The usual breakdown is to have a wireframe followed by three levels of prototypes. The wireframe remained as a 2D image. The changes to the prototypes are listed below.

- **Low Fidelity Prototype:** showed a representation of what the user would see. This is instead of the traditional *paper prototype*. A *paper prototype* is a hand-drawn visualization of what the final application would look like.

- **Medium Fidelity Prototype:** This prototype acted as a demonstration of the use of the application with the presentation of a scenario.

- **High Fidelity Prototype:** This acted as a proof of concept for the proposed functionality of the application.

3.3.1 Wireframe & Low Fidelity Prototype

The *wireframe* was developed with the use of *Balsamiq Mockups*. The design for this application was to have two screens as shown in Figure 3.2. The circular Scan button is consistent between both screens. The screen on the left shows the virtual content after scanning an AR marker, or the selection of a model. On the right-hand side, there are three drop-down buttons.

- **Camera Type** allowed the user to select a predefined camera. Each camera had optional lenses available. Once selected the user could view the virtual model of the area visible with the camera.

- **Saved** revealed a list of previously selected camera and lens combinations. This would have worked in situations where a new director is going to an already

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2https://www.webopedia.com/TERM/P/paperprototype.html
established location. This linked in with the functional requirements for snapshots. The snapshot in this instance is an image of the camera placement and its corresponding FoV.

- **Share** was for sharing the collected snapshots. This could be done by either email or other messaging service. Similar to applications like [Panascout](https://www.panavision.com/products/panascout) the users could write descriptions of the blocking.

![Application Wireframe](https://www.panavision.com/products/panascout)

Figure 3.2: Application Wireframe
Figure 3.3: Low Fidelity Prototype

Figure 3.3 is a representation of the difference in the FoV of two cameras with the same lens. The orange line represents a Canon 5D MKIV while the blue line is an ARRI Alexa LF - 16:9. Even though there is only a slight difference between the two lines this could cause a significant difference in what was seen.

3.3.2 Medium Fidelity Prototype

The next stage of the prototype can be seen in Figure 3.4. This prototype was also created using a Balsamiq Moqups. This prototype was a demonstration of the navigation through the application. Figure 3.3 presents the medium fidelity prototype while Figure 3.4 was an representation of a scenario for the system.
The design has remained similar to the wireframe in Figure 3.2. The main differences were the additional buttons for ease of navigation between the two screens and selection of the lighting type. Lighting was included as a result of the research. There was to be a limited amount of interaction between the user and the application. This was because during the workflow on a film set there needs to be smooth transition between tasks. This led to a “point and shoot” style of design. In Figure 3.5 the pen lid represents
the camera with FoV visible. All the Os are visible by the camera and the Xs are not.

3.3.3 High Fidelity Prototype / Proof of Concept

For this research the creation of two high fidelity prototypes occurred. One of these for marker based AR and the other, markerless. The first prototype was for the marker based AR application. It was created using a combination of AR.js and ARToolKit. The second prototype was a proof of concept of how markerless implementation could operate on a film set. The Implementation and Results chapter demonstrates the high fidelity prototype and proof of concept.

3.4 Experiment Design

Three experiments were conducted during the course of this research. Each experiment shifts focus to a different element of the study. UX was the subject of the first experiment. The second experiment analysed the source code of the application. The third experiment concerned the accuracy of marker-based and markerless AR.

The first experiment was a qualitative analysis, while the other two experiments were quantitative analysis. Qualitative analysis is an understanding of opinions and quantitative is about numbers. Acceptance of the hypotheses occurred if there was a significant increase in the efficiency of how a scene was blocked and a significant improvement to the process by the proposed application.

Various reasons could have led to the rejection of the proposed hypotheses. The main one was, if both marker and markerless implementations of AR were not suitable for solving the problem. This could have been because of the absence of available resources or the complexity of the application.

Rejection of the hypotheses would be caused by a dismissal of the idea by the experts.
CHAPTER 3. DESIGN AND METHODOLOGY

This could be because of the feasibility of using the application within a working environment. If there was no engagement from the demographic it would render the technology useless within the proposed context.

3.4.1 User Experience Experiment

Stage 1: Filmmakers Survey

The first stage of this experiment focused on a single demographic. The demographic chosen was people who are currently working within the Irish film industry. The professions of these people include directors, AD, DPs, location managers and members of the art department. The art department of a film handles all the props. The source for this demographic was the Irish Film and Television Network (IFTN) website crew database. This is a catalogue of people working within the industry today. This gave an overview of the perception of AR within the Irish film industry.

Stage 2: Expert Interviews

The second stage of this experiment presented the proposed application design to experts working in the fields of filmmaking and AR. On the filmmaking side, this provided a deeper analysis of the usability of the application. It expanded on the knowledge gathered from Stage 1 of this experiment. The filmmakers critiqued the design and offered suggestions for future iterations.

AR experts provided an insight into the programming languages used and potential pitfalls in the design. This provided the researcher with a granular analysis of the technology. This got to the core of whether the application was feasible. These experts gave their opinions on the proposed solution and made suggestions for future versions.
3.4.2 Code Experiment

The code aspect of the experimentation was an AGILE development of the mathematical components of the application. The mathematical component is because there are SDKs on the market to facilitate camera permissions and computations for global positioning. AGILE development was the best choice for this research project because of its iterative nature.

This development was in three stages to reflect the design and testing aspects of AGILE development. Stage 1 was the initial creation of the functions and tests for speed and memory consumption. Stage 2 was the static analysis of each of the programs. Stage 3 took the information from Stage 2 and rewrote the programs to reflect the feedback. The tests were run again and the results compared.

Stage 1: Alpha Version

There were five calculations before the virtual object was created. Scanning a QR code triggers the creation of the object. To achieve this there were five functions created, one for each of the calculations. A sixth function will call the other five functions and return the results. The first two calculations linked with the camera itself and vary dependent on the type of lens used. Equation 3.1 and 3.2 represent the AoV and FoV.

\[
AoV = 2 \arctan \left( \frac{\text{Sensorwidth}}{2 \times \text{focallength}} \right) \times \left( \frac{180}{\pi} \right) \quad (3.1)
\]

\[
FoV = 2 \tan \left( \frac{AoV}{2} \right) \times \text{Distance to Subject} \quad (3.2)
\]

Equation 3.2 depended on the result of Equation 3.1. The FoV is required for the creation of a frustum. Figure 3.6 is a 3D depiction of the frustum of a cone.
CHAPTER 3. DESIGN AND METHODOLOGY

This had the potential to be one of the most efficient ways of presenting what a camera can see. The small side at the top represents the lens of the camera while the large side is the area visible. The three equations linked with a frustum were lateral surface area (Equation 3.3), surface area (Equation 3.4) and volume (Equation 3.5).

\[
Lat = (\pi \times (R + r)) \times L \tag{3.3}
\]

\[
SA = \pi(R + r) \times \sqrt{(R - r)^2 + h^2} \tag{3.4}
\]

\[
V = \frac{\pi}{3}h(R^2 + r^2 + R \times r) \tag{3.5}
\]

The four programming languages under review for this experiment were C++, Java, JavaScript and Swift. All four languages are object oriented.

C++ and Swift are the main programming languages for ARCore and ARKit. C++ is compatible with OS X application development. Swift is only for OS X devices. Java is one of the languages at the foundations of Android programming. Java 8 libraries link with ARCore. JavaScript links to AR via AR.js which allows devices of differing capabilities to run AR applications.

Stage 2: Static Analysis

The second stage of this experiment was a static analysis. The aim of static analysis is to analyse code without execution. This analysis is at a syntax level and concerns
the declaration of variables and indentation. Due to the nature of this analysis various software packages were required. From the research conducted the four tools chosen were:

- CPPCheck (C++)
- Infer (Java)
- JSLint (JavaScript)
- Xcode (Swift)

There are some differences with how this experiment was conducted for Swift. The code will be written in Notepad++ and compiled using Rextester on a Windows computer. However, the static analysis was conducted on a Macbook Pro. The Swift was copied from Notepad++ and analysed in Xcode which has a built in static analyser.

**Stage 3: Beta Version**

Following on from Stage 2, the static analysis results were analysed and the feedback applied to the four programs. Once these improvements were made, the speed and memory tests were run again to determine whether there was a significant difference between the two versions of the program. It is important to note here that there may not be an overall improvement as static analysis improves readability and syntax more than functional operations. The results of these tests were graphed alongside Stage 1.

### 3.4.3 Accuracy Experiment

This experiment was divided into two stages.

- **Stage 1:** focused on the use of AR markers and QR codes. With the use of these codes the distance between the marker and the device needed to be

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5 http://cppcheck.sourceforge.net/
6 http://fbinfer.com/
7 https://www.jslint.com/
determined. The conditions for the use of Marker-based AR were considered in this experiment. This is because the available space on a film set is limited.

- **Stage 2:** turned the attention to the replication of objects which could be used for blocking a scene. These objects could be placed in different locations on a set when the shot was set up.

**Stage 1: Marker-based**

One hypothesis which this experiment was trying to prove was whether the distance between the source and the marker is proportional to the size of the marker required. For example if a standard marker which is 400x400px had a maximum distance from a camera of four feet. Then if the ratio between the two was 1:1 a marker which was 1600x1600px would have a maximum distance of 12 feet. With the first part of the experiment the exact ratio between the marker and the source was calculated and evaluated.

The other crucial element regarding the marker experiment was the level of interference that the camera can deal with in relation to the marker itself. A marker which is unusable with any interference would be pointless for the task at hand.

All of the markers created for this experiment were 96dpi and as a result the corresponding markers in inches can be seen in Figure 4.14.

**Stage 2: Markerless**

There are alternatives to how the virtual models were presented. This was where the markerless version of AR came into play. To determine the accuracy of using markerless AR for displaying content a comparison with physical objects was required.

To achieve this objects were scanned with the applications *Qlone*[^9] and *SCANN3D*[^10]. These applications were chosen because they represent the different methods used for

[^9]: https://www.qlone.pro/
[^10]: https://3dscanexpert.com/scann3d-android-photogrammetry-app-review/
scanning objects.

With *Qlone*, objects are placed on a grid like the one in Figure 3.6. This renders a 3D version of the object that can then be imported into *Augment* for testing. *SCANN3D* uses *photogrammetry* to scan the image using multiple points.

![Qlone mat](image)

Figure 3.7: Qlone mat.

The results of this experiment were classified under three headings, *scanning time*, *rendering time* and *similarity to original*. This experiment was similar in nature to the one conducted in the research paper about the use of a *Fisheye lens*. Their experiment used 3D printing and 3D modelling techniques for AR to offer a direct comparison. In contrast, this experiment used “*off the shelf*” applications. This linked with the previously defined functional requirements for a *MAR application*.
3.5 Chapter Summary

Figure 3.7 is a mind map of the design process for this research project. The right hand side of the map is the experimentation while the left is concerned with the prototyping of the applications. The nodes labelled red are avenues pursued during the course of this research that were dead ends. One of these was sentiment analysis which was the original Stage 1 of the UX experiment. The idea was to gather opinions about AR and AR in filmmaking by an analysis of tweets. During this process a decision was made to write a sentiment analysis script in Python instead of the traditional method of using R. The results found proved to be insignificant for inclusion in this thesis. There was a very high level of neutral tweets which didn’t provide any substantial data to analyse.

![Design process mind map](image)

Figure 3.8: Design process mind map

The other roadblock occurred during the prototyping stage of the research. Originally prototypes were to be designed using one of the available SDKs namely ARCore or
ARKit. Due to the limitations of the hardware available adjustments were made to how these prototypes were conducted. The shift was towards an analysis of proof of concept using existing applications such as AR.js and Augment. Throughout the design process various decisions were made in an overall AGILE approach to the research. This iterative approach allowed for changes to be made “on the fly” while still retaining the core ideas of the thesis.
Chapter 4

Implementation and Results

4.1 Introduction

This research was implemented using a combination of programming languages together with existing applications such as Augment.

An explanation of the different software packages used for the prototyping and experimentation is given. The results of the experiments were also shown.

4.2 Software Used

4.2.1 Low and Medium Fidelity Prototypes

The software package used for the creation of the wireframe and medium fidelity prototypes was Balsamiq Moqups. PhotoCineView was used to present the low fidelity prototype. Alternate software packages considered in this research were Proto.io\(^1\) and UXPin\(^2\).

\(^1\)https://proto.io/
\(^2\)https://www.uxpin.com/
4.2.2 High Level Prototypes / Proof of Concept

Marker based prototype

To create the marker based prototype AR.js was used which has an ARToolKit back-end. The code to initialise the AR.js is a HTML file which was created by Jerome Etienne and was available from his GitHub page[3].

AR.js allowed the camera on a device to be able to render virtual information for AR. Code written with ARCore or ARKit has a device compatibility larger than code written with AR.js. The device used for AR.js was running Android 5.0 (Lollipop) and was therefore not compatible with ARCore or ARKit.

The second part of the program was concerned with what markers can be used for presenting the AR. The code for this prototype can be seen in Appendix A Figure. Figure 4.1 shows a Hiro marker which was the AR marker chosen for this research study. An alternative can be seen in Figure 4.2, this type is called a Kanji marker. Figure 4.3 is a screenshot of what occurs when Figure 4.1 is scanned using a mobile device with AR.js activated.

Figure 4.1: Hiro Marker

Figure 4.2: Kanji Marker

Figure 4.3: Example of AR.js

Markerless prototype

The idea behind the markerless proof of concept was the combination of multiple existing application features with additional complexity. A breakdown of the proof of concept presents was as follows. The application takes stored mathematical information which has been gathered on cameras and stored within a database either in the cloud or local storage device. For example, if the film was shot in an area where internet access was limited then stored information on the local storage device would be more efficient, even though it may slow down the speed of the application at loading time.

The application Augment\textsuperscript{4} was used for this proof on concept. After the mathematical information has been received a 3D image would be created with a variety of programming languages. This displayed the frustum of a camera. There are drawbacks to the use of this application such as the size of the models in relation to the environment.

\textsuperscript{4}www.augment.com
CHAPTER 4. IMPLEMENTATION AND RESULTS

Figure 4.4 is a representation of the Saved models page as shown in Augment. Figure 4.5 is how a model looks when application is used. In the image the edges of the model are obscured by the sides of the screen even if the device is moved. The transparency of the model is crucial because without it, the subjects to be arranged would not be visible. However, if the model is too transparent then the accuracy of the model would decrease accordingly.

4.2.3 Coding

All of the source code was written in Notepad ++. The online compiler was Rextester\(^5\) which is written in JavaScript and can compile each of the languages. The four static analysis programs were JSLint, PMD and CPPCheck. Xcode 9 has a built in static analyser for Swift. After the code was originally written in Notepad++ it was copied into Xcode for testing.

\(^5\)http://rextester.com
CHAPTER 4. IMPLEMENTATION AND RESULTS

4.3 Results

4.3.1 User Experience Experiment

Stage 1: Filmmaker Surveys

Participants for this stage were contacted via the IFTN crew database. Of the 165 messages sent there were 9 replies. This was a 5.5% response rate. In Figure 4.6 the red represents the amount of people who responded to the survey. The answers from these surveys are available in Appendix B.

![Response Rate Pie Chart]

Figure 4.6: Experiment Response Rate

1. *Are you familiar with AR and if so have you ever used an AR application?*

   (a) This question gauged the familiarity of the participants with AR. Over 40% of the participants were familiar with AR. However, not many had used the technology. In Figure 4.6 the blue segments represents the amount of people familiar with AR.
2. **Would you ever consider using an AR application for work?**

(a) The responses for this question were relatively close. Those against AR were reticent about using the technology. However, those who were unsure about AR provided the most interesting insights about what to consider when using the technology. These considerations included the level of complexity and the cost. The Figure 4.8 Yes in blue, No in red and Maybe is yellow.
3. As part of your daily work are there aspects if any which could be improved by the use of AR?

(a) There were mainly positive response for this question. One participant in particular demonstrated a knowledge of the subject matter. They explained various potential uses for AR which included previsualization and how to determine the angle of the sun. Other responses included the need for specificity of shots where AR would be more efficient than traditional filmmaking methods. In Figure 4.9 the yellow represents Real Time concepts with red showing CGI / Green screen content. The large blue segment are the participants who couldn’t determine any additional uses for AR.

![Improvements with AR](image)

Figure 4.9: Improvements with AR

Stage 2: Expert Interviews

AR Experts

The interview questions for the AR experts were slightly different from those given to the filmmakers. The participants were Niall Campion from VRAI and James Corbett from Simvirtua. The results for this stage will be presented with (a) representing James Corbett and (b) for Niall Campion. James’ answers are from an email interview while Niall was interviewed in VRAI’s office.

1. From an industry standpoint does the proposed idea sound feasible?
(a) “Yes. I think it is a great idea and an appropriate application of the technology. I should mention that I have seen something like it before but that is a good thing because if you do not have competition you probably do not have a good idea! Beyond that I do not know enough about the movie making business to give a more informed opinion.”

(b) Niall was in agreement about the feasibility of the proposed application.

2. Which programming language would you recommend for the development of the application and why?

(a) “Our tool of choice for AR/VR development is Unity which means coding in C sharp. Unless you have a particular need for Unreal Engine (e.g. top level photo-realistic graphics) then I would recommend Unity.”

(b) The staff in VRAI mainly utilise AR SDKs which are primarily written in C++ or Swift.

3. Would you have a preference over the use of marker or markerless AR from a development point of view?

(a) “With ARKit and ARCore we are rapidly moving away from marker based AR, and that is the way I would recommend to do it if you can. But it may be that for your particular application you will get better results using large markers. That will require lots of testing. From a user perspective markerless is to be preferred obviously.”

(b) Similar to the previous answer there is a move away from using marker-based AR. The suggestion was made to use a combination of the two techniques which could achieve the best results.

4. Based on your knowledge and experience have you any feedback about the proposed application?

(a) “As I said above, I think it is a great idea and application. And I have seen someone else doing it (I can not remember who). I can see how it solves a
problem in a way that is better than other approaches (i.e. the tech adds real value).”

(b) The feedback was the idea of using HMDs such as Microsoft HoloLens which could easily scan a room and determine all of the surfaces. The process of renting devices as a comparison to traditional filmmaking techniques was also discussed.

5. **Have you any recommendations for potential areas of research within AR as a whole?**

(a) “It is a cliche but I really do think the only limit is your imagination. In the long term at least. In the short to medium term I think there will be huge opportunities in manufacturing, construction, architecture, engineering, etc.”

(b) Having covered most of the new research in the previous question there was a discussion about the concept of device free AR. This would be AR displayed on a screen without the need for a HMD. There are some prototypes available but the research is still ongoing. Other topics discussed were the use of AR for previz which mirrors Ichikari’s research (2) (3).

**Filmmakers**

The filmmakers interviewed for this stage were Flavia Pordominsky (Assistant Director) and Paul Brady (Director).

Both participants answered the same questions. Flavia answered the questions via email and her answers can be seen below. Paul was interviewed in person and the contents of his interview are shown in Figure 4.10.

1. **Are you familiar with Augmented Reality?**

(a) “I am familiar with Augmented Reality but not in films, I have seen it used in apps for home decoration where people can see where to place furniture in a room or to see how different paints or wallpapers look on the wall.”
2. **Would you consider using an Augmented Reality application as part of your daily work?**

   (a) “I think that an AR app would be very useful for pre production in films as crew members will be able to see how the sets are going to look by the art dept., how many extras are going to be needed for each scene and how lighting will affect the cinematography. On production, it will be very beneficial for the art and props dept when moving elements near the camera. It would help the work of the ADs to show other dept what is going to be filmed next, in case other crew members need to be informed.”

3. **Does the idea presented for the application make sense for its intended use?**

   (a) ”The photo does not represent much of what was explained about the app.”

4. **What improvements would you make to the design of the application?**

   (a) “I think it would be great if the app had a greater variety of colours as it would show better how the scenes are going to look. This will help the lighting dept. to show different moods on the film.”

5. **What alternatives would you see for the use of Augmented Reality applications on film sets?**

   (a) “It would be amazing if with the app we would be able to show movements and the different angles of the camera as well as showing which lights are on and off and change them just touching the screen.”

The interview with Paul Brady took the form of a brainstorming session regarding the application and potential uses for it. Figure 4.10 shows the output of that session. On the bottom left hand corner of the image the two boxes represent different views which the application could be used for blocking a scene. There is a top down view and a side angle view. This also determined the differences in FoV of cameras placed
beside each other. Having used AR applications for other tasks he had a high level of familiarity with the technology. Also recommendations for software to use as a part of this study can be seen including Panascout which was another application used for camera placement.

Figure 4.10: Expert Interview Brainstorming Session
4.3.2 Code Experiment

Stage 1: Alpha Versions

All four programs were run through the compiler Rextester [6]. The metrics revealed by the compiler were compilation time, absolute running time, CPU time, memory peak and absolute service time. With the exception of memory peak all of the values are in seconds. Rextester allows users to change the compiled language. Each of the programs ran three times and the average results calculated. The alpha versions of the code are in Appendix A.

Each program was given the same four variables: focal length; distance; radius and sensor width. From this information, the programs were tasked with calculating the AoV, FoV, lateral surface area, the surface area and volume of the frustum. The results of this experiment are in Figures 4.11 and 4.12.

![Average time (seconds) Alpha Version](image)

**Figure 4.11: Code Speed Comparison**

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The two figures show that Java was the most time and memory intensive. JavaScript was the most efficient. Swift and C++, used for ARKit and ARCore, are close in time but with C++ using the least amount of memory.

The final aspect of Stage 1 is a determination of the number of lines of code required for each program. Table 4.1 shows the number of lines for each program.

**Stage 2: Static Analysis**

When static analysis was run on the different source codes. C++ and JavaScript required changes while Java and Swift remained the same. C++ only required one change to the code which was to alter the return value in the main function.

Moving back towards the competition between ARCore and ARKit for development, C++ and Swift were analyzed side by side. Similar to Java, C++ appeared to have no issues after static analysis. Swift on the other hand proved difficult to analyze as there was no clear analysis tool which provided accurate results.
Table 4.1: Number of lines - Alpha Version

<table>
<thead>
<tr>
<th>Language</th>
<th>Number of lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>C++</td>
<td>67</td>
</tr>
<tr>
<td>Java</td>
<td>59</td>
</tr>
<tr>
<td>JavaScript</td>
<td>38</td>
</tr>
<tr>
<td>Script</td>
<td>49</td>
</tr>
</tbody>
</table>

Stage 3: Beta Versions

After applying all of the requested changes to the programs the speed and memory tests were run again and the results provided are shown in Figure 4.13.

Figure 4.13: Beta Version Speed Comparison

The results showed that there was no significant difference between the speed of the Alpha and Beta versions. Even though there was a small difference between the
different iterations of the programs. However, it was not large enough to distinguish or in the case of JavaScript worth the time taken to make the changes. The memory consumption of the programs remained the same. Table 4.4 displays the number of lines in the beta versions of the programs. The number of lines of code for the beta versions are in Table 4.2.

<table>
<thead>
<tr>
<th>Language</th>
<th>Number of lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>C++</td>
<td>63</td>
</tr>
<tr>
<td>Java</td>
<td>59</td>
</tr>
<tr>
<td>JavaScript</td>
<td>48</td>
</tr>
<tr>
<td>Script</td>
<td>49</td>
</tr>
</tbody>
</table>

Table 4.2: Number of lines - Beta Version

4.3.3 Accuracy Experiment

Stage 1: Marker-based

Table 4.3 shows the size of the markers used for this experiment in both pixels and inches. The difference in size between the two is also presented. This difference is because a QR code must be a perfect square. There was a size difference of 0.15% between the two types of marker.
The dimensions of an A4 sheet of paper are 8.27x11.69in. Any markers above size M would need to be printed on multiple pages. This is not possible as printers are not able to split markers and just print what the fit working from the centre of the image. This results in the sides of the marker being cut off.

Figure 4.15 presents the results of the comparison between the two types of markers. The different columns represent the minimum distance, maximum distance and average distance required to view the virtual content after the marker has been scanned. The most important measurement was the average distance because with the minimum and maximum there is the potential that measurements are not exactly correct and the average accounts for this. Figure 4.16 is a graphical representation of this experiment. It is important to note with the minimum size of the QR code that they are dependent on the camera being able to see all four sides of the code. This means that this distance is dependent on the size of the lens used and its corresponding FoV.
CHAPTER 4. IMPLEMENTATION AND RESULTS

Table 4.4: Marker distances

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Av</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AR Marker</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>3.9 in</td>
<td>37 in</td>
<td>20.45 in</td>
</tr>
<tr>
<td>M</td>
<td>6.3 in</td>
<td>104 in</td>
<td>55.15 in</td>
</tr>
<tr>
<td><strong>QR Code</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>5.9 in</td>
<td>31 in</td>
<td>18.45 in</td>
</tr>
<tr>
<td>M</td>
<td>7.9 in</td>
<td>137 in</td>
<td>72.45 in</td>
</tr>
</tbody>
</table>

Figure 4.14: Marker comparison

*Level of Interference* was taken into account when the markers were scanned. In this study the interference means the amount of the marker that can be concealed while still retaining the virtual content. From scanning the markers it was revealed that AR
markers had no tolerance for interference. On the other hand QR code allowed for full coverage of the marker once initially scanning had been completed.

**Stage 2: Markerless**

For the markerless stage of this experiment the element that was accessed was the accuracy of scanned objects to become virtual elements. The two applications up for consideration were *Qlone* and *SCANN3D*.

Figures 4.17, 4.18 and 4.19 were the reference items for this experiment. Each item was placed on the *Qlone mat* and scanned.

![Figure 4.15: glasses case](image)

![Figure 4.16: container](image)

![Figure 4.17: plastic cup](image)

These experiments were unsuccessful with the applications unable to correctly scan the objects. The reasoning behind this failure is discussed in the *Analysis, Evaluation and Discussion* chapter.

### 4.4 Chapter Summary

This chapter started with the description of the software used during the course of the research. Following this was a description of the marker based high level prototype and the markerless proof of concept.

The results of the experiments were presented. The order of these experiments were
UX, Code and Accuracy. There were two stages in each except for the Code experiment which had three.

The markerless experiment required an analysis of images to determine whether they were similar to the original.
Chapter 5

Analysis, Evaluation and Discussion

5.1 Introduction

This chapter was a critical analysis of the information gathered from the design and experimentation process in Chapters 3 and 4. The chapter started with a breakdown of the experimentation. This section was in two parts, how to set up the experiments and how to run them. The UX, Code and Accuracy experiments were individually analysed.

Following on from this there was an overall evaluation to determine if the chosen technology solved the problem at hand. Justifications regarding the change of research questions were presented.

At the end of this chapter the strengths and limitations of the study were presented and evaluated. Within this section, the problems encountered during the course of the research were addressed.
CHAPTER 5. ANALYSIS, EVALUATION AND DISCUSSION

5.2 Experimentation

5.2.1 Preparing the experiment

User Experience Experiment

Stage 1: Filmmaker Surveys

In preparation for this stage the first step was to create a dataset. This dataset contained people who worked within the Irish film industry. There were two reasons for the selection of the Irish film industry aside from the location. The reasons are familiarity and the size of the industry. The familiarity came from the researcher’s past working experience within the industry.

The contact details of the survey participants were obtained from the IFTN crew database\footnote{http://www.iftn.ie/crew/}. The original focus of this research project was on personas as a means of designing the application. Personas are representations of a user’s characteristics and work roles. \footnote{? ?} For this reason the job titles of those contacted were Director and Assistant Director, Director of Photography, Location Manager and Art Department. The criteria used for selection was that the participants had a direct influence on what appeared on camera. As a result of this criteria this eliminated those who work in the lighting department.

Stage 2: Expert Interviews

Interviews were conducted to get detailed reactions from filmmakers currently working within the industry. This was a more detailed analysis and used different people than those used in Stage 1. The filmmakers were asked for their unbiased opinion on the research topic. These opinions were incorporated as part of the qualitative analysis of the research topic.

Initially only filmmakers were included for this stage of the experiment. This left
a notable absence of a technical perspective. To alleviate these issues, experts from the Irish AR and VR industry were invited to participate. There are three organisations in Ireland. They were VRAI based in Dublin, Simvirtua from Limerick and 3MS which operates out of Athlone, Co Westmeath. These experts provided some context to the research study as a whole. They also determined the feasibility of the application idea based on the current workflows available to developers within the industry.

**Code Experiment**

To prepare for this experiment, six functions were created. The first step was to split the group of functions into three.

1. **aOV() & fOV():** These functions calculated the AoV and FoV of a camera. The parameters for aOV() were the sensor width and focal length of the camera. The result from aOV() became the parameter for fOV() coupled with the distance to the object.

2. **latFrust(), areaFrust() & volFrust():** These functions concerned the mathematical formulas required to create the 3D image. They were lateral surface area, surface area and volume. The required parameters were the result of fOV(), radius of a lens and the focal length of the camera.

3. **calValues():** This final function called the previous five and returned the results to the screen.

The four programming languages chosen were C++, Java, JavaScript, and Swift. These languages were chosen for the research study due to their prominence in the creation of AR applications. In AR development some features are SDK dependent. The previously defined functions allowed for testing the capabilities of the languages. The majority of the preparation occurred in *Stage 1* while *Stages 2 & 3* addressed during the running of the experiment.
Accuracy Experiment

Stage 1: Marker experiment

Stage 1 of this experiment dealt with the marker based implementation of AR. To prepare for this section examples of AR markers and QR codes were sourced. Two versions of each marker were created. The markers were labelled S and M to represent small and medium. The original parameters for this experiment concerned location and lighting sources. This would have involved running the experiment indoors, outdoors and through windows. This component of the element changed in favour of an analysis of the two types of marker.

The sizes chosen for AR markers were 306x265px and 611x529px. These were chosen after an analysis of DPI and the conversion of pixels to inches. The size of the QR codes were 305x305px and 610x610px. There was a 0.15% size difference between the AR markers and QR codes. This was because the QR code must be a perfect square. Figure 5.1 was the AR marker and Figure 5.2 was the QR code used for this experiment.

![Figure 5.1: AR Marker](image1.png) ![Figure 5.2: QR Marker](image2.png)

Stage 2: Markerless Experiment

In preparation for this stage the applications Qlone and SCANN3D were downloaded. The household objects chosen were a red plastic cup, a chewing gum container and
a glasses case. These were chosen as a result of their differing shapes. This was to determine how the software handled objects of different sizes and shapes.

5.2.2 Running the experiment

User Experience Experiment

Stage 1: Filmmakers Survey

The response rate for this survey was in line with the response rate for surveys used in marketing campaigns. According to Smart Insights\(^2\) the average marketing response rate is 4.43%. The response rate achieved in this study was 5.5%. It must be noted however that this study had a limit of 160 individuals while advertisers are contacting thousands.

The emails were sent in April 2018 with the recipients given a month to respond. This time limit encouraged those interested in replying to respond as soon as possible. It is important to note that the IFTN crew database was the source of data. This database gave direct access to individuals with the required relevant job titles. Alternatives to the use of IFTN were analysed but unable to yield the same results.

Stage 2: Expert interviews

There was an even split between interviews conducted in person and those done via email. This was due to the location and availability of the experts. At the time of writing two of the experts were in Spain and Limerick respectively and therefore unavailable to meet in person.

Regardless of the medium of the interview the same questions were asked depending on the field of expertise of the expert. The filmmakers and the AR experts each were asked a different sets of questions. The questions for the AR experts were on

\(^2\)https://www.smartinsights.com/email-marketing/email-communications-strategy/statistics-sources-for-email-marketing/
a more granular level concerning the feasibility of the application and the technology used. The questions for the filmmakers focused on their understanding of the application and how it could help them.

The results from these interviews were positive. Both of the AR experts agreed with the feasibility of the idea and even referenced its marketability. The filmmakers made suggestions for features which could enhance the application’s functionality. Future designs of this application would reflect the requested level of complexity.

The interviews that took place in person allowed for an extra level of discussion in relation to each answer. From one of the discussions it was discovered that the alignment of the FoV of the mobile device would not align with the FoV of the camera unless directly behind it. After further explanation it was agreed that the proposed mathematical formulas could in fact alleviate this problem.

One common thread throughout the expert interviews was the concept of marketability. As part of this study three of the four experts interviewed explicitly mentioned marketability. There were two different business models proposed depending on the industry discussed.

1. The rental of the equipment to film production companies. The cost of the devices in comparison with other filmmaking costs would need to be taken into account.

2. A freemium model similar to the one used for Pokémon Go. The idea would be that the application as standard would scan a room and display what the camera could see. However, there would only be one or two lenses available. Once the user signs up for a further subscription package there would be more lenses available.
CHAPTER 5. ANALYSIS, EVALUATION AND DISCUSSION

Code Experiment

Stage 1: Alpha Version

When this stage was initially run the programming languages were basic in nature with straightforward equations and print statements. During the course of the experiment these algorithms grew in complexity. Of the six previously mentioned functions only `calValues()` was called. Using Rextester the values for compilation time, absolute running time, cpu time, memory peak and absolute service time were gathered. For consistency all tests took place on an Acer Aspire A315-21 with Windows 10 and AMD A9-9420 processor. During tests of the compiler platform it was discovered that the values differed each time the program was compiled. To counteract this each program was compiled three times and the average calculated. Another observation was that the JavaScript program required compilation time. A review of the source code of the compiler revealed that the website was written in JavaScript. This eliminated the need for any external compilation time.

Stage 2: Static Analysis

For static analysis the programming languages were analysed using the relevant software package. Of the languages JavaScript had the most changes required. In comparison Java passed the static analysis test without any issues. For Swift the test needed to be run on another computer. The computer chosen was Macbook Pro with MacOS High Sierra and 2.5 GHz Intel Core i5. Swift static analysers are not available for Windows machines. Swift is only used for programming iOS applications and is an iOS offshoot of C#.

Static analysis is syntax dependent. If a variable was undeclared or unused a static analyser will flag it. In a normal compiler the program will run as expected with these errors in place. The source codes before and after analysis can be seen in Appendix A. In some cases there was little or no difference while others had changes on almost every line.
Stage 3: Beta Version

The algorithms were updated to reflect the requested changes from Stage 2. The languages were put through the compiler again. Similarly to Stage 1 each program was compiled three times. The average of the time and memory was also calculated. From the results gathered there was no significant difference between the compilation values. Even when the programs were compiled multiple times there was a change in the overall times but the average between the alpha and beta versions remained the same. This was because static analysis is only concerned with syntax and has little effect on how a program was run, and is more with its readability by others.

Accuracy Experiment

Stage 1: Marker-based

To run this experiment two copies of the markers were printed. One of each type $S$ and $M$. For this experiment AR.js was used in conjunction with the application 3DQR to scan the markers. While running the experiment the printed markers were placed against a wall or other surface. Holding the device the researcher started moving backwards from the marker until the virtual image appeared. This distance was the minimum distance of the marker. After recording the information, further movement backwards occurred until the model disappeared. This second distance established the maximum distance of the marker. Average distances were used due to the level of human error involved with manual measurement. The average distance accounts for human error during experimentation.

Even though the research has shown that QR codes are better than AR markers for marker-based AR, an analysis of both was conducted. Tools such as AR.js only operate with traditional AR markers. The feasibility of using AR markers was tested in this experiment and the overall result was the use of AR markers was unsuccesful. This failure was because of the following:

- The virtual content for AR markers disappeared if anything crossed the path between the camera and marker. This rendered the markers useless for a film
• The distance of the camera from the marker led to a degradation of the image. With a QR code the image retained clarity until it disappeared.

**Stage 2: Markerless**

To run this experiment the three objects (plastic cup, glasses case and chewing gum box) were photographed using the camera on a Samsung Galaxy J3(2016). Following this the objects were scanned using Qlone and SCANN3D. This experiment was to use standard applications from the Android store which could be used to complete the task of scanning objects. These two applications were unable to complete the task assigned to them for this experiment.

The errors for each application are:

- **Qlone:** This application would not read the object when it was placed on the Qlone mat. Despite multiple rotations and object changes it failed to render any images.

- **SCANN3D:** Using the guide the requisite number of images were scanned. For this experiment that number was 20. With the images captured, the rendering process began. In this case, the rendering process actually caused the device to crash.

An alternative method for scanning an object to render a 3D model would be to photograph the object from multiple angles and stitch together the images using an animation program, such as Unity or Blender. Using this method would have defeated the purpose of this experiment as specialist knowledge is required.

### 5.3 Evaluation

This section is an evaluation of the UX framework and the experiments carried out for this research study.
The UX framework in this study aligned with current research. Further experimentation could be done using the framework but only after the creation of operational prototypes. This framework could be further manipulated depending on the type of device used. Different amounts of information are required depending on the size of the FoV.

Time management and the availability of suitable hardware were two problems encountered during the course of this research study. In experiments, such as the attempted sentiment analysis, discussed in Chapter 3, the time taken to research and write the programs greatly outweighed the significance of the results obtained. In this instance a deeper analysis of tweets could have led to the same results.

In an effort to accommodate the complexity of the SDKs a lot of time was spent on device modification. In the end these modifications were unsuccessful due to the built-in camera specification needed for the devices.

For future experimentation the datasets collected would need to be larger in size. A larger group would provide a broader understanding of the subject matter due to the varying experiences of its members.

5.3.1 Comparison, conclusion and suggestions

Marker-based and markerless AR were compared as part of this research study. The research conducted favoured markerless AR. One of the AR experts interviewed suggested using a combination of marker-based and markerless AR. This combination would not be successful because of the limitations of marker-based AR. This limitation concerns the marker placement in relation to the camera’s position. To get the most accurate representation of a camera’s FoV the marker would need to be placed directly on the lens. This would render the marker useless for the task. Possible solutions include an exaggeration of the FoV to account for the distance from the lens. However, this would greatly decrease the accuracy.
CHAPTER 5. ANALYSIS, EVALUATION AND DISCUSSION

This research focused on the use of handheld mobile devices for AR. A logical next step would be the use of wearables, in particular smart glasses. The current market trend is towards the use of Microsoft HoloLens devices. An analysis of the cost of these devices would be required before widespread adoption could take place.

Cheaper alternatives which could be used are devices such as Google Cardboard. Google Cardboard is a housing for a mobile device made using cardboard and can be worn as glasses. The two limitations to the use of Google Cardboard are its weather dependent and depends on the device being used.

5.3.2 Strengths and limitations

Strengths

The strengths identified during the course of this study were:

- Pre-existing mental models
  
  - Mental models are the way a user understands how a device should work. From a user perspective AR is relatively easy to understand. In this instance users who are digital natives are accustomed to the idea of taking a photo and applying a filter. The addition of virtual information was not beyond comprehension. For digital nomads an understanding of AR comes from operating a camera which is “point and click”

- Size of hardware
  
  - Another strength of AR was the size of the hardware used. It was designed for handheld devices or HMDs. All the screen sizes used are of a relatively small size.
CHAPTER 5. ANALYSIS, EVALUATION AND DISCUSSION

Limitations

The limitations that needed to be addressed are as follows:

- Technical requirements
  
  This was because of the internal mechanisms required to operate AR correctly. For ARCore, the latest version of Android 7.0 Nougat is required. With ARKit it can only be run on the iPhone 6 or later. This requirement rendered older devices obsolete for AR. Earlier iterations of SDKs such as Google Tango needed external hardware to operate whereas ARCore, ARKit, and ARToolKit use the in device capabilities. AR applications such as Augment operate on older devices for some tasks. There should be the ability for backwards compatibility with the SDKs. This could limit the scope of use instead of blocking access.

- The evolution of AR technology.
  
  There are constant updates being made to AR technology as the research continues. During this research study there were several times when a concept was available for use but, as a result of the latest update became unavailable. Improvements to the technology are being made on a constant basis as often as once a month. A level of competition plays into this. When Apple releases their latest version of AR, Google are quick to follow and vice versa.

- Geometrical complexity
  
  It was discovered that the geometrical calculations required to run the proposed AR application are too complex for mobile devices. This was because the calculations are too memory intensive to operate and could cause the device to crash.
CHAPTER 5. ANALYSIS, EVALUATION AND DISCUSSION

5.4 Chapter Summary

This chapter began with an analysis of the experimentation conducted during this research study. The experiments for UX, code and accuracy were addressed during their preparation and execution. This was followed by an evaluation of the whole research study.

The chapter concluded with a list of the strengths and limitations of the research study. These included the mental models of the users as well as the technical limitations of AR.
Chapter 6

Conclusion

6.1 Research Overview

This research took the problem of blocking a filmed scene and applied the use of AR to solving it. *Blocking* is the placement of props and actors (either principal or background) in front of a camera. If the wrong visual information was presented it could completely change the end result of the film.

6.2 Problem Definition

The problem defined during this research project was whether AR could be used to increase the efficiency of blocking a filmed scene. The research question which was presented was:

“*Can the use of a Mobile Augmented Reality (MAR) application created using marker or markerless based Augmented Reality (AR) increase the efficiency of camera and subject placement in a filmed scene?*”
6.3 Design/Experimentation, Evaluation & Results

The design component of this research study involved the creation of a marker-based prototype and a markerless proof of concept. These were created using AR.js and Augment respectively.

Experiments were conducted in relation to the UX, Code and Accuracy of the technology with varying results.

The UX and Code experiments concluded that a markerless MAR written in C++ or Swift would be the best suited for alleviating the proposed research problem.

6.4 Contributions and Impact

The contributions gathered from this research include the following:

1. A solution to the research problem
   - This study showed that markerless AR could be used for blocking a filmed scene. However, the cost involved in the process would be too high for some productions. This is due to the hardware and software requirements to run AR efficiently.

2. UX Framework
   - This framework provided a basis for future research in AR and could be adapted depending on the device being used.

3. Geometrical calculations
   - The geometrical calculations which were proposed would alleviate the issue of aligning the FoV of the camera and device. However, the calculations proved to be too memory intensive for use on smartphones.

4. Locations for use
• There are situations where the proposed application would not be worth the resources required to operate it such as filming in a small location. In a small location everyone can see the camera feed on the monitors. Some larger locations with a lot of moving parts would be better suited to the application.

6.5 Future Work & recommendations

There are several avenues for future research which include:

1. The use of machine learning for camera placement.
   
   • The definition of machine learning is “an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed”[1]. When a location is scanned the AI could determine any obstacles and assign cameras accordingly. The AI would be required to follow a set of rules which could include visibility of objects, collision with surfaces, lighting sources and director preferences. Research has shown that the use of machine learning is an expanding consideration within the film industry.[2,?] This could also work in terms of pre-production when a location is being scouted. Scouting is when a potential location is inspected for its viability as a film set. Suitability for the story of the film is also considered. During this process the director and producers could be shown all possible camera placements.

2. A further evaluation of previsualization techniques using AR.
   
   • Virtual objects could be incorporated in the snapshots taken for blocking the scene. These assets could include weather conditions (clouds or mist), furniture, CGI characters (monsters) and even people. The addition of this content would ease the transition between production and post-production.

3. The choice of lighting placement in a scene with the aid of AR.

- This would use equations to calculate the levels of luminance and illuminance of lights. The same principles as the proposed application apply with the user able to determine visibility in an area.

6.6 Chapter Summary

This final chapter began with an overview of the research followed by a definition of the problem. This definition included the research question which was to be considered.

Conclusion from the design and experiments were presented next. Finally the contributions, impact and future work were discussed. The future work section talked about the incorporation of machine learning and the use of the application for lighting.
References


REFERENCES


Appendix A

Code

A.1 Experiments

A.1.1 Alpha Versions

C++

#include <iostream>
#include <math.h>
using namespace std;

// function declaration
double aOV(double sw, int h);
double fOV(double a, int dis);
double areaFrust(double R, double r, int h);
double latFrust(double R, double r, int dis);
double volFrust(double R, double r, int h);
double calValues(int h, int dis, double r, double sw);

int main () {
    int h = 24; //focal length
    int dis = 13; //distance also L
double r = 7.5; //radius
double sw = 15.5; //sensor width
double cal;

cal = calValues(h, dis, r, sw);

return 0;
}

//aOV = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
double aOV(double sw, int h) {
    double a;
    a = (2 * (atan(sw / (2 * h)) * (180 / M_PI)));
    return a;
}

//fOV = 2 (TAN (Angle of View / 2) * Distance to Subject)
double fOV(double a, int dis) {
    double R;
    R = 2 * (tan(a/2)) * dis;
    return R;
}

//latFrust = (pi*(R+r))L
double latFrust(double R, double r, int dis) {
    double lat;
    lat = (M_PI * (R+r)) * dis;
    return lat;
}

//areaFrust = pi(R + r)* sqrt(R - r)^2+h^2)
double areaFrust(double R, double r, int h) {
    double c;
    c = M_PI * (R + r) * sqrt(((R - r)*(R-r))+(h*h));
return c;
}

//volFrust = pi/3h(R^2+r^2+R*r)
double volFrust(double R, double r, int h) {
    double d;
    d = M_PI / (3 * 12) * ((R*R)+(r*r)+(R*r));
    return d;
}

//Calculate all of the values
double calValues(int h, int dis, double r, double sw){
    double a;
    a = aOV(sw, h);
    cout << "The Angle of View is " << a << endl;
    double R;
    R = fOV(a, dis);
    cout << "The Linear Field of View is " << R << endl;
    double c;
    c = areaFrust(R, r, h);
    cout << "The Surface Area is " << c << endl;
    double lat;
    lat = latFrust(R, r, dis);
    cout << "The Lateral Area is" << lat << endl;
    double d;
    d = volFrust(R, r, h);
    cout << "The Volume is " << d << endl;
}

Java

import java.util.*;
import java.lang.*;
class Rextester {

    public static void main(String[] args) {
        int a = 11;
        int b = 6;
        int h = 24; //focal length
        int dis = 13; //distance also L
        double r = 7.5; //radius
        double sw = 15.5; //sensor width
        double R = 1;

        //Calling the function
        double cal = calValues(h, dis, r, sw);
        System.out.print(cal);
    }

    public static double aOV(double sw, int h) {
        double a;
        //Angle of View(in degrees) = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
        a = 2 * (Math.atan(sw / (2 * h))) * (180 / Math.PI);
        return a;
    }

    public static double fOV(double a, int dis) {
        double R;
        //Linear Field of View = 2 (TAN (Angle of View / 2) * Distance to Subject)
        R = 2*(Math.tan(a/2)) * dis;
        return R;
    }
public static double latFrust(double R, double r, int dis) {
    double lat;
    // Lateral area of frustum = (pi*(R+r))*L
    lat = (Math.PI * (R+r)) * dis;
    return lat;
}

public static double areaFrust(double R, double r, int h) {
    double c;
    // Surface area of frustum = pi(R + r)* sqrt(R - r)^2+h^2
    c = (Math.PI * (R + r) * (Math.sqrt((R - r) * (R - r) + h * h)));
    return c;
}

public static double volFrust(double R, double r, int h) {
    double d;
    // Volume of frustum = pi/3h(R^2+r^2+R*r)
    d = (Math.PI / (3 * h) * ((R * R) + (r * r) + (R * r)));
    return d;
}

public static double calValues(int h, int dis, double r, double sw) {
    double a = aOV(sw, h);
    System.out.println("The angle of View is " + a);
    double R = fOV(a, dis);
    System.out.println("The linear field of view is " + R);
    double c = areaFrust(R, r, h);
    System.out.println("The surface area of frustum is " + c);
    double lat = latFrust(R, r, h);
    System.out.println("The lateral area of frustum is " + lat);
double d = volFrust(R, r, h);
System.out.println("The volume of the frustum is " + d);
return 0;
}
}

JavaScript

h = 24; //focal length
dis = 13; //distance also L
r = 7.5; //radius
sw = 15.5; //sensor width

function aOV(sw,h) {
    //aOV = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
    a = 2 * (Math.atan(30 /(2 * h)) * (180 / Math.PI));
    print("The angle of view is " + a);
}

function fOV(a,dis) {
    //fOV = 2 (TAN (Angle of View / 2) * Distance to Subject)
    R = 2*(Math.tan(a/2)) * dis;
    print("The Linear Field of View is " + R);
}

function latFrust(R, r, dis) {
    //latFrust = (pi*(R+r))*L
    lat = (Math.PI * (R+r)) * dis;
    print("The Lateral Area of Frustum is " + lat);
}
function areaFrust(R,r,h) {
    //areaFrust = pi(R + r)* sqrt((R - r)^2+h^2)
    c = (Math.PI * R + r) * Math.sqrt(((R - r)^2) + (h^2));
    print("The surface area of frustum " + c);
}

function volFrust(R,r,h) {
    //volFrust = pi/3h(R^2+r^2+R*r)
    d = (Math.PI / (3*h) * ((R^2)+(r^2)+(R*r)));
    print("The volume of frustum is " + d);
}

function calValues(h,dis,r,sw) {
    //Call all of the other functions
    print(aOV(sw,h));
    print(fOV(a,dis));
    print(latFrust(R,r,dis));
    print(areaFrust(R,r,h));
    print(volFrust(R,r,h));
}

calValues(h,dis,r,sw);

Swift

import Foundation

let h = 24; //focal length
let dis = 13; //also L
let r = 7.5;
let sw = 15.5;
print (calValues(h:dis:r:sw:))

func aOV(sw: Double, h: Int) -> Double {
    // aOV = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
    let a = (2*atan(sw / Double(2*h))) * (180 / Double.pi)
    return a
}

func fOV(a: Double, dis: Int) -> Double {
    // fOV = 2 (TAN (Angle of View / 2) * Distance to Subject)
    let R = 2*(tan(a / 2) * Double(dis))
    return R
}

func latFrust(R: Double, r: Double, h: Int) -> Double {
    // latFrust = (pi*(R+r))*L
    let lat = (Double.pi * Double(R+r)) * Double(dis)
    return lat
}

func areaFrust(R: Double, r: Double, h: Int) -> Double {
    // areaFrust = pi(R + r)* sqrt((R - r)^2+h^2)
        let x = R-r;
    let c = (Double(M_PI)*(R + r)) * (((Double(x*x) + Double(h*h)).squareRoot()))
    return c
}

func volFrust(R: Double, r: Double, h: Int) -> Double {
    // volFrust = pi/3h(R^2+r^2+R*r)
        let y = R*R;
    let z = r*r;
    let d = (Double(M_PI) / Double(3 * h))
    let e = (y + z + (R*r))
    let f = Double(d) / Double(e)
return f
}
func calValues(h: Int, dis: Int, r: Double, double sw: Double) -> Double {
    let a = aOV(sw:h:)
    print("The angle of view is ",a)
    let R = fOV(a:dis:)
    print ("The linear field of view is",R)
    let c = areaFrust(R:r:h:)
    print ("The surface area of frustum is", c)
    let lat = latFrust(R:r:h:)
    print ("The lateral area of frustum is", lat)
    let d = volFrust(R:r:h:)
    print ("The volume of frustum is",d)
    return 0;
}

A.1.2 Beta Versions

C++

#include <iostream>
#include <math.h>
using namespace std;

// function declaration
double aOV(double sw, int h);
double fOV(double a, int dis);
double areaFrust(double R, double r, int h);
double latFrust(double R, double r, int dis);
double volFrust(double R, double r, int h);
double calValues(int h, int dis, double r, double sw);

int main () {

int h = 24; //focal length
int dis = 13; //distance also L
double r = 7.5; //radius
double sw = 15.5; //sensor width
double cal;

cal = calValues(h, dis, r, sw);

return cal;
}

//Angle of View(in degrees) = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
double aOV(double sw, int h) {

double a;
    a = (2 * (atan(sw / (2 * h)) * (180 / M_PI)));

    return a;
}

//Linear Field of View = 2 (TAN (Angle of View / 2) * Distance to Subject)
double fOV(double a, int dis) {

double R;
    R = 2 * (tan(a/2)) * dis;

    return R;
}
APPENDIX A. CODE

//Lateral area of frustum = (\pi*(R+r))L
double latFrust(double R, double r, int dis) {
    double lat;
    lat = (M_PI * (R + r)) * dis;

    return lat;
}

//Surface area of frustum = \pi(R + r) \sqrt{(R - r)^2+h^2)}
double areaFrust(double R, double r, int h) {
    double c;
    c = M_PI * (R + r) * sqrt(((R - r)*(R-r))+(h*h));

    return c;
}

//Volume of frustum = \pi/3h(R^2+r^2+R*r)
double volFrust(double R, double r, int h) {
    double d;
    d = M_PI/ (3 * 12) * ((R*R)+(r*r)+(R*r));

    return d;
}

//Calculate all of the values
double calValues(int h, int dis, double r, double sw){
    double a;
    a = aOV(sw, h);
    cout << "The Angle of View is " << a << endl;
double R;
R = fOV(a, dis);
cout << "The Linear Field of View is " << R << endl;
double c;
c = areaFrust(R, r, h);
cout << "The Surface Area is " << c << endl;
double lat;
lat = latFrust(R, r, dis);
cout << "The Lateral Area is" << lat << endl;
double d;
d = volFrust(R, r, h);
cout << "The Volume is " << d << endl;
}

Java

import java.util.*;
import java.lang.*;

class Rextester {

    public static void main(String[] args) {
        int a = 11;
        int b = 6;
        int h = 24; //focal length
        int dis = 13; //distance also L
        double r = 7.5; //radius
        double sw = 15.5; //sensor width
        double R = 1;

        //Calling the function
double cal = calValues(h,dis,r,sw);
System.out.print(cal);
}

public static double aOV(double sw, int h) {
    double a;
    // Angle of View (in degrees) = 2 \arctan\left(\frac{\text{Sensor width}}{2 \times \text{focal length}}\right) \times \left(\frac{180}{\pi}\right)
    a = 2 * (Math.atan(sw / (2 * h))) * (180 / Math.PI);
    return a;
}

public static double fOV(double a, int dis) {
    double R;
    // Linear Field of View = 2 \tan\left(\frac{\text{Angle of View}}{2}\right) \times \text{Distance to Subject}
    R = 2 * (Math.tan(a/2)) * dis;
    return R;
}

public static double latFrust(double R, double r, int dis) {
    double lat;
    // Lateral area of frustum = (\pi \times (R+r)) \times L
    lat = (Math.PI * (R+r)) * dis;
    return lat;
}
public static double areaFrust(double R, double r, int h) {
    double c;
    //Surface area of frustum = pi(R + r)* sqrt(R - r)^2+h^2
    c = (Math.PI*(R+r) * (Math.sqrt((R-r)*(R-r)+(h*h))));
    return c;
}

public static double volFrust(double R, double r, int h) {
    double d;
    //Volume of frustum = pi/3h(R^2+r^2+R*r)
    d = (Math.PI / (3*h)*((R*R)+(r*r)+(R*r)));
    return d;
}

public static double calValues(int h, int dis, double r, double sw){
    double a = aOV(sw,h);
    System.out.println("The angle of View is " + a);
    double R = fOV(a,dis);
    System.out.println("The linear field of view is " + R);
    double c = areaFrust(R,r,h);
    System.out.println("The surface area of frustum is " + c);
    double lat = latFrust(R,r,h);
    System.out.println("The lateral area of frustum is " + lat);
    double d= volFrust(R,r,h);
    System.out.println("The volume of the frustum is " + d);
    return 0;
}
JavaScript

```javascript
var h = 24; //focal length
var dis = 13; //distance also L
var r = 7.5; //radius
var sw = 15.5; //sensor width
var a;
var R;

function aOV(sw, h) {
    "use strict";
    //AoV = 2 ARCTAN(Sensor width / (2 * focal length)) * (180 / pi)
    a = 2 * (Math.atan(sw / (2 * h)) * (180 / Math.PI));
    return ("The angle of view is " + a);
}

function fOV(a, dis) {
    "use strict";
    //FoV = 2 (TAN (Angle of View / 2) * Distance to Subject)
    R = 2 * (Math.tan(a / 2)) * dis;
    return ("The Linear Field of View is " + R);
}

function latFrust(R, r, dis) {
    "use strict";
    //Lateral area of frustum = (pi*(R + r))*L
    var lat = (Math.PI * (R + r)) * dis;
    return ("The Lateral Area of Frustum is " + lat);
}
```
function areaFrust(R, r, h) {
    "use strict";
    //Surface area of frustum = pi(R + r) * sqrt(R - r) * (R - r)+(h * h))
    var c = (Math.PI * R + r) * Math.sqrt(((R - r) * (R - r)) + (h * h));
    return ("The surface area of frustum " + c);
}

function volFrust(R, r, h) {
    "use strict";
    //Volume of frustum = pi/3h(R^2+r^2+R*r)
    var d = (Math.PI / (3 * h) * ((R * R) + (r * r) + (R * r)));
    return ("The volume of frustum is " + d);
}

function calValues(h, dis, r, sw) {
    "use strict";
    //Call all of the other functions
    aOV(sw, h);
    fOV(a, dis);
    latFrust(R, r, dis);
    areaFrust(R, r, h);
    volFrust(R, r, h);
}

calValues(h, dis, r, sw);
Swift

A.2 Prototypes

A.2.1 AR.js

<script src="https://aframe.io/releases/0.6.0/aframe.min.js"></script>
<script src="https://jeromeetienne.github.io/AR.js/aframe/build/aframe-ar.js">
<body style='margin : 0px; overflow: hidden;'>
    <a-scene embedded arjs='sourceType: webcam;'
        <!-- handle marker with your own pattern -->
        <a-marker type='pattern' url='path/to/pattern-marker.patt'>
            <a-box position='0 0.5 0' material='color: red;'>
        </a-box>
        </a-marker>
        <!-- handle marker with hiro preset -->
        <a-marker preset='hiro'>
            <a-box position='0 0.5 0' material='color: green;'>
        </a-box>
        </a-marker>
        <!-- handle barcode marker -->
        <a-marker type='barcode' value='5'>
            <a-box position='0 0.5 0' material='color: blue;'>
        </a-box>
        </a-marker>
        <!-- add a simple camera -->
        <a-entity camera>
        </a-entity>
    </a-scene>
</body>
Appendix B

User Experience Questions

B.1 Survey Questions & Responses

• **Q1. Are you familiar with AR and if so have you ever used an AR application?**

  – “Have heard about it but not used it.”
  – “Familiar with use but have never used it.”
  – “I am familiar with it, however, I have not used it and given the type of director I am – human stories/drama etc., it probably unlikely I would do so.”
  – “I am familiar with what AR is, but have never used AR for a production.”
  – “I am not familiar with AR and have yet to use an AR app.”
  – “Not Really familiar and no have not used an AR application.”

• **Q2. Would you ever consider using an AR application for work?**

  – “Yes, it could help the re-design of existing buildings.”
  – “Yes, could be useful in a creative presentation to potential financiers.”
  – “Unlikely, but you just never know what comes along! Never say Never!”
– “I would consider it if a suitable project came up and an AR App would streamline the production process. It would have to be a benefit: time, creativity or financial, and not unnecessarily complicate the process.”

– “I would be very interested in using AR in my workspace.”

– “Would need to know a lot more about it and the costs involved.”

• Q3. As part of your daily work are there aspects if any which could be improved by the use of AR?

– “Yes, it would be great for realtime concepts”

– “Not sure?”

– “Once again, no. I tell “human, emotional stories”, however…”

– “AR Apps could be of use, but daily, not so sure. As I’m sure you’re aware there are AR apps that can be used to plot the sun’s position or block out scenes, plot camera positions, etc. I haven’t used them though. On the sun’s position, a compass would give enough information for most needs - where due south is, and so what path the sun takes around a location. It would have to be a very specific shot in order to need the actual azimuth. I can see how AR could potentially be useful if a production involved CGI and live action, or where detailed storyboards can be a requirement. And situations where corporate clients are involved, they tend to like everything laid out for them and often aren’t very visually literate, so supporting material produced through an app could potentially be useful.”

– “It sounds like it could work well in a green screen situation where I could line up the plate shots with the green screen shots etc. So that the character can work within the eventual environs which would be built in post.”
APPENDIX B. USER EXPERIENCE QUESTIONS

B.2 Expert Interviews

B.2.1 AR Experts

Q1. From an industry standpoint does the proposed idea sound feasible?

Q2. Which programming language would you recommend for the development of the application and why?

Q3. Would you have a preference over the use of marker or marker-less AR from a development point of view?

Q4. Based on your knowledge and experience have you any feedback about the proposed application?

Q5. What improvements would you make to the design of the application?

Q6. Have you any recommendations for potential areas of research within AR as a whole?

B.2.2 Filmmakers

Q1. Are you familiar with Augmented Reality?

Q2. Would you consider using an Augmented Reality application as part of your daily work?

Q3. Does the idea presented for the application make sense for its intended use?
Q4. What improvements would you make to the design of the application?

Q5. What alternatives would you see for the use of Augmented Reality applications on film sets?