AR in Cultural Historical Museum

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Abstract

Acknowledgements

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Acronyms

2D Two Dimensional. 39

3D Three Dimensional. 1, 39

AR Augmented Reality. iii, iv, 1, 2, 5, 6, 8, 9, 13, 14, 16, 28, 32, 37, 38, 39, 40, 41

CAVE Cave Automatic virtual Environment. 5

HMD Head Mounted Display. 5

VR Virtual Reality. iii, 1, 5, 38

Glossary

prefab It is an asset type in Unity that allows to store a collection of GameObjects with all its related components and basically acts as a template which can be reused creating new instances of it. 24

Chapter 1

Introduction

This thesis describes the research of using digital technology in Historic site. This project is guided by Centre for New Media. In this work I have investigated the modern AR frameworks to develop an application that can be used in historic sites with primary focus for indoor and outdoor environments. During the timeframe, I had several meetings with Centre for New Media to discuss the possibilities of using AR in bringing life to the Fjell fortress.

1.1 | A word about Centre for New Media

Centre for New Media is a department within HVL which works with digital productions such as graphics design, web design, digital photography, development of applications for mobile phones and tablets. It also has offered online distance learning courses in media and communication topics. The center works in collaboration with researcher, educators and motivates students for developing and researching new technological aspects at the HVL [2].

Centre for New Media in collaboration with Bachelor groups performed the scanning of the Fjell fortress and have created some virtual Three Dimensional (3D) models of the tunnels and monuments. They have also created a VR supported Unity scene of the fortress.

1.2 | Motivation

In earlier times, museums have used brouchers, guides, illustrations and texts, and multimedia guiding systems to deepen engagement and education. However, these materials do not interact directly with visitors. It depends upon the visitors' motivation to invest further time and effort to read the contents or watch a video and construct the meaning of the artifact. Museums and cultural heritages are facing increasing challenges engaging the visitors and providing museum knowledge. Museums are always adopting new technologies to provide an interactive environment for visitors. Recently AR is gaining popularity among the museums. AR is the leading technology outlined in many research works and projects to engage the users in an enhanced perception of surrounding [3]. As AR and its supporting technology is continuing to flourish, it makes an ideal platform for enriching historic architecture and remains of cultural heritages [4].

Having an interest in cultural heritages and some experience in mobile application development, I feel motivated to work on this project that will enhance my knowledge in AR and can contribute the technology for the society.

1.3 | Thesis goals and Research Questions

Guided Research Question:

- How can a modern AR framework be used enhance a visitors experience?

In order to answer the question I will do these tasks:

- A modern AR framework is reviewed

- The problems are defined

- A mobile application will be developed

- The application will be tested to determine the user experience

1.4 | Related Works

There were lots of approaches from the past to use AR in historical sites and museums.

ARCHEOGUIDE in 2002 provided personalized AR tour in order to help visitors and researchers better appreciate and enjoy the past glory of the site [5]. Zoellner in 2008 show how historic media like drawings, paintings, and photographs can be superimposed on the real environment [6].

1.5 | Report Structure

This section gives a sketch of the chapters in this thesis work by briefly mentioning the contents.

Chapter 1 (Introduction) sets the nature of this thesis work by discussing the context of this research, its goals, research questions, and related works.

Chapter 2 (Background) presents the background information of museums and AR.

Chapter 3 (ARCore Overview) sheds light on ARCore and different studies done with ARCore.

Chapter 4 (Application development) discusses the steps taken for the development of the application

Chapter 5 (Evaluation) presents details of the evaluation of the application.

Chapter 6 (Epilouge) concludes the thesis with discussion and Future work.

Chapter 2

Background

Museums are essential institutions that care for the collection of artistic, cultural, historical, or scientific importance artifacts. They hold the cultural wealth of the nation and helps the future generations to understand and appreciate their history and culture and take pride in the achievements of those before them. Museums are concrete evidence from the past. Visits to the museum should be developed and encouraged as they educate and inspire people. Museums also play a vital role in providing economic benefits, creating many employment opportunities by attracting national and international visitors.

This chapter will present the technology used in museums over time and description of interactive experiences in museums.

2.1 | Museums and Technology

Traditionally, museums used to offer static experience to the visitors. The museums were just the collection of artifacts exhibitaed behind the glass. The emergence of the visitor studies described in Hein 1998 has led the cultural instutions to understand the museums visitors and become more responsive to their interests. Hein in 2000 notes that the museums are shifting the focus from object-oriented towards visitor-centered instutions. During the past 30 years, museums of all types have tried to attract and become more responsive to the interests of a diverse public black 2012. The

importance of online presence was realized and the first museum website was created in the mid-1990 Jones 2007. Museums are continuously exploring new methods to improve the visitors experience using new technologies. Paper description, audio description, video and animation description are the common trends in almost all the big museums today. These technologies only provide digital information rather than interactive experience. It depends the visitors interest and motive in understanding the content provided. Study conducted in history and science collections-based museums proved that the interactive experiences in museum supported visitors' learning.

2.1.1 VR

Cave Automatic virtual Environment (CAVE)

The CAVE systems are one of the best virtual reality devices available for potraying the virtual environment [7]. It allows a user to enter a cube wearing stereoscopic glasses and can experience the presence in virtual environment. The walls, floors and celling of the cube acts as displays. The CAVE achieved the international recognitation after it was displayed at the 1992 SIGGRAPH conference as reviewed in [7].

Head Mounted Display (HMD)

HMDs are becoming

2.1.2 Other Technologies

2.1.3 AR

2.1.4 AR in museums

AR technology started to enter to the museums' environment in the early 2000s. Using AR museums can add a layer of extra information on top of existing exhibits and make use of the virtual space. The benefits of

technology can be different in museums depending on the situations.The study on the visitor experience shows the potential of AR in museums.

A detailed discussion about AR in cultural heritages can be found in section **??**.

There are several reasons why museums are using AR technology; some of them are discussed:

AR is engaging

AR is used to add an extra layer of information which can be reached out to more audiences. AR is more flexible in adding any information which can be made personalized so that the user users get more connected in learning. This makes it easy to understand the complex relations and processes of the museum.

AR brings artifacts to life

By adding a digital layer of augments, museums can bring life to artwork and artifacts.

AR is fun and interactive

Many museums have integrated AR with little fun into the artifacts to attract families and young visitors. AR gaming has made a way in new generations where the players can make use of real-world and virtual world to play the games.

AR is easily accessible

AR can run on most of the existing smart devices, and they do not need extra hardware to integrate or an expert in using it. Most of the sensors needed for AR are packed in the device itself, which makes it popular among the users. The usage of AR is as simple as using mobile phone applications. These applications can be connected to a central system, and changes can be made instantly.

AR gives visitors a reason to visit - and revisit

With AR the museums can refresh the outdated information integrating it with other technologies which provide the reason for visitors to revisit the museums to gain another new experience.

Chapter 3

Augmented Reality : An Overview

This chapter

3.1 | What is AR?

Augmented Reality (AR) in a general term is to blend the virtual world with the real world. In AR, users interact digitally with the information in the real world. As AR, is not a new idea, but with the advancement of smartphones and tablets, it has now extended its possibilities in many ways; Augmented Reality applications have been developed to run on them. AR applications use the device sensors (camera, GPS, compass) and fuse useful information on top of the image from the camera viewed on the device's screen.

The figure 3.1 describes the concept of Paul Milgram; the continuous scale ranging complete real and complete virtual [8]. On the left lies a real world and, on the right lies the virtual world. Everything in between is a mixed reality where physical and digital objects interact together. Unlike virtual reality, which replaces the real world totally with the virtual world, AR adds a layer of virtual object preserving and understanding the real world.

Figure (3.1)   Reality-Virtuality Continuum (Paul Milgram 1994)

3.2 | History of AR

Although AR seems a new technology the story begins in 1968, a head-mounted display developed by Ivan Sutherland [9] but the term "Augmented Reality" was first used by Boeing researcher Tom Caudell in 1992 [10] while helping workers to assemble the wires and cable for aircraft. In 1994 Paul Milgram presented a continuum diagram that spans from the real environment to the virtual environment [8]. Ronald Azuma in 1997 provides a most used academic definition for AR identified by three characteristics: it combines real and virtual, it is interactive in real-time, it is registered in 3D [11]. In 1998 the broadcast company "Sportvision" used AR to cast a virtual yellow first-down marker in a live NFL game and NASA to provide virtual-navigation during test flights. A year later Hirokazu Kato and Mark Billinghurst introduced a template-based approach for recognition using square fiducials: ARToolKit, available as open-source under the GPL license [11]. Bruce Thomas developed the first outdoor mobile AR game ARQuake in 2000 [12] and in the following years, more and more AR applications were developed such as Wikitude AR travel guide launched in 2008 [13]. Google brought "Google Glass" to the market in 2012, which used AR to show real-time information on the glass. Although it was not a commercial success product, some companies found it useful, such as medical and automobiles. After the massive success of an AR mobile game application Pokémon Go in 2016, lots of other applications started exploring. Snapchat, Facebook, Instagram added entertaining AR face filters, which was a new experience to the users. The announcement of ARKit and ARCore in 2017 made it more popular among the mobile phone application developers and users. With the growing attraction of AR, companies are spending millions of dollars to harness its

potential, so it is fascinating to see every new release of this technology.

(a) Ivan   (b) Google Glass   (c) Pokémon Go

Figure (3.2)   History

3.3 | Key Technologies

The technology for AR is developing rapidly. Hardware is getting cheaper and smaller, and the software is becoming more faster. The essential components for AR are tracking and registration technology, object detection and recognition, calibration, model rendering, and display technology [14].

3.3.1   Display Technology

Displays are used to view the final output of AR. There are three major types of displays used for AR: head-mounted displays (HMD), handheld displays, and spatial displays [13]. HMD is worn over the head like a helmet, and a pair of displays are adjusted over eyes. It has cameras attached to take the images, and the virtual graphics are fused then is displayed on the screen. Handheld displays are the ones that are easy to hold in the hands, and smartphones are the most popular. Spatial Augmented Reality (SAR) makes use of digital projectors to display graphical information onto the physical world. It separates most of the technology from the user and integrates it into the environment [13].

The essential display technologies for providing an AR experience are described below:

- *Marker-Based AR:* It depends on the fiducial markers to calculate the orientation and position of the device. The markers can be QR/2D codes or the images which have lots of details which can be easily recognizable [15].

- *Markerless AR:* Also known as location-based AR or Vision-based AR. Location-based AR is based on the hardware like GPS, accelerometer, digital compass, and a velocity meter. These sensors provide the location and direction information of the device which can be used to get the orientation and position of the device. Vision-based AR uses Image processing algorithms to determine the unique feature points from the environment, and these points are used to determine the pose of the device. This technology is getting more popularization because of the availability of smartphones, which are packed with all the needed sensors are capable of running complicated calculations [15].

- *Projection-Based AR:* In projection-based AR, artificial light is projected onto the real world surfaces and can sense the interaction by differentiating the known projection and the altered projection. The result is displayed using digital projectors. Although there are some of the demonstrations of this technology, still it is in the early stage of development [15].

- *Superimposition-Based AR:* Computer vision and object recognition are the critical factors for superimposition based AR to partially or fully replace the object from the real world with the virtual object. It has excellent use when more information of the object has to added [15]. Some of the appliances are museums where additional information has to be provided about the artifacts, medical field to examine the patients and provide treatment, military operations, self-driving vehicles to detect the objects in front of them and many more.

3.3.2 Tracking and Registeration Technology

This is the most significant technology to align the virtual world with the real world. Accurate position and orientation tracking are needed to align virtual objects in the real world in AR. In the registration process, the virtual object should align itself correctly in the real world. Tracking process involves

(a) Marker-Based AR

(b) Markerless AR

(c) Projection-Based AR
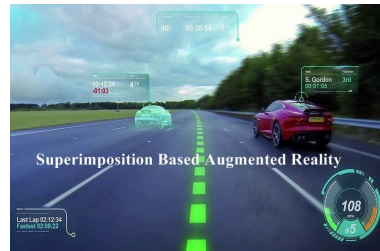
(d) Superimposition AR

reconstructing the correct position between the real world and virtual objects when the user changes the position.

There are three types of tracking and registration methods:

- *Hardware-Based:* Tracking sensors are used to track the motion of the user and continuously update the user location in the virtual world. The different hardware that helps in motion tracking are accelerometer, gyroscope, and camera. The accelerometer measures the change in velocity. The gyroscope measures the orientation and angular velocity. The camera provides the live images of the surrounding, which is used in understanding the real world. The hardware that enables location-based AR is Magnetometer and GPS. Magnetometer lets the device know the earth's magnetic field and global navigation satellite system provides geolocation and time information to the GPS receiver [14].

- *Vision-Based:* Vision-based Tracking uses complex image processing algorithms to determine the feature points in the environment. The images are feed through the camera of the device. The algorithm compares vital points with the stored points to determine the orientation

and position of the device. The advantage of this method is fast and applies to smaller areas but needs high power for processing complex algorithms [14].

- *Hybrid:* This method is promising for indoor and outdoor AR environments. It uses both the hardware-based and vision-based technology for tracking and registration process [14].

3.3.3   Registeration

The key concept is to understand the scene by discovering and finding the target. It is classified into two parts: detection and classification and image processing. Detection and classification are emphasized to provide supplementary information. Image processing deals with storing the points to the server and find the relevant image by the matching method to locate the target in the environment and identifying the precise location of the image [14]. Camera from mobile devices captures the images; then these images are processed with the stored images and display enhanced information in the screen in the intended position.

3.3.4   Calibration

Calibration is a technology which utilizes pixels in-camera for restoring the object in the real world. It detects the position and orientation and reports the resulting data to the system. The values measured by calibration are the scope of vision, camera parameters, sensor offset, deformation, and object localization [14].

3.4 | How AR system works?

For Augmented Reality to work, it utilizes the technologies that are described in section 3.3. Augmented reality needs to understand the world in terms of semantics and 3D geometry. Semantics is "What the object is?" and Geometry is "Where the object is?". Computer vision is used to answer the questions for AR. computer vision acts as the eyes and brain to understand
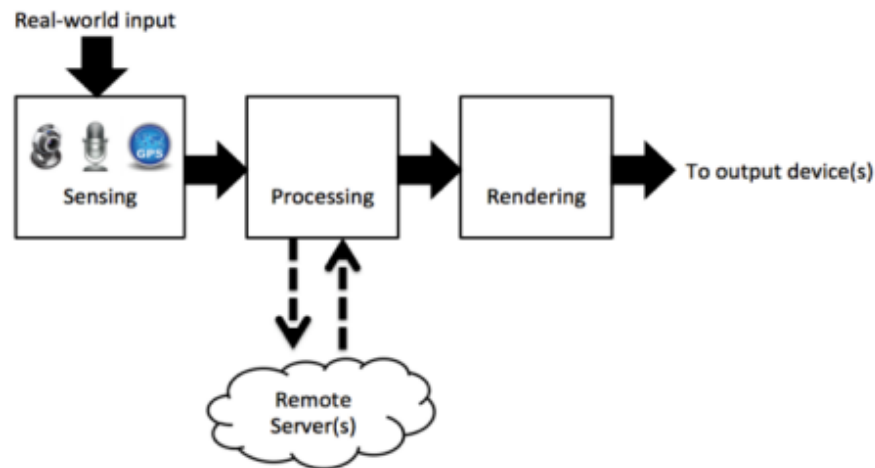
Figure (3.4)   Overview of an augmented reality system

the world like humans, although it cannot determine as humans but is getting advanced. First Computer vision understands the world around by fetching the information from the 2D images provided by the device camera. Then this information is used to show the relevant digital content on output devices in a realistic way, so as it looks the part of the environment- this is called rendering. Modern phone camera works at 30 frames per second, which gives only 30 milliseconds to process the whole pipeline.

3.5 | Current Uses of AR

3.6 | AR frameworks

AR is a technology that has recently started gaining popularity. AR is gaining popularity in multiple areas such as tourism, entertainment, education, art and many more. The report prepared by Tractica shows that the users for mobile AR will reach 2 billion by 2022, and with the advancement of the affordable software development kit (SDKs), more applications tend to include AR [16]. Several frameworks provide a solution in building practical AR applications. Some of the popular frameworks are listed below with their features described briefly.

3.6.1   ARKit

In June 2017 Apple announced the ARKit framework at World Wide Developers Conference (WWDC). This framework supplies numerous and powerful features to build Augmented Reality applications and games for iOS devices. ARKit uses technologies such as Metal, SceneKit, SpriteKit, Unity, Unreal Engine to handle the processing of the 3D models in the scene. ARKit can be used in the devices that have minimum A-9 processor hardware and iOS 11 operating software [17].

ARKit can track different surfaces, images and 3D objects. It also provides a feature to react in different lightning conditions. In June 2018 ARKit was updated with version 2 which provides a feature that can communicate with other devices to create a multiuser application or game. In the recent update it is loaded with the feature to persist between different sessions [17].

ARKit API is free to download and use but an annual Developer Program account is needed for store distribution which is priced US$99.

3.6.2   ARCore

Google started the journey of AR with Project Tango from 2014. ARCore is the new software development kit announced in 2017 for developing AR applications and games. ARCore works on different devices with android 7.0 and higher in android devices and iOS 11 or higher in apple devices. ARCore satisfies most of the developers by providing SDK for Android, Android NDK, Unity for iOS and Android, iOS, Unreal Engine. ARCore uses Sceneform SDK which is a 3D framework for developing applications without the knowledge of OpenGL for android development.

ARCore can detect 2D images and planar surfaces. With cloud anchors it lets users to have same AR experiences simultaneously in different devices iOS or Android[18]. With recent updates in handling Augmented images and movement of light ARCore is getting more impressive.

ARcore is free to download and use and distribute.

3.6.3   Vuforia

Vuforia is the popular software development kit (SDK) for mobile devices that enables in creating Augmented Reality applications for Android, iOS and UWP. The applications can be built with Unity, Android Studio, Xcode and Visual Studio.

It uses computer vision technology to recognize and track image targets in real time. It implements different functionalities such as recognition of different types of visual objects, text, environment, VuMark. Also, the object targets can be created using Vuforia Object Scanner [19].

All plugins and functionalities of the platform are free to use but it includes a Vuforia watermark. There are different pricing plans with different features and removal of watermark.

3.6.4   Comparision

With the frameworks developed recently it is difficult to choose an SDK engine. Many portals [20, 21] describe the differences between the popular ones and provide their opinions. Each of the engines have their own pros and cons along with their distinct features.

[1] has provided a comparision chart among the different mobile platforms to develop AR applications. The table features the comparision based on the characteristics that each framework points out the most. Among the different platforms listed in the table, I have only looked to the popular and freely available platforms Apple ARKit, AR Core, Vuforia. ARKit and Vuforia provides 3D objetc tracking but ARCore only provides 2D image tracking. Both ARCore and ARKit uses GPS and IMU sensors for localization of the device but Vuforia does not use GPS sensors, it uses only IMU sensors to provide AR experience. None of the three platforms provide dynamic occlusion feature. In the whole list only ArUco and Tango provides occlusion. ARCore and Vuforia uses SLAM for mapping whereas the mapping technology for ARKit is not specified. ARCore and ARkit are SDKs from biggest tech gaints available free of charge. ARCore and ARkit platforms have their own stregths and weakness, it is difficult to differenciate which of them is better. Both the platforms are well suited to provide a good AR experience [22].

| Framework | Last version found | Markers | | Sensors | | SLAM | Dynamic occlusion | Implementation |
		2D tracking	3D object tracking	GPS	IMU			SDK package
Apple ARKit		✓	✓	✓	✓	Not found	✗	iOS
AR Core	8 May 2018	✓	✗	✓	✓	✓	✗	Unity Unreal
ArUco	17 May 2018	✓	✗	✗	✗	✗	✓	✗
Augmented Pixels	26 Apr 2017 (protype)	✗	✗	✓	✓	✓	✗	✗
Catchoom CraftAR	28 Mar 2017	✓	✗	✗	✗	✗	✗	Unity
EasyAR SDK Basic	6 Mar 2018	✓	✗	✗	✗	✗	✗	Unity
EasyAR SDK Pro			✓			✓		
Kudan	23 Mar 2018	✓	✓	✓	✓	✓	✗	Unity
MAXST AR	19 Mar 2018	✓	✓	✗	✗	✓	✗	Unity
NyARToolkit	24 May 2016	✓	✗	✗	✗	✗	✗	Unity
Tango	1 Mar 2018	✓	✗	✓	✓	✓	✓	Unity
Vuforia	1 Mar 2018	✓	✓	✗	✓	✓	✗	Unity
Wikitude	21 Feb 2018	✓	✓	✓	✓	✓	✗	Unity

Figure (3.5)   Comparitive study of the SDKs available to implement AR mobile systems [1].

Chapter 4

ARCore: An Overview

The support for ARCore starts from 7.0. From the data provided by google around 50% of devices use the versions that supports ARCore.

ARCore works on the android devices running Android 7.0 (Nougat) and later. The devices supporting ARCore are available in

https://developers.google.com/ar/discover/supported-devices.

4.1 | ARCore and Project Tango

Earlier to ARCore, Project Tango was an effort from Google to bring augmented reality to phones. Project Tango was introduced in 2014, and a couple of consumer devices were launched. These devices were optimized with extra hardwares, a barometer for elevation, dedicated motion-tracking camera, dedicated infrared depth-sensing camera, a high megapixel camera to view the objects.

In 2017 Google released ARCore a software-only AR solution that can work on many android supported devices. ARCore only requires a color camera and does not need any extra hardware, which made Google shut down Tango in 2018 officially.

Tango uses its refined hardware to generate a 3D map of the designated area, which makes it more accurate in providing an AR experience. While ARCore works good in flat surfaces, Tango wins the race in mapping larger

and irregular surfaces with the complicated environment. Even though Tango is better than ARCore, ARCore will be able to bring AR to millions of devices without need of extra hardwares.

4.2 | Development Environments

ARCore applications are Android applications that can be developed using popular development environments.

4.2.1   Android Studio

Android Studio is the official Integrated Development Environment (IDE) for developing Android applications. ARCore was initially released with OpenGL which was difficult for someone with basic graphics. Later Sceneform SDK was introduced to work with 3D scenes. With Sceneform, ARCore applications can be written as normal android applications in Java (or Kotlin) without having much knowledge in 3D graphics programming. Android Studio also offers the Native Development Kit (NDK) that allows using C, C++ with Android.

4.2.2   Unreal Engine

Unreal engine is a game engine, supports for 2D and fully 3D rendered games. It provides complete features for creating high-quality games across PC, mobile, VR and AR. It uses Blueprint Visual Scripting technology, which allows creating games using the Blueprint only. The coding language is C++.

4.2.3   Unity

Unity is also a game engine which gives the ability to create 2D and 3D games. The primary scripting language is c sharp but it also supports UnityScript (javascript for Unity). It has easy to use tools and workflows with tons of optimizations features. It provides one-click deployment to

different platforms. The scene is like a container in Unity which stores all the asset that is used in a given moment. The Scene can be one or many in the application. Each scene can be thought of as a level in the game and each of the scenes can be designed with its environment, obstacles, and decorations.

3D models can be imported from most popular 3D applications. Unity can read .FBX, .dae(Collada), .3DS, .dfx and .obj files. It can also import 3D models through conversion: Max, Maya, Blender, Cinema4D, Modo, Lightwave and Cheetah3D files e.g. .MAX, .MB, .MA etc.

Unreal offers high-fidelity visuals than any other game engines, but it demands high processing power. Unity, on the other hand, enables to create complex projects on lower-powered devices. It is more matured and provides lots of pro features like custom shaders etc. It is famous among graphics developers because of its simplicity and reusability. Sceneform is relatively new and immature.

4.3 | ARCore Fundamental concepts

The fundamental concepts used in ARCore are discussed below. Together with these fundamental concepts ARCore is able to provide an Augmented Reality experience.

4.3.1   Pose

Pose in ARCore describes the transformation from the object's local coordinate space to the world coordinate space. Poses from ARCore can be consideredof as equivalent to OpenGL model matrices. The transformation is defined using a quaternion rotation about the origin, followed by a translation [23].

4.3.2   Feature Points

Feature points are the visually distinct features in images- for example, corners, edges. Every feature point has a unique fingerprint. These feature

points are used in combination with the device sensors to find out the device location in the space and estimate the pose [24].

4.3.3 Plane

ARCore takes the images from the camera and detects the planar surface using image processing algorithms. These detected planar surface called plane is used to anchor the virtual objects to the scene [25].

4.3.4 Hit Result

It is the intersection between a ray and estimated real-world geometry [26]. ARCore runs a hit test from the (x,y) coordinate of the screen and returns planes or feature points intersected by this ray along with the pose of the intersection. This result is used to create anchors and attach virtual objects to the real world.

4.3.5 User Interaction

ARCore uses hit testing to get the planes and feature points to the area user tapped on the mobile screen. These allow the user to select or interact with objects in the environment [24].

4.3.6 Anchors and Trackable

The anchor is the numerical description of fixed location and orientation in the real world. The virtual objects are anchored to a fixed location in the real world, and this point is updated accordingly with the change in the pose of the device.

Trackables are something that ARCore can track. Anchors are attached to trackable to ensure the relationship between the virtual objects and real objects remains stable [24].

Anchors can be added to the scene either using a trackable or the ARCore Session. Using trackable maintains the position of virtual object to the

trackable and same rotational effect is applied as trackable. Anchor added with ARCore Session lets the object to stay at the same pose in world space throughout the session [27].

4.3.7   Augmented Images

Augmented Images in ARCore are the set of 2D images, which can form a image database. Augmented Image is a trackable. Each dataset can contain 1000 augmented images. The images in the database are distinguished using the feature points. The feature points are different for every image. ARCore can track up to 20 images simultaneously but cannot track moving image. Image dataset is present within the application so internet connection is not required for tracking the image. ARCore session has the instance of the database [24].

There are certain tips from the developers of ARCore to be followed for a good reference image. PNG, JPG and JPEG image formats are supported. The image's resolution should be at least 300*300 pixels and the image should have more details rather than images having repetitive patterns. Every image in the dataset has a score which determines the quality of the reference image. The score above 75 is recommended. The physical image should cover at least 25% of the device screen.

4.3.8   Motion tracking

ARCore uses a process called concurrent odometry and mapping (OCM) to understand the position of the device in the real world. ARCore makes use of computer vision to get distinct feature points from the environment to understand and uses these points to compute its change in location. The visual information is combined with inertial measurements from the device to estimate the pose of the device. The pose of the virtual camera is aligned with the pose of the device's camera provided by ARCore to render the virtual content [24].

4.3.9 Environmental understanding

ARCore is continually looking for clusters of feature points to improve its understanding of the real-world environment. Feature points play a vital role in understanding the environment. Flat surfaces without texture, such as a white wall are not detected correctly [24].

4.3.10 Light estimation

ARCore can estimate the lighting conditions around the environment. This information allows adjusting the colors of the virtual objects under the same environment around them, increasing the sense of realism [24].

4.4 | Case Study

This section provides the detail of studies done with the features of ARCore.

4.4.1 Visualizing Planes and Placing Objects

This behavior is the most commonly used feature in AR applications such as Google camera playground, IKEA furniture. The application detects the planar surface around the environment, and the anchor is created with the detected trackable. The anchor is then used to hold the virtual object.

The Frame.GetNewPlanes() method provided by ARCore returns the list of reference to all newly detected planes from the current frame. The detected planes grow as ARCore understands the environment, and later, these planes are merged.

The sample application generates different planes with different colors to differentiate between the planes more visible. An object is placed on the plane when the user taps on the screen. The application registers the touch event generated by the user, and a raycast is performed to the plane from the touch position. This action is performed by Session.Raycat() method of ARCore SDK. As a hit with the plane is detected, the method returns true and stores the information about hit point. This information is used to

create an anchor. The virtual object is glued with the anchor, which ensures the object retains its physical location in the real world.

The speed of detection is incredible when the plane has many detailed structures. It was difficult to detect the planes when they had fewer details. The planes are sometimes more extensive than the real plane and at a different height. The height of the planes was incorrectly determined most of the time. Placing an object in the real world is also good enough. The tracking of the object was impressive.

The major limitation of this approach is that the planes cannot be detected at far distance. A simple RGB camera can detect the planes up to 4 to 5 meters. It allows creating an anchor within the short-range which limits to place an object at far distant. This procedure is suitable for the situation where the virtual objects are near to the device camera or user.

4.4.2 Light Estimation

ARcore SDK provides a prefab for environmental light. In general, the prefab reads the estimated light from the environment and saves it called GlobalColorCorrection. This value can be used by the shaders to adjust the color of the object's surface.

In the sample application,Environmental Light prefab is included in the scene which contains EnvironmentLight.cs script, responsible for reading the light estimate from the frame. DiffuseWithLightEstimation shader provided by ARCore use the value from the GlobalColorCorrection and is assigned to the sample object.

The light estimation feature in ARCore helps to make the overall impression of the scene more realistic. Only one GlobalColorCorrection is provided for the whole scene. The object shader can be adjusted as a whole scene, not to the specific position of the virtual object in the Augmented Reality scene.

4.4.3   Using Augmented Image

Object on top of Image

A sample application is developed to test the different features of ARCore while using Augmented Image. The application is designed to appear a virtual object on top of the image when the image is detected.

QR code consists of black squares arranged in a square grid on a white background. These codes can be read by an imaging device such as a camera which made it the first choice of image to use in the application. The score assigned by ARCore is 100 for the QR code.

The image is placed both on the vertical and horizontal planes. The distance between the camera and image depends upon the size of the image.The image should cover at least 40% of the screen in normal environments. In a good lightning room, the size of the image used is 10cm by 10cm, and the distance between the camera and image is 40cm. ARCore is able to track 5-6 pictures at the same time when placed close to each other.

The image detection was fast, and tracking of the object was impressive. The object is fixed on top of the image and does not respond to the moving image. The image has to be rescanned to move the object to the new position of the image. The object is tracked even the image is not visible on the screen. In the test the object is tracked till 15m.

Object away from Image

To put the object at a desired distance from the detected image, two cases are experimented. In one case the anchor was created at the center of the detected image, and the object was transformed to the specific position from the anchor. In another case, the anchor was created at the distance at which the object has to be placed and the object is glued with the anchor. Both approaches have the same result in the placement of the object.

To measure the accuracy, the exact distance from the image is measured, and a spot is marked where the object should appear in augmented reality. The object appears near to the spot but not precisely on the spot. The object is never in the same position, every time there is a displacement in

the position. It is because the ARCore measurement of the distance is not accurate as manual measurement.

The object can also be placed at a distance independent of the image. The image is only used to trigger the event to make the virtual object appear. In this case, the anchor is created at a certain distance without attached to any trackable. The position of the device acts as the origin, and the object depends on the pose of the device. The object is stable in this approach, but the difficulty is that the device should always be at the same distance from the image with the same rotation value. The device is used by the user where the precision cannot be expected due to the human error.

When the object is placed at a distance then the tracking of the object is also effected. ARCore has to cover large area with lots of details to keep the position of the object relative to the real world.

4.4.4   Using Multiple Augmented Images

For the better tracking of the object in vast distances, multiple images are used. Multiple images can be used to provide a position to place the object back into the place.

In this approach, the tracking starts when the ARCore detects the image. The object is placed at a distance away from the image. When the user moves around the area, the object gets displaced from the actual position. The images can be placed on the way towards the object or in different locations around the object so that it can provide a new position for the object. The new position puts the object to the original position if it is displaced while moving towards the object. The position can be a position from the newly detected image or the average position calculated from the total detected images. The new position from the image is better to use than the average position because the average position is not precise.

To test this method, an object is placed 200 meters away in the positive x-direction from the first image. In every 50 meters, a new image is placed, which provides a position of the object relative to itself i.e., the second image will place the object 150 meters away in the positive x-direction. While the object is far from the device position, there is a displacement of position when moving towards the object. The new image introduced will bring the

object back to the original position.

4.5 | Conclusion

ARCore is relatively new, there are many areas where improvements can be done. The platform is actively updated fixing the issues and adding new functionalities in every release. Many startups have come up with innovative ideas to create various AR technologies which indicates high competition. The competition will result to apperance of competitive features. Hence a lot of problems will be solved in the near future.

Chapter 5

Fjell Fortress: A Case Study

After the study of AR and investigation of ARCore features, this chapter will discuss the use technology in case of Fjell fortress.

Norway is home to many cultural heritages, one of them is fjell fortress. It has a great historical background from world war-II. It is located on the top of Fjedalfjellet mountain, in Fjell municipality. Germans built it during second world war to defend the sea entrance to Bergen. It has an impressive underground military base with dormitories, kitchens, washing facility, heating facility, saunas, showers, a center and a network of command bunkers. It also has railways, military equipment, ventilation systems, and advanced electrical installations. The fortress has several bunkers with interesting stories and plays an important role to understand the fortress shown in figure 5.1

During the second world war, Germans used a ship "Gneisenau" for the invasion of Norway. The British force later damaged the ship in February 1942 [28]. The ship had two cannons, one of them was set up at Fjell Fortress. After the war was over, the fortress was taken over by the Norwegian military, and the guns and cannon were scrapped in 1968. The fortress was a restricted area and used as a coastal radar station until 2003. Now the area is made public as a museum and is preserved as a military heritage by The Central Office of Historic Monuments [29]. There are still many types of equipment and structures which are in the original state untouched, but some are rebuilt for safety and preservation purpose.

Figure (5.1)   Overview of Fjell fortress

5.1 | Defining the problem

The top view of the fortress along with the structure of the tunnel underground is shown in the figure 5.1. From the figure it is clearly evident that the fortress is spread over the large.

The circled area on the map are different infrastructures on the ground which are associated with the history of the fortress. These infrastructures have their story to tell about the history. Without a guide it is not easy to visit the whole area and understand the overall structure.

The yellow circle on the map is the location of the cannon which is the main attraction of the fortress. The cannon has been removed now and a cafe is built shown in figure 5.2. Not only the cannon, several other equipments from the past are removed from the location.

The next difficulty during the visit is to understand and connect with the

underground tunnels. The cafeteria is now the main intrance to the tunnels. The cafeteria has stairs which leads to deep under the ground to the tunnels. The tunnels has a complex structure. The tunnels are connected to different infrastructures on the ground at different locations.
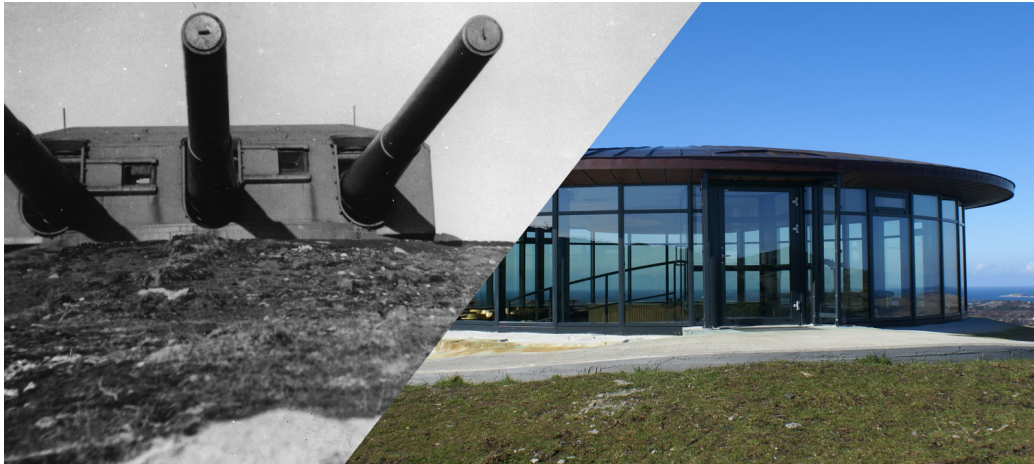
Figure (5.2)   Cafe Build in place of cannon

5.2 | Development Process

The application will include three different features to address the problems described in 5.

- Supplement Reality

- Outdoor Guide

- Indoor Guide

The application is developed in different phases. Initially a standalone application for each feature is developed and tested. The target is to combine all the features into a single application at the end. Each phase describes the development of a feature.

5.2.1 Phase 1

The aim of this phase is to develop a feature to reconstruct the past by providing supplement reality. In the application the constructed 3D objects from the past are superimposed in the real world that has been removed or changed at present. This feature will recreate the past and allow the visitors to see what is impossible to view now.

To place the 3D virtual object in the desired position the possible options are to use HitResult, marker-based AR and location-based AR. When user clicks the screen, ARCore returns the HitResult. A HitResult is either a plane or a feature point and this information is used to create an anchor. It lets the user to place the object anywhere in the environment hence this technique is not suitable to locate the object in the specified position for all the users. As described in ******** marker based AR has the advantage of accurately overlaying the object in the environment. However location based AR is more scaleable and do not rely on markers. Location based AR can be used to provide general information about the location where accuracy is not an important factor.

To superimpose the real object with the virtual object accurate positioning is an important factor. So the markers are used in the application to supplement reality and reconstruct the past. The markers are called Augmented Image in ARCore.

A scene is created in unity. ARCore SDK for unity provides "ARCore Device" and "Environmental Light" for building the AR applications.

ARCore Device creates and initializes an ARCore session. It provides a background renderer to the Unity Camera. It is also responsible for requesting the user to grant permission for using Camera in the application. ARCore Device has two subcomponents ARCore Session and First person camera.

ARCore Session is responsible for handling AR system state and session lifecycles. An image database is created with the list of images that will be used. The session is loaded with the image database so that the session can keep track of the tracked images. ARCoreSessionConfig holds the settings that are used to configure the session.

First Person Camera is the window to the real world augmented with virtual objects. The attached ARCoreBackgroundRenderer uses the camera of the

device to get images of the real world and provides background to the AR scene. The attached TrackedPoseDriver updates the first person camera's local position and rotation to match the real camera pose.

Environmental Light is used to adjust the lightning of the virtual object in the AR scene with respect to the real environment.

A C# script SceneController keeps track of images and checks the state in each frame. The script is responsible for performing the actions in the scene. After a image is detected by ARCore in the scene, an anchor is created. The anchors keeps track of the attached object.

Discussion

Among the different technologies provided by modern AR frameworks markers are considered to overlay the objects to the real world accurately. Hence the markers are used in order to provide supplement reality. However there are certain challanges faced while using the markers. Some of the historic sites and museums restrict to add any additional contents in the environment. The addition of other contents violates the originality of the site. So markers are no use for this situation.

The 3D models can be big most of the times for outdoor use, which makes difficult to place the objects on top of the markers. To get the complete view of the object the marker has to be placed few meteres away from the position depending on the size of the model. The accuracy of markers in overlaying the object is accurate as long as the object is attached on top of the marker. When the object is moved further the marker there is increase in unstability in the position of the object. The scanning of the markers is a mannual work that has to be done by the user. The marker should cover 25% of the device screen for scanning the marker, which includes more task for the user. First the user has to scan the image and after the successfull scanning the user has to turn towards the location where the virtual object is expected to appear. This makes markers not user friendly using in the sites.

Additionally the markers are vulnerable to different lightning conditions and the type of image used as the marker. The markers are need to be scanned by the device camera which uses computer vision to detect the feature points to identify the image correctly. For the cameras to do the task a good lightning

condition is required. The image used sould contain a lot of detail to help computer vision to correctly identify the image. Using markers also lead to change in position of the object if there is change in the position of the marker.

The markers are best suitable for the indoor and controlled environment. They are accurate in positioning the objects in the small and fixed space where the objects are small and can be placed on top of the marker itself.

5.2.2 Phase 2

The second feature in the application is to provide a outdoor guide to the visitor. The outdoor environment is large and use of marker based technology is not feasible. Location based AR will be used to superimpose the supplement information in the real world. A challange with Location based AR is to position the object precisely. This feature is therefore used to provide the general information of the big area where accuracy is not a crucial factor. For this approach, Mapbox is used to get real-world map data and convert the GPS positions into Unity coordinate space.

Abstract Map is a base abstract class provided by mapbox which controls the visualization of map data. It encapsulates the image, terrain and vector sources and provides a centralized interface for controlling the visualization of the map.

Mapbox uses a SimpleAutomaticSynchronizationContext to align the map with the position of the AR camera. This uses the AR position deltas (a vector) and GPS position deltas (mapped to Unity coordinates) to calculate an angle. The basic idea is taking the GPS reading when the application is started and taking another GPS reading after some time. This points can give the walking direction of the user. V1 and V2 are the direction and position defined by AR and GPS respectively and the angle between these vectors is taken as a heading offset. Calculating the heading offset was more reliable and accurate than using compass data.

SimpleAutomaticSynchronizationContectBehaviour is a wrapper around the context which allows to specify settings in the inspector. It is responsible for listening location updates from location provider and adding synchronization nodes to the context. Lastly the result of a successful syncronization offers a

rotation and position offset value which is used to transform the camera in the scene.
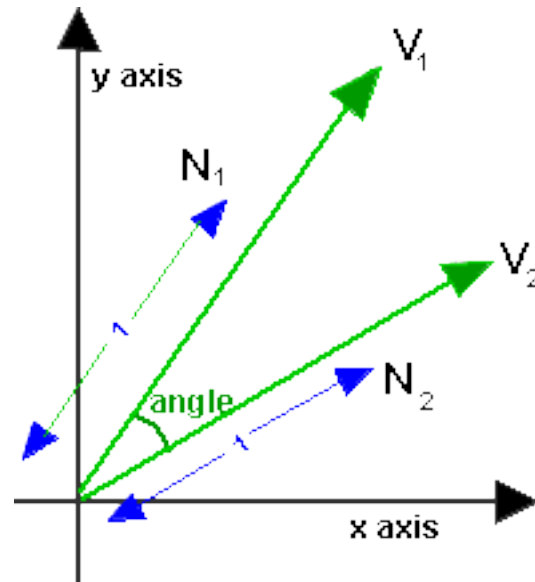

Figure (5.3)   Offset between AR position and Gps position

DeviceLocationProvider object provides the location reading of the device. SPawnOnMap script takes the world coordinates and maps to unity coordinates to place a virtual object in the specified location.

Discussion

The outdoor environment is large and has lots of uncontrolled factors. Location based AR is a good choice to use for outdoor environment because of its advantage in scalability. It does not require any mannual work which makes it user friendly and easy to use. However it needs internet connection to get the location information. The disadvantage of using this technology is that the accuracy depends on the sensors of the device. Getting the accurate orientation value using the earth's magnetic field is problematic in mobile device since its own electronics are interfering.

In the application this feature is used to give the direction and the location information of the POI. With this feature the user will get the information of the visiting spots in the site. During the development of this feature

3D circles were placed at different locations around the university to test the applicability. The objects were found in the intended positions. The coordinates for the POI were taken from google map.

5.2.3   Phase 3

In this phase a feature to an indoor guidance to a visitor is developed. Location based AR uses GPS positions but unavailability of good GPS signals inside the tunnels results in the need to find a good solution for indoor navigations. Several application has been developed and purposed using different sensors and radio signals such as WiFi signals, Bluetooth beacons, NFC, RFID. The problems with these techniques are need of more sensors to be deployed, need for regular maintenance and difficulty in using for users.

ARCore is enabled with motion tracking capability which can be used to track the position of the device. Motion tracking explained in ****** provides the pose of the device. The change in the pose value can be used to graphically illustrate the position of the device on the map.

An image of the floor plan is used as a map to navigate. The relationship between any distance between two points on the map and the correspondent distance in the "real world" should be 1 to 1.This guarantees the distance covered in the physical world is the same on the map. Therefore the map is scaled to the realworld scale.

A 3D sphere is placed at the point, the starting point. The device should be in the same position before the tracking starts. This point can be manually set on the map or markers can be used to initialize the starting point. The markers will tell the application where the device is on the map and this point can be used as the starting point.

A c# script is written to get the pose in every frame update. The delta position is calculated in every frame and this traslation is used to move the sphere on the map. The translation is only applied to X and Z-axes because the tracking is done on the XZ plane and any changes to Y-axis would make the pointer move below the plane.

Discussion

To test the usability of this feature a model of the floor is made and used as a test location. The tracking is impressive in good lightning condition and when the environment has lots of detail. Motion tracking technology works with the computer vision and other hardwares so it needs to find lots of feature points to map the environment. It looses its tracking when the camera is covered and in dark lightning conditions. The camera cannot get the image of the environment to get the feature points. The environment around should have lots of detail, it doesnot work good in the environment with repetative patterns like in corridors. The floor in the corridor has a repetative pattern and the walls hava a plain color no details to get feature points. The overall experience with this feature was that it has a good tracking capability in the small and controlled indoor environment. This will not serve good in the tunnels of the museum because of the low lightning conditions and lack of details. However this feature can be used for other different purposes where the environment is controlled.

Chapter 6

Discussion

This chapter will discuss the overall experience in developing the features of the application. It will describe the challanges faced while using AR technology. A user study at the end of the chapter will provide the effectiveness of the application.

6.1 | The Development of the Application

To get an answer to the research question an application was developed to enrich the visitors experience. Before developing the application the features of a modern AR framework, ARCore was reviewed. The review helped to get the idea of AR functionalities to use while developing the application. During the research the development was split into three phases. Each of the phases were focused on the different features of application.

During the first phase the feature to reconstruct the past by supplementing the real world with the reconstructed virtual objects from the past is developed. This feature used marker based technology to superimpose the virtual object. Markers were used to get some accuracy in placig the object in correct position. The result was good except when the object placed has to be far from the marker.

The second phase focused on the outdoor guide feature of the application. Location based technology was used to provide the location and directional

information along with the general description of POI. Mapbox was used to get the map data and convert the GPS coordinates to unity coordinate values.

Indoor guide feature was developed during the third phase. This feature was focused for the tunnels of the fortress where GPS fails to provide a navigational guidance. It uses the core functionality of ARCore, motion tracking. This feature provides a precise tracking of the device but is limited to controlled environment.

The success of the application would be determined by examinming to what extent these features were able to enrich the visitors experience. Unfortunately the application development was not completed during the time period. Some of the simplifications were made during the development due to lack of experience in unity application development. For instance, simple geometric shapes are used instead of the real models from the scene.

6.2 | Challanges

With the increase of the AR market, lots of vendors are providing their solutions through the development of SDK. These Vendors exaggerate the capabilities of the technology maturity hiding the weakness. They present the videos and description on web to impress the users. This leads the users to get the misconception of the technology which in real is not possible to develop using the frameworks.

As AR has opened a wide range opportunities to build interactive applications. The task of combining the real and virtual is more critical than the VR system. The full potential of AR still faces many technical challanges. Some of them are discused below.

Estimation of Light

Lightning is a difficult phenomenon to study in the real world. It is challenging to estimate the source light and light direction in the real world due to limited available resources. The AR frameworks only gets the average light estimation for each frame, which is used for all the objects in the current

frame. It is not possible to shade each object individually with the different values.

Accuracy

The accuracy of of pose estimation is not sufficient for registration of virtual object in the real world. A small error in registration of object breaks the sense of realism. Simple marker based approach can provide some accuracy but it is not scaleable in large scenarios.

Occlusion

It is one of the biggest puzzle in AR. It is the ability to hide virtual objects by the real objects. If the geometry of the virtual object is not hidden behind the real world objects when it should be, the illusion of reality is broken. The device should be able to sense 3D information from camera (Two Dimensional (2D)) images. Considering this as a hard problem many researchers are working to solve it.

6.3 | User Study

Although the application was not completed to evaluate among the visitors. To get the impression of the features developed, a small study was done with random people. A document with the problems faced in historic site and using AR to solve the problems was described. The description of the solution is based on the features developed in this project. It also provided a small defination of AR for the user who are unaware of the technology. At the end some questions for the reader was provided.

The document was published in different social media groups. Twenty people participated in studying the document and answering the questions within the time period of one week.

Chapter 7

Epilogue

7.1 | Conclusion

This aim of this thesis work was to develop a mobile application investigating the use of AR in museums. From the background review in the initial part of study the need of AR in museums is highlighted. With the review of the AR framework the general capabilities of the framework is identified which helped in the development of the features for the application. During the work of thesis three different features to provide a supplement reality, outdoor guide and indoor guide using AR is developed. Although the development of the application was not completed but the features developed justifies the use of AR in historical sites.

The review of the study conducted shows that AR technology has the potential to be further used in historical sites. This is because the advantages and beneficial use of AR to engage visitors and enhance their visit. These good responses are important because they indicate the willingness of visitors to use the application during the visit. Despite the growing popularity of AR and advancement of technology there are several challanges and issues. When the potential of AR technology is fully explored, the benificial functions of AR can be used widely in providing even better solutions.

7.2 | Future Work

With the exponential spread of AR devices and research works carried out for the development of computer vision and other technologies, the future of virtuality and integration with the physical world is promising. The work presented here is a small step to make use of AR in museums. Based on the result of the study, the application has a good impression among the readers and greater useability in historical sites. This provides a motivation in further research and development of the application.

Firstly, future work is required to develop a reliable application for real world implementation. Research can be done in making the application more adaptable to the environment. Aditionally, the research can be carried out on the different features of application. Further evaluations would need to be performed after the application is fully developed to gather more insight into the users opinions.

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Appendix A

Application Setup

A.1 | Requirements

A.1.1 Hardware

- An Arcore supported phone.
- A USB cable to connect the phone to the device.

A.1.2 Software

- Unity 2017.4.15f1 or later with Android build support during installation.
- Android SDK 7.0 or later.
- ARCore SDK 1.6.0 or later.

The features of PC that is used in developing the application. It is not mandatory to have the following requirements.

- OS : windows 10 Home 64-bit
- Processor : Intel(R) Core(TM)i7-7700k CPU @ 4.20GHz
- RAM : 32867 MB

- Graphics : NVIDIA GeForce GTX 1080 Ti

- Graphics memory : 27441 MB

A.2 | Setting up the Unity project for ARCore

A 3D project is created in Unity and the path for the Android SDK is set **Unity>Preferences>External Tools**. ARCore SDK is also imported **Assets>Import Package>Custom Package**, provides some sample applications to test how the technology works.

Load the scenes in the project and select the scene to install in the device and switch the platform to android **File>Build Settings**. Use "Player Settings" to change the options:

- Other Settings > Multithreaded Rendering : **off**

- Other Settings > Package name : **a unique app ID**.

- Other Settings > Minimum required API level : **7.0**

- Other Settings > Target API level : **7.0** or **highest installed**

- XR Settings > ARCore Supported.

A.3 | Pictures of Fortress

Figure (A.1) Detailed map of the fortress

HOVEDTUNNEL
A1 - Hovedinngang
A2 - 3 x 28 cm kanontårn
A3 - MG SK maskingeværbunker
A4 - R 633, tilknyttet hovedtunnelen
A5 - 35P8 kuppel for to MG, tilknyttet hovedtunnelen
A6 - S 446, tilknyttet hovedtunnelen
A7 - SK Inngang nord
A8 - SK Inngang vest
BATTERISIKRING
01 - 2 x R 672 Pakgarasjer
02 - R 629SK tilknyttet tunnel og observasjonskuppel
03 - Bunker
04 - 2 x R 638 sanitetsbunkere
05 - R 632 for MG
06 - 2 x R 633
07 - R 621
08 - 2 x R 668
09 - Rs 58
10 - Byggegrop
11 - Brakkefundamenter/grunnmur
AMMUNISJON
M1 - Ammolager med to inn-/utganger og nærforsvar
M2 - Ammolager
M3 - Ammolager, U-formet
LUFTVERN
F1 - 6 x Stillinger for 10,5 cm Flak
F2 - Avstandsmåler
F3 - 6 x Fl 242
F4 - 2 x stillinger for lyskaster eller lett luftvern
F5 - R 622 med stilling på taket
F6 - Feltmessig forsterket ammolager
F7 - Garasje
F8 - Strømforsyning/aggregat
F9 - luftvernstilling (nord)
RADARSTILLINGER
R1 - Würzburg Riese / FuMo 214
R2 - Freya Freiburg, med "Radattel" peiler / FuMO 303
R3 - Würzburg Dora / FuMO 213
INFANTERISIKRING
I1 - Løpegraver med 2 x Rs 58 + 2 x Rs 61
I2 - Løpegraver med 5 x Rs 58 + 1 x Rs 61
I3 - Liten tunnel, kanonstilling og løpegraver
     med 2 x MG-stillinger + Rs 58
I4 - Løpegraver med 4 x Rs 58 + 2 x Rs 61 + MG-stilling
I5 - Løpegraver med 3 x Rs 58 + 1 x Rs 61 + 1 x mannskapsbunker

MAIN TUNNEL SYSTEM
A1 - main entrance
A2 - triple gun turret
A3 - MG bunker with steel plate
A4 - R 633 with emergency exit
A5 - 35P8 steel turret for two MG
A6 - S 446 fire control bunker
A7 - Exit north
A8 - Exit west
MAIN BATTERY DEFENCE
01 - 2 x R 672
02 - R 629 connected via a tunnel to an observation cupola
03 - 2 x Fl 242 light AA gun bunkers
04 - 2 x R 638 first aid bunker
05 - R 632 bunker for one machine gun in a steel turret
06 - R 633 for grenade launcher M19
07 - R 621 crew shelter
08 - 2 x R 668 crew shelter
09 - Rs 58
10 - Building area
11 - Barrack foundations
AMMUNITION DEPOT
M1 - U-shaped underground system with two entrances
M2 - ammunition
M3 - U-shaped underground system
HEAVY AA BATTERIY
F1 - 6 open emplacements for 10.5 cm SKC/32 guns
F2 - Fire control post
F3 - 2 x Fl 242 light AA gun bunkers
F4 - 2 x searchlight position
F5 - R 622 with emplacement on the rooftop
F6 - Vf ammunition bunker
F7 - Garage
F8 - Power generator
F9 - AA emplacement north
RADAR
R1 - Würzburg Riese / FuMo 214
R2 - Freya Freiburg, with "Radattel" detector / FuMO 303
R3 - Würzburg Dora / FuMO 213
INFANTRY DEFENCE
I1 - Trench system with 2 x Rs 58 and 2 x Rs 61
I2 - Trench system with 5 x Rs 58 and 1 x Rs 61
I3 - small underground system, emplacement for anti tank gun,
     trench system 1 x Rs 58 and 2 x MG position
I4 - trench system with 4 x Rs 58 and 2 x Rs 61and 1 x MG position
I5 - trench system with 3 x Rs 58, 1 x Rs 61 and a small crew shelter

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Figure (A.2)   Data about the map from A.1

Kart over tunnelanlegget
1 - Hovedinngang
2 - Nærforsvar med 4,7cm Pak(t)
3 - Generator
4 - Tårnsjakt / trippeltårn
5 - Mannskapsforlegning
6 - MG-Kasematt
7 - Sykestue
8 - Kjøkken
9 - R 633 for granatkaster M19
10 - Kommandobunker S 446
11 - 35P8 Panserkuppel med 6 skyteskår
12 - Utgang nord
13 - Utgang vest

Map of the main tunnel
1 - Main entrance
2 - Entrance defence with 4.7cm PAK (t)
3 - Generator
4 - Turret shaft / Gunturret
5 - Crew rooms
6 - Machine gun casemate
7 - Sick rooms
8 - Kitchen
9 - R 633 grenade launcher for M19
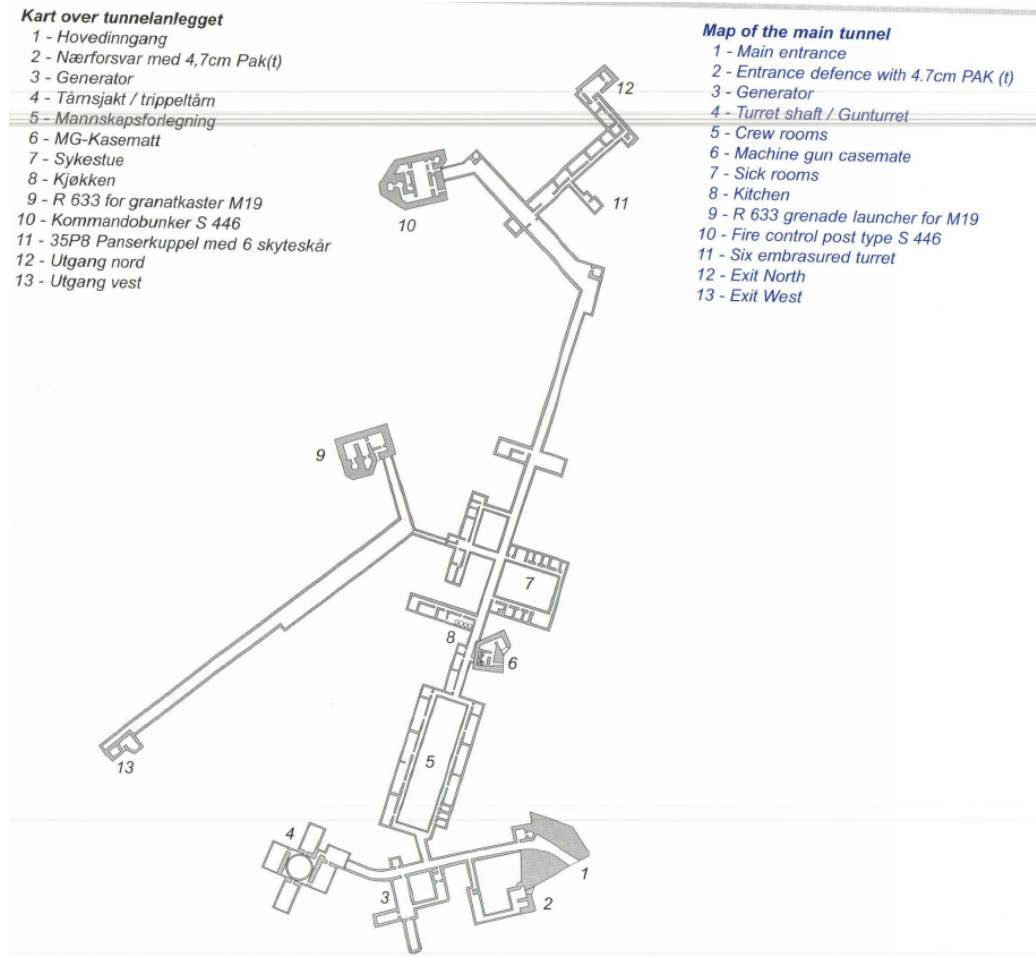10 - Fire control post type S 446
11 - Six embrasured turret
12 - Exit North
13 - Exit West

Figure (A.3)   Map of tunnel