YAŞAR UNIVERSITY
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MASTER THESIS

IMPLEMENTATION OF AN APPLICATION USING AUGMENTED REALITY ENVIRONMENT

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ABSTRACT

IMPLEMENTATION OF AN APPLICATION USING

AUGMENTED REALITY ENVIRONMENT

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Augmented Reality (AR) has begun to be widely used in various fields along with the advancing technology of our age. AR combines the real world image with the virtual image in order to assist learners in technology-based educational systems. The perception of AR systems in education field seems to attract more people in recent years. one of the areas that draw attention is medical education. In this thesis, AR technologies were investigated in order to explore how AR can be used for human anatomy teaching in medical education. The concept of AR systems and mathematical background were given. Then a prototype was built with Unity and Vuforia to demonstrate different ways to interact with a 3D object with AR. Certain human body parts have been visualized via AR application and presented to the learners as in mobile use.

Key Words: Augmented Reality, Virtual Reality, Computer Vision

ÖZ

ARTIRILMIŞ GERÇEKLİK ORTAMI KULLANILARAK BİR UYGULAMA GELİŞTİRİLMESİ

AK, Vedat Can
Yüksek Lisans Tezi, Bilgisayar Mühendisliği
Danışman: Dr. Öğr. Üyesi İbrahim ZİNCİR

TEMMUZ 2018

Günümüzün ilerleyen teknolojisiyle birlikte Artırılmış Gerçeklik (AG) çok farklı alanlarda yaygın bir şekilde kullanılmaya başlanmıştır. Teknoloji destekli eğitim sistemlerinde öğrenenlerin anlamalarını kolaylaştırmak amacıyla, AG gerçek görüntü ile sanal nesneleri birleştirmektedir. Son yıllarda, özellikle eğitim alanında AG ile yapılan çalışmların dikkat çektiği görülmektedir. Bu tezde, AG teknolojilerinin insan anatomisi eğitiminde nasıl kullanılabileceği araştırılmıştır. AG çalışma şekli ve arkasındaki matematiksel yöntemler açıklanmıştır. Son olarak, Unity ve Vuforia kullanılarak kullanocaların 3 boyutlu objeler ile etkileşime girebilceği bir prototip uygulama geliştirilmiştir. Bu prototipte insan vücudunun bazı organları AG kullanılarak görselleştirilmiş ve mobil cihaz üzerinden öğrenenlerin kullanıma sunulmuştur.

Anahtar Kelimeler: Artırılmış Gerçeklik, Sanal Gerçeklik, Bilgisayarlı Görü

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I would like to express my enduring love to my parents, who are always supportive, loving and caring to me in every possible way in my life.

Vedat Can AK

İzmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled "IMPLEMENTATION OF AN APPLICATION USING AUGMENTED REALITY ENVIRONMENT" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Vedat Can AK

Signature

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August 8, 2018

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

SDK Software Development Kit

IDE Integrated Development Environment

AR Augmented Reality

VR Virtual Reality

SYMBOLS:

P Location coordinates of a point

S Scaling factor.

t The distance for translating the point

$\mathbb{R}^3$ 3D vector space of Real numbers

1. INTRODUCTION

Augmented Reality (AR) is the technology that integrates the information obtained from the real world with the digital information that has been generated by computers. AR basically combines 3 dimensional (3D) objects designed by computer aided graphics with the real world images. It adds virtual objects as a layer on top of real images by enabling interaction to the generated scene in real-time. (Amin & Govilkar, 2015). This characteristic of AR makes it different from Virtual Reality (VR), in where the user is totally immersed by a 3D environment that is generated by the computer graphics (Azuma, 1997). Unlike in VR, both the real world image and 3D objects can be seen in the same space in AR. Figure 1.1 shows how VR and AR work. The first picture is a real world image taken by a digital camera. There is no extra layer of computer graphics added on to it. The second picture is an example of AR environment. The same picture as in the first one is taken but an extra layer of 3D computer aided design is added on to the real world image. The yellow car is designed by computer graphics and is added to the real world image. The third picture is a VR example. There is no real world image in it. Everything is designed with a 3D computer graphics.

Figure 1.1. *Reality, Augmented Reality, Virtual Reality*
(Virtual & Augmented Reality for Engagement, 2017)

According to Azuma (1997), AR systems have these three characteristics in common: combining the real world and virtual world environments, providing a real time interaction to the users, and they all being registered in 3D space.

AR technologies can differ according to the fields and purposes in which they are used. Some AR systems require Head Mounted Displays (HMDs) and others Handheld Displays (HhDs). For the former, special head or eye worn devices were developed. For the latter, any monitor or screen of a phone, tablet or computer is enough (Kesim & Ozarslan, 2012). Figure 1.2 shows the examples of HMDs while Figure 1.3 shows HhDs.

a) (FUJITSU UBIQUITOUSWARE Head Mounted Display IOT001. (n.d.), 2018)

b) (Are Smart Glasses the Future for AR and VR? (n.d.), 2018)

Figure 1.2. *Head Mounted Displays (HMDs)*

a) (Nieuws, 2017)

b) (Robbins, 2015)

Figure 1.3. Handheld Displays (HhDs)

Some AR technologies do not provide an interaction with the user, such as AR in movies. In these environments the virtual objects seem blended with the real environment in 3D yet the audience cannot interact with them (Azuma, 1997). On the other hand, there are AR technologies that allow interaction with the users. For example, the AR environments designed for education help learners to see the objects in 3D and to explore them by rotating or moving them around (Kesim & Ozarslan, 2012).

AR increases the perception and interaction of the user with the virtual objects displayed in a real world image. It helps the user to obtain information from the digital environment that he/she cannot detect with his/her own senses. For these reasons, AR technologies continue to be developed.

1.1 Motivation

Human-computer interaction is a discipline dealing with design, implementation and evaluation of interactive systems for the use of people along with the wide study areas to investigate. Augmented Reality is one of the technologies that use human-computer interaction (Schuemie, 2003). In augmented reality, virtual reality elements are combined with environment in real world. This makes it look like there are virtual objects in the real world. As mentioned in previous section, augmented reality has a use in various fields that includes education, military or daily life activities.

In these days, human anatomy is still taught by using textbooks and dissections. Pictures and diagrams commonly used for making it easier to understand. In this area, an augmented reality application has great potential to be beneficial for anatomy teaching. By using 3D visualization of the human body parts, students might easily understand human anatomy.

1.2 Aim and Goal

This thesis will investigate potential use of augmented reality in human anatomy and investigate about augmented reality technologies, how augmented reality interacts with real world. Furthermore, it will look into tools that will be used in development of augmented reality.

The goal of this thesis is to develop a prototype application that provides 3D visualization of some part of human anatomy, allowing users to manipulate object with few different ways. To reach this goal, following questions are established:

- Is AR good option for teaching human anatomy?
- What are the benefits and drawbacks in Augmented Reality for teaching human anatomy?

1.3 Literature Review

According to Karray, Krid, & Sellami (2016), studies on AR began in 1960s. In 1965, Ivan E. Sutherland wrote an essay about creating a VR environment through an ultimate display. Shortly after this essay, in 1968, he constructed an HMD by which the user can view and move among the virtual elements in a real world environment.

Since then studies on AR have been done in many fields including education, medicine, military, robotics, manufacturing, architecture, maintenance and repair, navigation, entertainment, etc. (Kesim & Ozarslan, 2012). The following provides a general idea about the state-of-the-art studies done in AR.

Medical field has been one of the major study and application fields for AR. Bajura, Fuchs, & Ohbuchi (1992) scanned the womb of a pregnant woman with an ultrasound sensor, generated a 3D representation of the fetus based on the ultrasound data and displayed this 3D representation on the belly of the patient through a HMD. Their goal was to lay a foundation for a 3D stethoscope for doctors in analyzing the move of the fetus inside the womb. Grimson et al. (1994) developed an automatic technique for clinical data obtained by Magnetic Resonance Imaging (MRI) or Computed Tomography (CT) with a view of the patient on the operating table. They also showed the application of this technique on a neurosurgery. State et al. (1996), analyzed 50 biopsies on a breast cancer surgery. In 25 of these biopsies AR technology was used. According to the results, State et al. (1996) assert that identifying the tumor and guiding the biopsy needle to its target with the help of AR statistically improved the accuracy of the operation. Wen et al. (2014) proposed a cooperative surgical robot system, guided by hand gestures and supported by AR-based surgical field, for robot-assisted percutaneous treatment. Ribeiro, J. M. T., Martins, J., & Garcia, R. (2018) proposed an AR platform that assists health care professionals how to use and control the medical equipment in their treatments or surgeries. This AR platform allows users to be able to obtain real-time data during a medical procedure. This AR platform was applied in a specific field. According to the authors, the obtained results showed that this AR platform can be used as a support tool for medical activities. Tang et al. (2018)

developed an AR method which improves the AR approach of delivering workstation-independent radiological screening training. This new AR method contributed to more realistic effects and the impacts of environmental illumination. This method also provides a real time recording, computer-based analysis of training data. According to the authors, this new AR model accurately located user-drawn points with 80% success. Besides these studies, there have been many other AR studies done in medical area (especially on displaying MRI and CT data directly registered on the patient) and these studies continue to develop.

In military field, AR has begun to be used for training and in operations. Soldiers are given a wearable computer and HMDs and send to the training areas. This way, it is desired to see soldiers improve in accomplishing their tasks, help trainers to get real time data from their trainees so that the can intervene the situations in real time. Furthermore, some military aircrafts and helicopters have used Head-Up Displays (HUDs) and Helmet-Mounted Sights (HMS) in order to display information on the pilot's view of real world. This information contained navigation, flight information, targets as well as the interaction of the pilot with the aircrafts' weapons (Sutherland, 1965 and Azuma, 1997). Mao, Sun, & Chen (2017) analyzed the effects of an AR system, which imported Army Command and Staff learning methods, on officers' situational awareness and intentions. The experiments on 40 officers demonstrated that the perceived usefulness and perceived ease of use of this AR system had a comparable effect on the attitude of the officers.

AR has been applied in different areas in educational field, as well. University of Utah made a project for teaching molecular biology using AR to high school students. Furthermore, developers and researches in Switzerland established a virtual chemistry laboratory for students to observe atoms and create molecules by dragging and combining these virtual atoms. A group of researchers at the University of Singapore developed an AR system that mimics the moves of the dancers and lets its users analyze the actions of the dancers (Shelton & Hedley, 2004). Thomas, John, & Delieu (2010) developed a system called the Bangor Augmented Reality Education Tool for Anatomy (BARETA), which combines AR technology with models produced by using Rapid Prototyping technology. This system allows students to touch as well as see the objects in AR. The major goal of this work was to provide a more intuitive interface and to evaluate the support of this system to the traditional cadaver based education.

Akçayır & Akçayır (2016) demonstrated that AR technology both improves the laboratory skills of university students and assists them to develop positive attitudes concerning their laboratory work. Behmke et al. (2018) built an AR application with Aurasma app in order to visualize molecules in 3D for university students. The professors asked questions to their students via this developed AR application and the students could find the correct answer by analyzing the molecules shown in the AR application. According to the experimental results, Behmke et al. observed that the students answered the questions by using the AR application were roughly 5% more successful than the ones who did not use the AR application. There has been numerous AR studies done in the educational field. The advantages and challenges of the AR technology in education is still discussed. New developments in AR techniques in education continue to be provided (Akçayır & Akçayır, 2017).

AR technologies have also begun to be used in robotics area. The ARGOS system was developed to compare robot path planning with AR versus traditional monoscopic interfaces. The studies being done with the ARGOS demonstrated that stereoscopic AR provided an easier and more accurate way in robot's planning than the traditional one (Milgram et al., 1993). Peng et al. (2018) developed a Robotic Modeling Assistant (RoMA) which provides its users a modelling experience with AR technology. While the user sees and designs a model of a 3D image, a printing robotic arm of RoMA constructs the same design on a 3D printer. Brizzi et al. (2018) used an AR tool for improving the learning process of the learner in remotely controlling the Baxter robot. The authors claim that AR tool used in this process shortened the learning time of the learner and overcame the differences in perception between telepresence and actual presence.

There have also been AR applications and studies done in designing, maintenance and repair. A group of researchers at Boeing company developed an AR technology for helping their electric technicians in constructing the wire harness of the airplane's electrical system. This AR technology helps those technicians to see the instructions better, save space and reduce the cost for their experiments (Sims, 1994). A group of researchers at Columbia developed an AR system that instructs users in carrying out the maintenance of a laser printer (Azuma, 1997).

Entertainment area has also adopted AR technologies. Thomas, John, & Delieu (2000) developed an AR first person application called ARQuake. This application is the AR version of the classical Quake game. It tries to provide an environment to the gamer in which he/she gets the feeling of playing the Quake game outdoor as first person. Pokemon Go is one of the famous examples of AR technology in games. It took the attention of many young people in a short time. Despite its entertaining characteristics, many researchers began to explore the effects of these AR games on users (Rauschnabel, Rossmann, & Dieck, 2017). Samir et al. (2018) developed an AR game named The Wanderer, which improves the object position awareness by combining geolocation methods with object detection algorithms. These methods and algorithms use markerless augmented reality algorithm object detection. According to the authors, this game has a potential of including real and existing stores and places into the game.

Büschel, W., Vogt, S., & Dachselt, R. (2018) used AR application in LAN and network link capacities and connectivity levels. They visualized the nodes, connections between these nodes and their edge attributes via this AR application. They explored the suitability of various data encodings on network links. Zaher, M., Greenwood, D., & Marzouk, M. (2018) developed an AR application named BIM-Phase which visualizes and informs about the construction progress. The authors suggest that the use of BIM-Phase application in a specific case has provided an improvement in time, cost and quality in construction process.

2. HOW A SIMPLE AR WORKS

AR system architecture vary depending on the device and programs used in it. The simple version of it, however, consists of a camera, computational unit and a display (Siltanen, 2012). Basically, the camera captures the real world image. Computational unit generates 3D virtual images, add them on the real world image, and respond to the user's interactions. Display device shows the result of the AR system. Figure 2.1 shows the flowchart of a simple AR system.

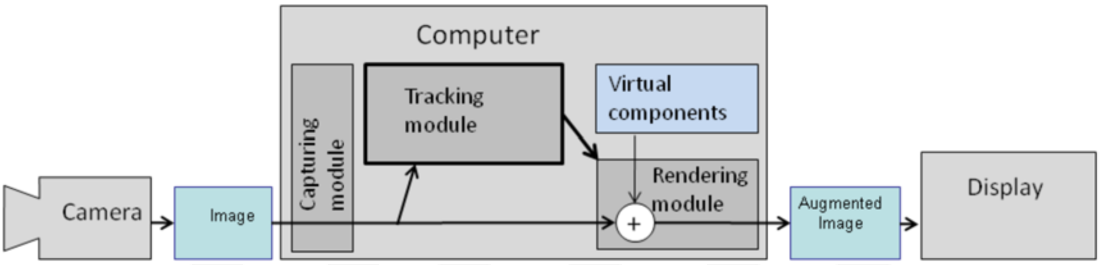

Figure 2.1. A Simple AR Flowchart (Siltanen, 2012)

The major work of AR is done in the calculation unit. This unit has several components. Capturing module constantly captures the real world image data from the camera. Tracking module calculates the location of the 3D virtual components generated by the system. Finally, rendering module augments the real world image with the virtual components on their correct locations. This rendered image is then displayed on the display image (Siltanen, 2012).

Although each part in computational unit has a unique role in the system, the tracking module plays a central role. It is responsible for calculating the relative pose of the camera in real time. Pose of an object in this system refers to the 6-tuple geometric information about the object (Figure 2.2). The first three data in the tuple give the Cartesian coordinates of the object's location in 3D space, while the last three represents the orientation angles of the object with respect to the 3D coordinate system in AR. The tracking module helps the rendering module to add the extra layer of virtual components on their exact location in the real image

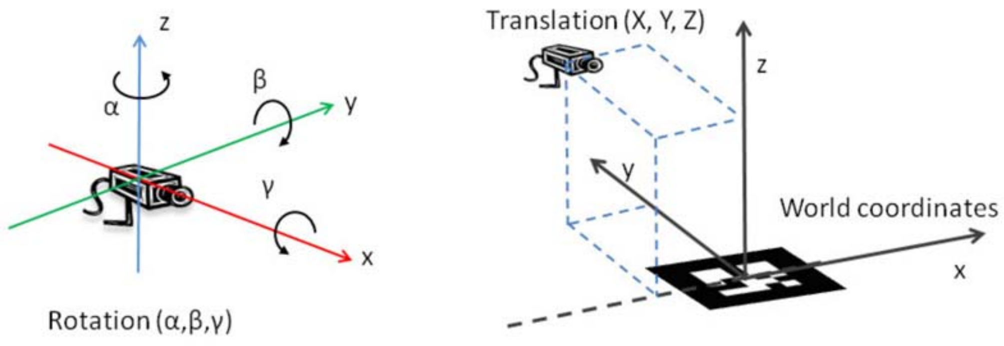

Figure 2.2. The pose of an object in 3D space (Siltanen, 2012)

Projective geometry plays a crucial role in calculating the pose of the virtual objects. Projective geometry defines and describes the 3D space with its projections. In other words, 3D space is transformed into 2D space with scaling, rotation and translation methods in projective geometry (Figure 2.3).

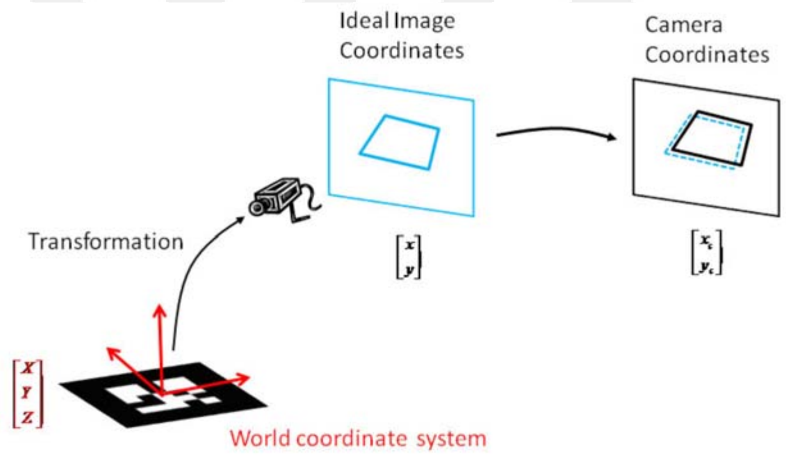

Figure 2.3. Transforming images from 3D to 2D (Siltanen, 2012)

Transformation methods (i.e. scaling, rotation and translation) are done via matrix operations in 3D space first and then the result is projected to 2D space. Each transformation method is represented by its own matrix and each point of the 3D virtual object is projected by the multiplication of its coordinates with the transformation matrices. Let the location coordinates of a point P in 3D space is represented as $P = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \in \mathbb{R}^3$.

Scaling matrix in 3D is $\begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & S_z \end{bmatrix}$. Here S_x, S_y and S_z are the scaling factor for scaling the object in x, y or z axes respectively. Hence, the new coordinates of the scaled point is calculated as $P' = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & S_z \end{bmatrix} . \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$.

Rotation in 3D can be done in x, y, z, or any combination of these three axes. Rotation matrix for x-axis is $\begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & sin\theta \\ 0 & -sin\theta & cos\theta \end{bmatrix}$, y-axis is $\begin{bmatrix} cos\theta & 0 & -sin\theta \\ 0 & 1 & 0 \\ sin\theta & 0 & cos\theta \end{bmatrix}$ and z-axis is $\begin{bmatrix} cos\theta & sin\theta & 0 \\ -sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$, where θ is the rotation angle on the axis. Therefore, the new coordinates of the point rotated on x-axis is $P' = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & sin\theta \\ 0 & -sin\theta & cos\theta \end{bmatrix} . \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$. The same process can be done for other axes with the respective rotation matrix multiplication. The point P can be rotated on multiple axes' with different angles at the same time. Then it must be multiplied by the respective rotation matrices consecutively. An example of rotating the point P on the xy-axes would be,

$$P' = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & sin\theta \\ 0 & -sin\theta & cos\theta \end{bmatrix} . \begin{bmatrix} cos\varphi & 0 & -sin\varphi \\ 0 & 1 & 0 \\ sin\varphi & 0 & cos\varphi \end{bmatrix} . \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}.$$

Translation matrix in 3D is $\begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \end{bmatrix}$ where t_x, t_y and t_z are the distances for translating the point P in 3D space. Therefore, the new coordinates of the translated point is

$$P' = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \end{bmatrix} . \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}.$$

These transformation matrix operations are done in 3D space. The positioning, moving or scaling of the virtual objects all take place in 3D space. However, the capturing and displaying components of AR are in 2D space. Therefore, a transformation from 3D space to 2D space and vice versa are needed for the AR system. Projective geometry plays role in this transition, as well. At each stage of converting from 3D to 2D and vice versa, there is a transformation matrix that is multiplied by the current coordinates of the system. Here is a general structure of converting real image coordinates to display coordinates in AR system:

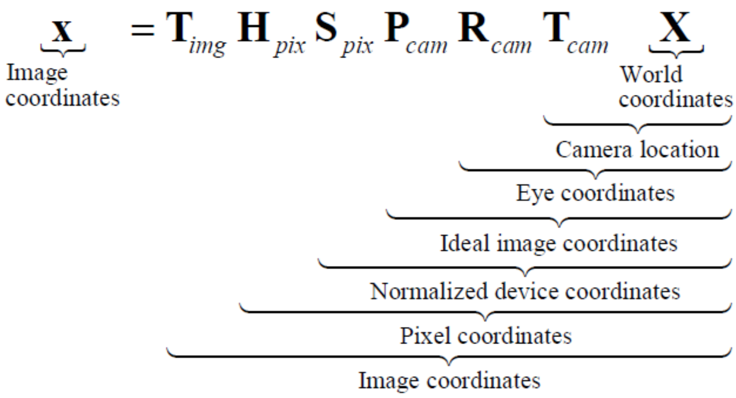

Figure 2.4. Transformation Process from Real World Image to Display Image (Siltanen, 2012)

2.1 Marker Based Tracking in AR

The location and orientation of the virtual objects in AR are calculated by the mathematical calculations in real time. Determining the pose of the camera and these objects can be done in many ways. The most common method is using markers. Markers are reference point images on which the virtual objects are displayed. Good markers should be easily detectable under any circumstance. Generally, markers are preferred in black and white (Figure 2.5). This is because differences in brightness are more easily detected by cameras than the differences in color (Siltanen, 2012).

Figure 2.5. A Black and White Marker (Pneumonia Follow, 2014)

Marker detection and tracking consists of several stages. First, the objects in the space are detected via image processing. Then, the distortion in captured virtual object images are removed. The corners of these objects are detected by line fitting methods. Next, the marker is to be detected out of all the other detected objects. All the detected images are compared with the marker template that was identified to the AR system as marker at the beginning. The most matched detected image is the marker. From now on, the virtual objects are displayed on this marker in real time (Figure 2.6).

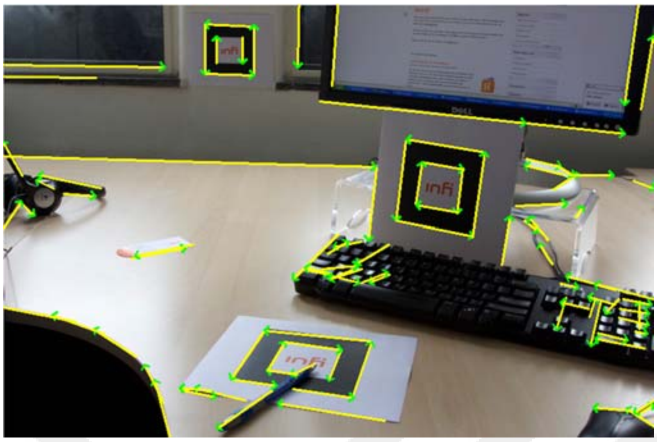

Figure 2.6 Detecting Markers (Ons nieuws. (n.d.), 2018)

2.2 AR Frameworks

There are many frameworks that help coders and users to build up their own AR programs and applications. Writing everything in an AR system from scratch can be done but it would be reinventing the wheel with unnecessary workload. On the other hand, the existing frameworks provide powerful tools and make it simpler to program in AR. They also regularly update their codes which expands the productivity and efficiency of their users. The following chart provides a detailed comparison of current AR frameworks.

	ARToolkit	Vuforia	ARmedia	XZIMG	Kudan AR Engine	Wikitude
Type	Open Source	Free + Commercial SDK option	Free + Commercial SDK option	Free + Commercial SDK option	Free + Commercial SDK option	Free + Commercial SDK option
iOS	✓	✓	✓	✓	✓	✓
Android	✓	✓	✓	✓	✓	✓
Marker	✓ Basic	✓ Advanced + VuMark	✓	✓	✓	✓ Advanced
NaturalFeature	✓	✓	✓	✓	✓	✓
Windows Mobile	✓	✓ Vuforia now available for windows app dev & also for MS Hololens	– Soon		✓	✓
Web		✗	✓	✓ HTML5	✗	
PC/Mac/Linux	PC/Mac/Linux		ARmedia supports PC/Mac and Linux	via Unity/Native	Cros-platform development Unity3D	
3D Object Tracking	✗	✓ Only on box and cylinder and small size 3D objects too	✓	✓ Beta	✓ SLAM	✓
GPS		✓	✓		✓	✓
IMU Sensors		✓	✓		✓	✓
VisualSearch		✓		✓	✓ unlimited local visual search (no network connection required)	✓ Cloud Recognition and Offline (on device)
FaceTracking		✗	✗	✓	– Extensible with FT/FR Plugins	– Face Detection
ContentAPI		✓ With Vuforia Cloud		✓		✓ with Wikitude Studio and Cloud Recognition
Unity (3D)	✓	✓	✓	✓	✓ With SLAM	✓ 3D Tracking included
Plugins API						Integration with 3D party libraries available
Website	artoolkit.org	vuforia.com	inglobetechnologies.com	xzimg.com	kudan.eu	wikitude.com

Figure 2.7. Comparison of AR Frameworks (AR frameworks. (n.d.), 2018)

3. DEVELOPING AN AR APPLICATION FOR ANATOMY EDUCATION

In this thesis, it is aimed to visualize human body parts in an AR system in order to assist users related to medical education. For this purpose, Unity3D game engine and Vuforia AR framework were used. The 3D models which were used in the program were obtained from the designers that shared their works on the non-commercial and free license web sites (i.e. Sketchfab).

3.1 Unity3D

Unity3D is a cross-platform game engine developed by Unity Technologies (http://unity3d.com). It allows its users to build games or animations in 2D or 3D. It has its own built-in IDE and gives opportunities to export developed applications to various platforms such as iOS, Android, Windows, Mac OS, etc. The programming languages C# and JavaScript are supported by Unity3D. Users can develop parts of their applications in any of these languages. Unity3D supports Direct3D, OpenGL and WebGL.

The editor of Unity3D has a drag and drop functionality (Figure 3.1). Users can add and remove objects to the scene, control the camera and light positions, add effects to the scene, and apply fundamental physic laws such as gravity, rotation, translation, scaling, etc. Unity3D does not include 3D model design and yet it allows importing models from 3D modeling applications such as 3D max, Maya, Blender, etc.

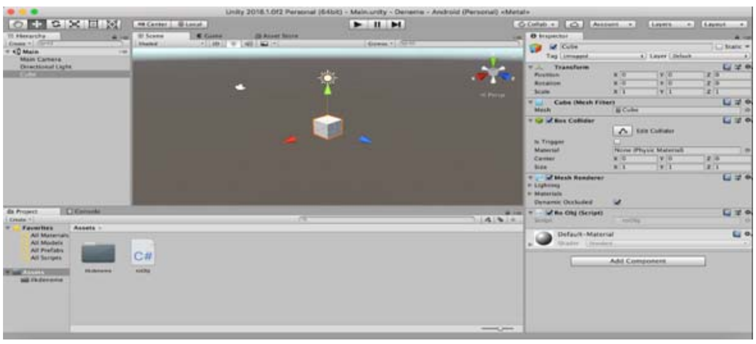

Figure 3.1. Unity3D Editor

3.2 Vuforia

Vuforia is one of the most common AR SDKs for mobile devices. It enables detecting and tracking 2D and 3D models in real-time via the Computer Vision technology it uses. Vuforia SDK uses both marker or markerless tracking and multi target configurations. It also supports image targets and virtual buttons.

Vuforia SDK can be built in native environment for iOS and Android, and also be imported into Unity3D for cross-platform development. Figure 3.2 shows the Vuforia SDK architecture.

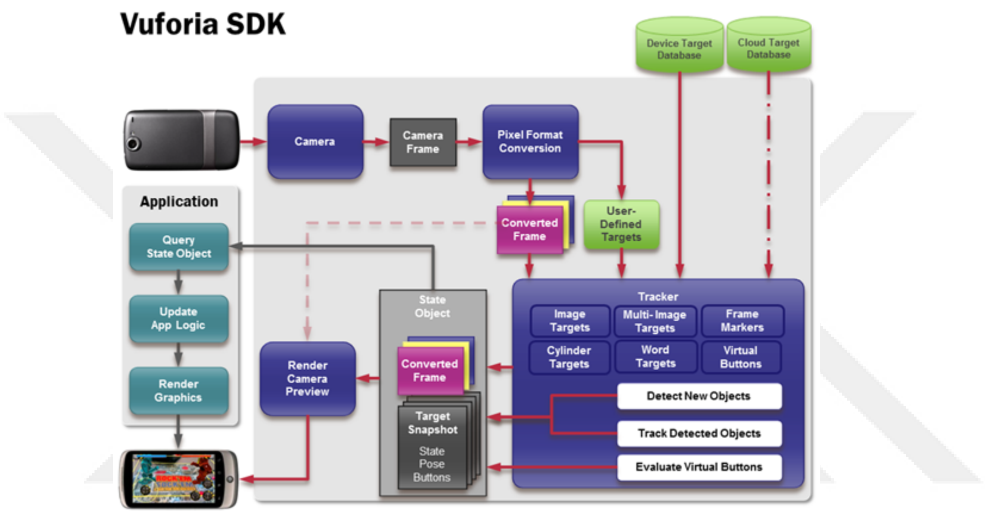

Figure 3.2. Vuforia SDK Architecture (Grubert & Grasset, 2013)

3.3 Implementing prototype

In this thesis, the prototype was implemented for Android. The purpose of building this prototype is to determine how AR can be used for human anatomy education and how this prototype can be used together with current teaching methods. The flowchart of overall process of developing this prototype is presented in FigureFlowChart below.

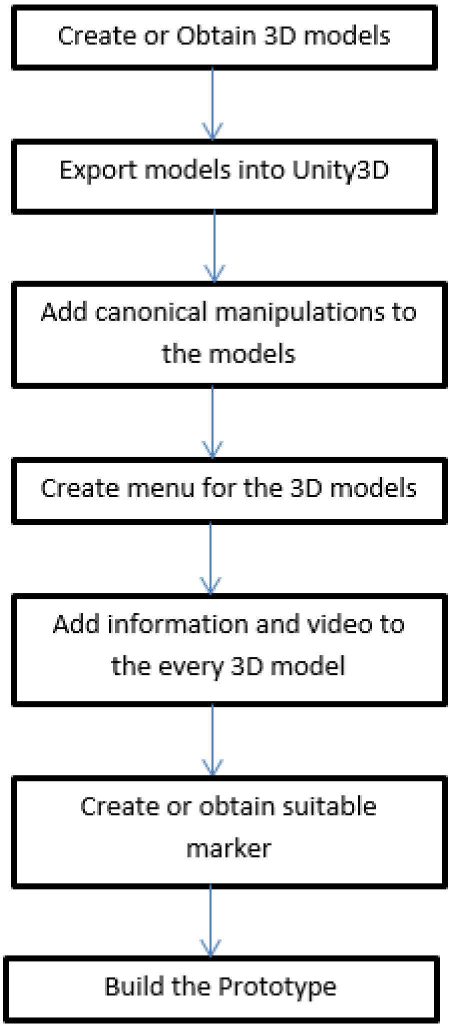

Figure 3.3. Flowchart of Developing The Prototype

At the time of design in this prototype, two primary requirements that should be satisfied were defined to build a useful prototype:

- Reliable and Stable: For building stable and reliable software, frameworks that are small or driven by the community for building AR application are not the best choice. Usually, Big companies most of the time offer the best software quality with well-prepared documentation. However, this quality brings some limitations to use of software such as trial time and restriction of some functionality.

- Free or free for non-commercial use: in order to not to break any laws, elements, tools, and frameworks that are used in this prototype should be free or at least free for non-commercial use.

Considering those two requirements to fulfill, available choices for frameworks are not much. Most of the frameworks have a paid license. Though, there is one AR framework that is free for non-commercial use. It is Vuforia, as previously mentioned, Vuforia offers a well-established framework for developing AR applications. For these reasons, instead of coding in a native programming language, Vuforia SDK was used to build an AR system. The developed AR system uses a marker based tracking. An image has to be uploaded to the Vuforia Developer Portal to obtain a trackable marker for the AR system. After providing the image to Vuforia, it adjusts the image for given size and uses its algorithm to find certain points in the image for recognition. After that, it rates the image to indicate how good is the given image for tracking. Figure 3.3 shows the example marker and the rated result of marker.

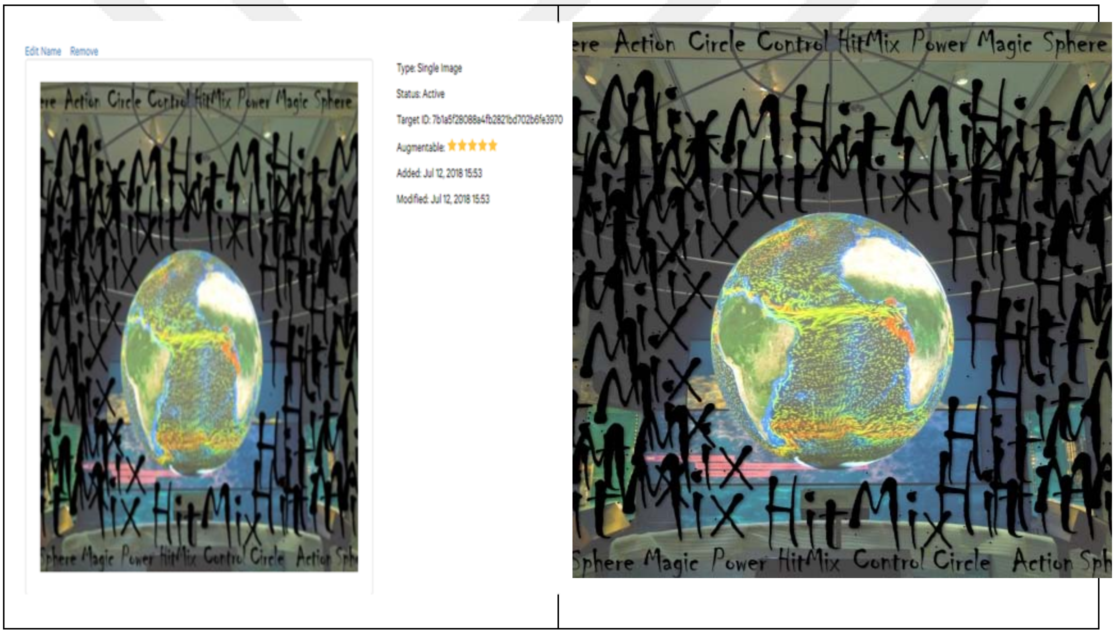

Figure 3.4. Example Marker used in the AR system in this study

Vuforia has tracking algorithm that uses scale-robust corners of the image extracted with a modified version of FAST (Features from Accelerated Segment Test) (Rosten,n.d). Due to the Vuforia uses natural images for tracking, in theory, every image can be used as a tracker if it is detailed enough. Besides image should not include repetition. The process of the FAST algorithm is shown in the flowchart below.

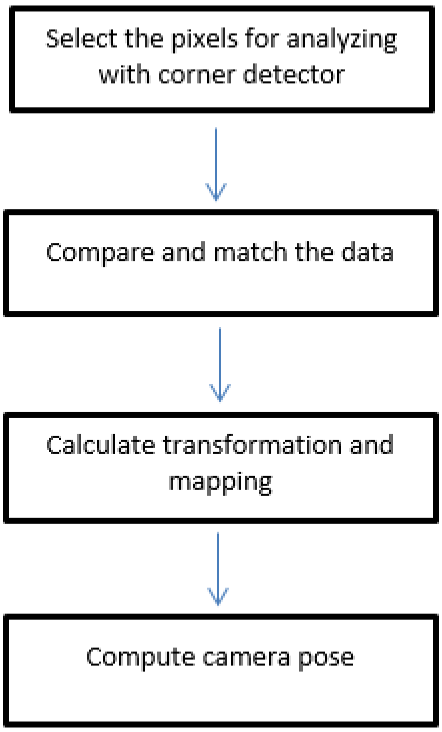

Figure 3.5. Flowchart of FAST Algorithm

The steps of FAST algorithm are explained below (Engineering High speed matching and tracking - Qualcomm. (n.d.).

- The first step is analyzing the marker that is chosen for tracking with the corner detector. After that, the detected points are stored in a database. Data stored in the database will be used as reference data for identifying and tracking the marker. These operations should be completed before the tracking process begins.
- In the second step, data that is coming from the camera of the device is analyzed in real-time with the corner detector. Then, detected points in the camera and reference data that is pre-calculated are compared, and matching points between them are found for each corner.
- In the third step, If the number of matching points that are established is decent, the projective transformation matrix which is also called as homography is computed. This transformation matrix is explained in details later in this section. The homography is responsible for mapping the points in the reference data to the data that are obtained from the device camera, and pair these points.

- In the last step, by using a convenient camera model, the camera pose is computed. Then, it will be possible for the 3D models that are desired to be on the marker with the desired angle and perspective. Figure 3.4 shows the example output for tracking algorithm.

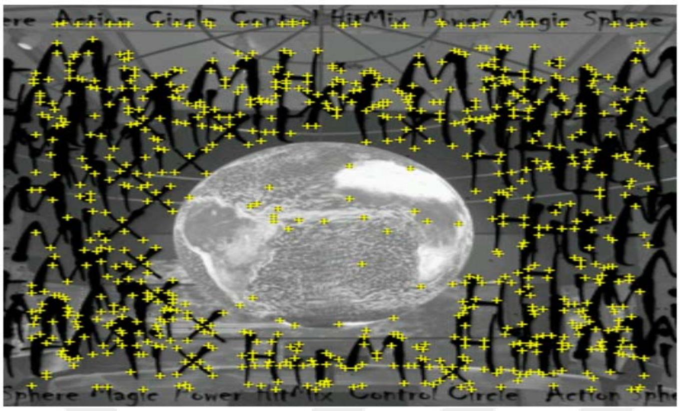

Figure 3.6. Example output for tracking algorithm

In the early process of developing the prototype, the image in Figure 3.3 was chosen to be used as the marker for the system. This marker was uploaded to Vuforia developer portal in order to apply FAST algorithm. As a result of this algorithm, all the corners of the image were detected (Figure 3.4). This marker got a five star rating as an outcome of the FAST algorithm. It means that this marker is very suitable for to be used in tracking. Later on in the code development process, the image shown in Figure 3.13 was selected to be the marker for the system. The FAST algorithm also rated this marker with five stars. The reason for this change in the marker has purely aesthetic purposes. The design of this new marker aesthetically fits better to the purpose of the prototype.

The framework itself was not enough to build a prototype application. It was only enough for recognizing the marker image. This means that all the 3D scenes, writing appropriate loader for 3D models, dealing with proper textures for 3D models and manipulations of 3D models had to be managed indepentedly from the Vuforia framework. The 3D models of human body parts (i.e. brain, lung, etc.) were obtained from Sketchfab.

Visualizing these models of human body parts are done with projection transformations in Vuforia. Vuforia uses a right handed coordinate system in which positive x-axis is to the right, positive y-axis direction is down-wards and positive z-direction points out of the target-plane. The camera in Vuforia is located at coordinates (0,0,0) and points to the positive z-axis direction. Therefore, the 3D images must be displayed on a 2D surface of the display as 3D imaged depending on the Vuforia's 3D Coordinate system. Vuforia uses OpenGL projection matrix for this conversion (Technical - How is the Projection Matrix defined? (n.d.)).

OpenGL projection uses two types of projections: perspective projection and orthographic projection. Both of these projections convert the real world coordinates to display coordinates by using different projection matrices.

Perspective Projection

In perspective projection, a point in eye coordinates is mapped to Normalized Device Coordinates (NDC). Because of the perspective of the eye coordinates, the 3D space of eye coordinates represented in a Truncated Pyramid Frustum (TPF) in OpenGL but NDC is represented with cubical 3D coordinate system (Figure f1). (Ahn, (n.d.))

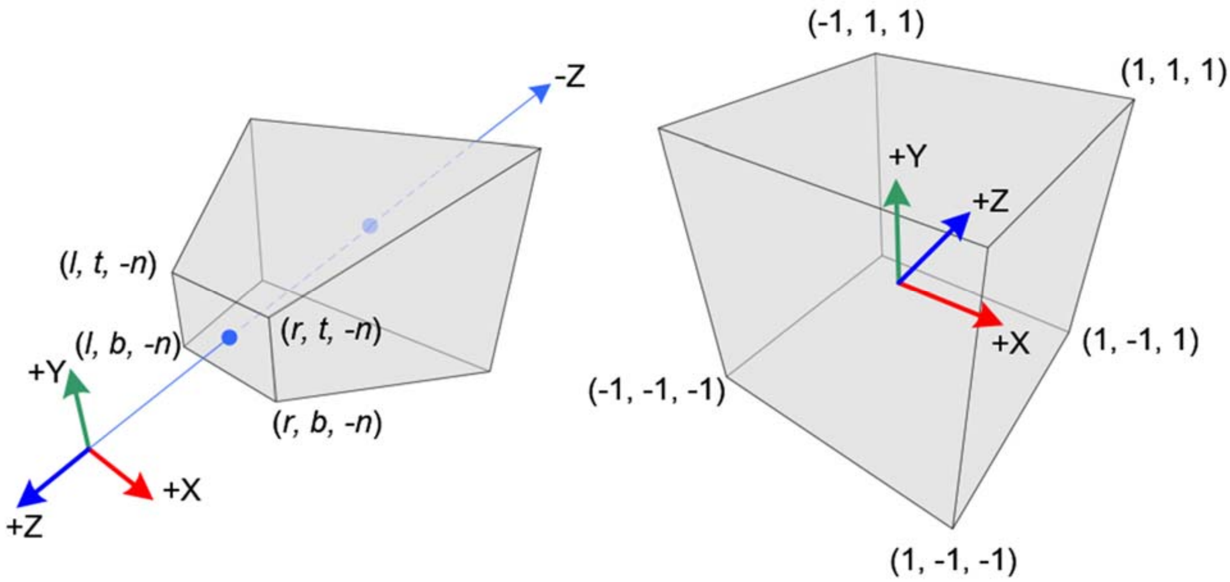

Figure 3.7 – TPF and NDC (Ahn, (n.d.)).

In perspective projection, all the points of the object in TPF are projected on the near planes called projection planes (i.e. the planes of xy, yz and xz). This operation is done by multiplying each point of a 3D object in TPF by the perspective projection matrix (Ahn, (n.d.)):

$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

Here, l and r stand for left and right boundaries of TPF on x-axis, t and b stand for top and bottom boundaries of TPF on y-axis, and n and $-n$ stand for the boundaries of TPF on z-axis.

Orthographic Projection

Orthographic projection is simpler than perspective projection. In orthographic projection, the real world coordinates are represented in an Orthographic Volume Space (OVS) (Figure f2). Every point in OVS is mapped to NDC by using the orthographic projection matrix below (Ahn, (n.d.)).

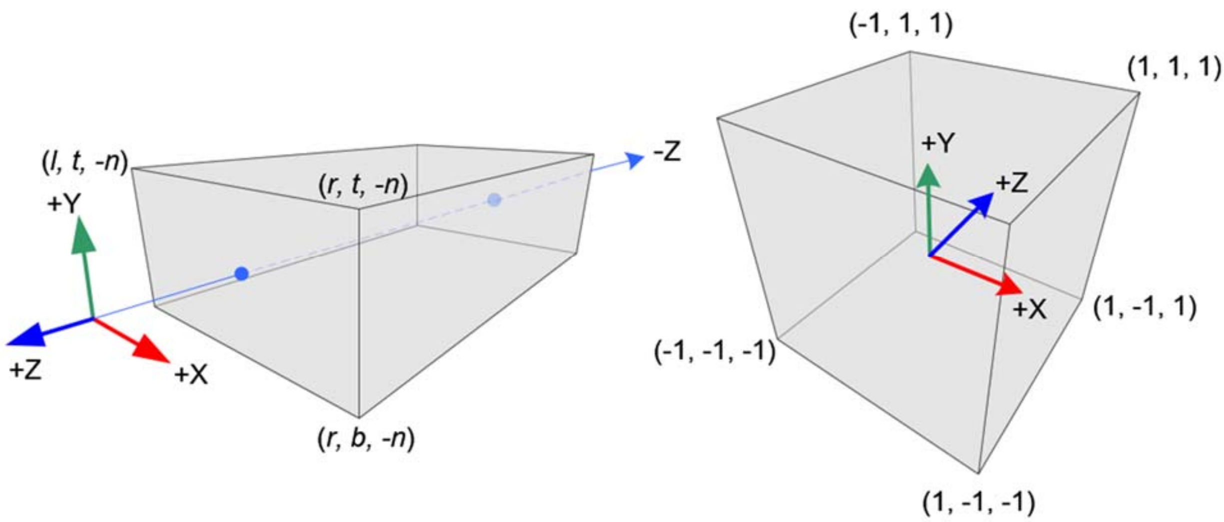

Figure 3.8 – OVS and NDC (Ahn, (n.d.)).

Each point of a 3D object in OVS is almost linearly mapped to NDC. Each coordinate in OVS is scaled to a rectangular volume first, and then this rectangular volume is translated to the origin of NDC. All of these transformations and operations are done via the orthographic projection matrix (Ahn, (n.d.)):

$$\begin{bmatrix} \frac{2}{r-l} & 0 & 0 & \frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & \frac{t+b}{t-b} \\ 0 & 0 & \frac{-2}{f-n} & \frac{-(f+n)}{f-n} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Again, here l and r stand for left and right boundaries of OVS on x-axis, t and b stand for top and bottom boundaries of OVS on y-axis, and n and $-n$ stand for the boundaries of TPF on z-axis.

3D object manipulations which are also called canonical manipulation, are the changes that users make to a virtual object to alter its size, positioning or orientation. There are four canonical manipulations:

- Rotation is the ability for a user to alter the orientation of the 3D object.
- Translation is the ability for a user to maneuver associate object from one location to different.
- Scaling is the ability for a user to alter the size of an object.
- Selection is the ability for a user to choose a single 3D object from a group of 3D objects.

Three of these manipulations were implemented in the prototype: rotation, scaling, and translation.

Users can rotate the 3D models by rotating their fingers. The rotation angle is calculated as the angular difference between the line that passes through the starting points and the line that passes through the end points. Rotation process continues while the user's both fingers are touching the display screen. When the fingers ceased to touch the screen the rotation ends. Rotation in the application is done on z-axis by default. However, rotation on x and y axes can be done via the user interface buttons. The mathematical background of rotation procedure is explained in Chapter 2. Figure 3.5 shows an example of rotation on z-axis that is done by Unity. Rotation on other axes are done in a similar way.

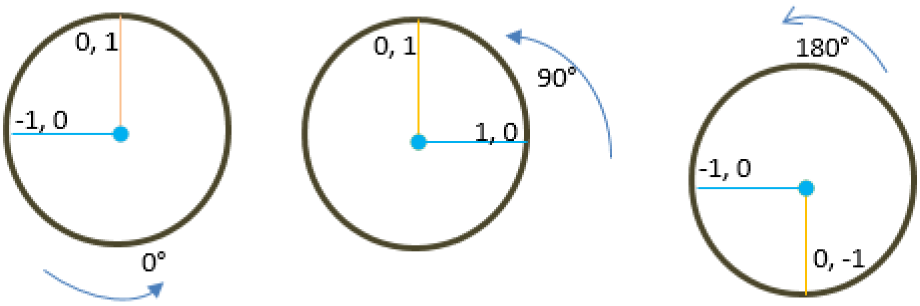

Figure 3.9. Example rotation on z-axis by Unity

The screenshot and code for rotation is presented below:

```
public void RotateRight ()
{
    GameObject.FindWithTag ("Model").transform.Rotate (0, -rotationSpeed * Time.deltaTime, 0);
}
public void RotateLeft ()
{
    GameObject.FindWithTag ("Model").transform.Rotate (0, rotationSpeed * Time.deltaTime, 0);
}
public void RotateRightPressed ()
{
    repeatRotateRight=true;
}
public void RotateLeftPressed ()
{
    RotateLeft=true;
}
public void RotateLeftRelase()
{
    RotateLeft = false;

}
public void RotateRighRelase()
{
    RotateRight = false;

}
```

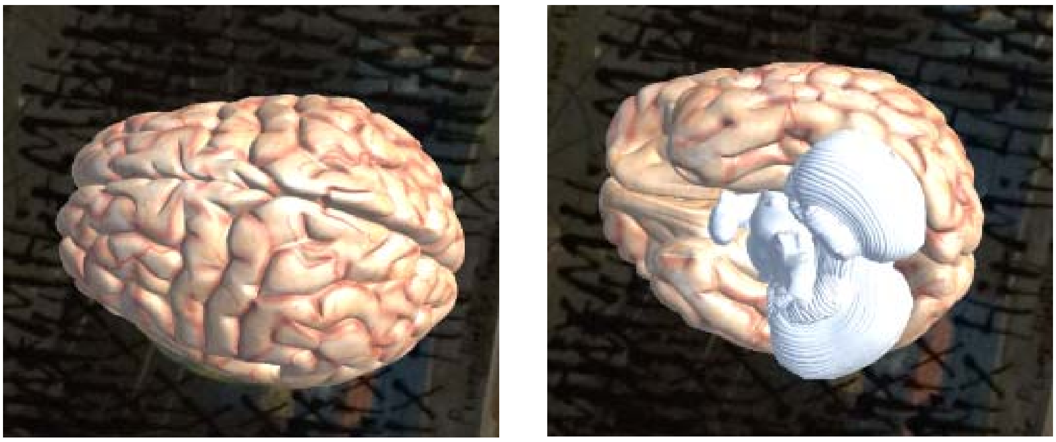

Figure 3.10. Screenshot and code for rotation

Scaling is applied in the same way rotation is applied. Scaling the 3D objects in the application is done by a gesture that requires two fingers. When these two fingers gets closer to each other, the object is scaled down, while the two fingers are moved away from each other the object is scaled up. Scaling ends when the fingers are removed from the display screen. The screenshot and code for scaling is presented below:

```
public void ScaleUp ()
{

    GameObject.FindWithTag ("Model").transform.localScale += new Vector3 (scalingSpeed, scalingSpeed, scalingSpeed);
}
public void ScaleDown()
{

    GameObject.FindWithTag("Model").transform.localScale += new Vector3(-scalingSpeed, -scalingSpeed, -scalingSpeed);
}

public void ScaleUpPressed ()
{
    ScaleUp = true;

}
public void ScaleDownPressed ()
{
    ScaleDown = true;

}
public void ScaleUpRelease()
{
    ScaleUp = false;

}
public void ScaleDownRelease()
{
   ScaleDown = false;

}
```

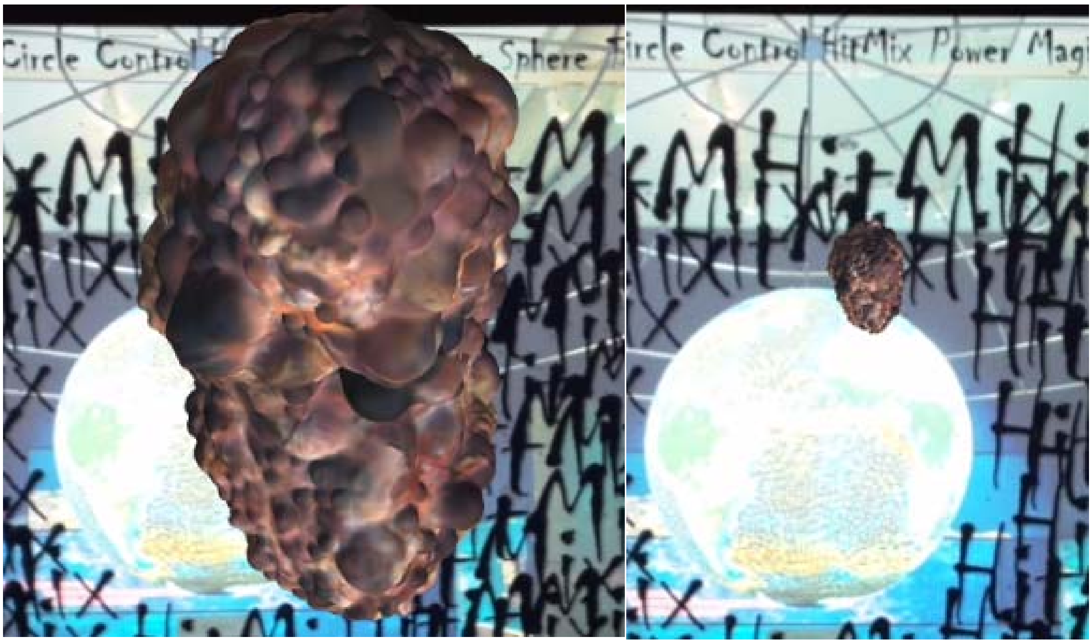

Figure 3.11. Screenshot and code for scaling

Translating the 3D model is done by grabbing the model and dragging it via a finger. Translation continuously takes place while the user keeps his finger on the display screen. When the user removes his finger from the screen, the translation ends. The code for translating is presented below:

```
public void MoveUp ()
{
    GameObject.FindWithTag ("Model").transform.Translate (0, 0, -translationSpeed * Time.deltaTime);
}

public void MoveDown ()
{
    GameObject.FindWithTag ("Model").transform.Translate (0, 0, translationSpeed * Time.deltaTime);
}
public void MoveUpPressed()
{
    MoveUp = true;
}
public void MoveDownPressed()
{
    MoveDown = true;
}
public void MoveUpRelase()
{
    MoveUp = false;

}
public void MoveDownRelasef()
{
   MoveDown = false;

}
```

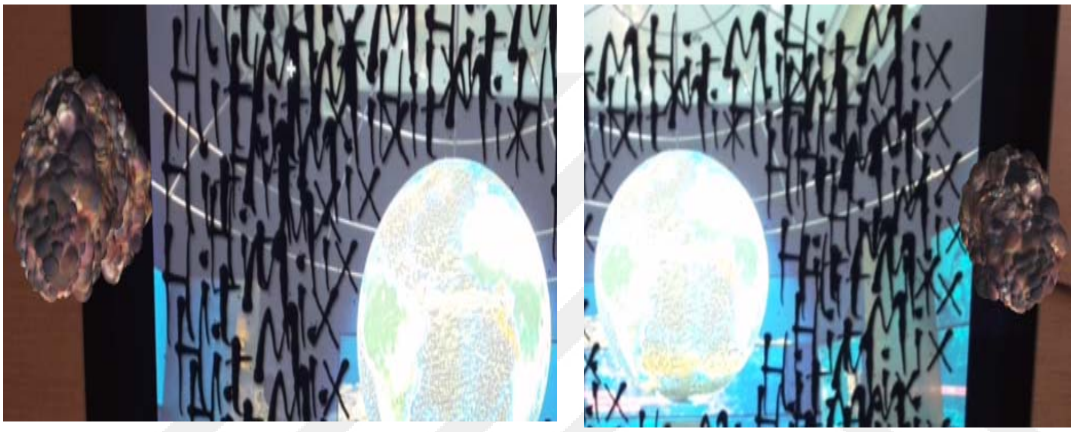

Figure 3.12. Screenshot and code for translating

In prototype, users can select different organs by pressing on the menu button. When the menu button is pressed, a menu window shows up on the top left corner of the display. This menu window provides users to make a selection out of four human organs. As soon as any organ is selected from the menu, the selected organ's 3D model appears on the corresponding location on the marker. The prototype allows users to read an explanation about the selected organ by pressing on the information icon which appears on the top right corner of the display. Users can also watch a video about the selected organ via the video panel located next to the information icon. Final marker for the prototype as mentioned above is shown in Figure 3.11. In addition, the screenshots of the prototype which includes the menu of the organs, video and information icons are shown in Figure 3.12.

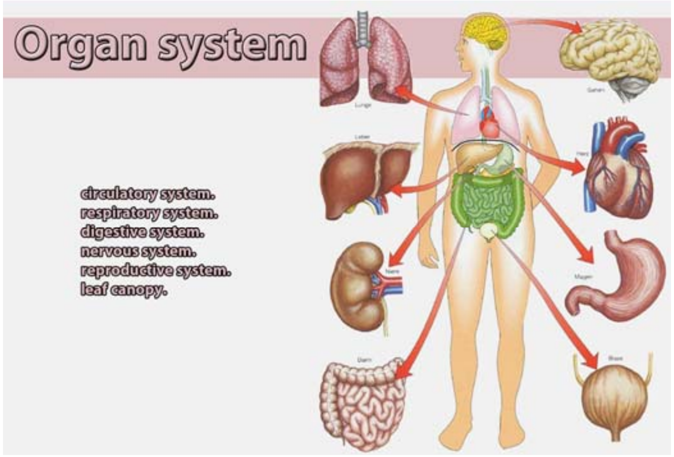

Figure 3.13. Final Marker for the Prototype

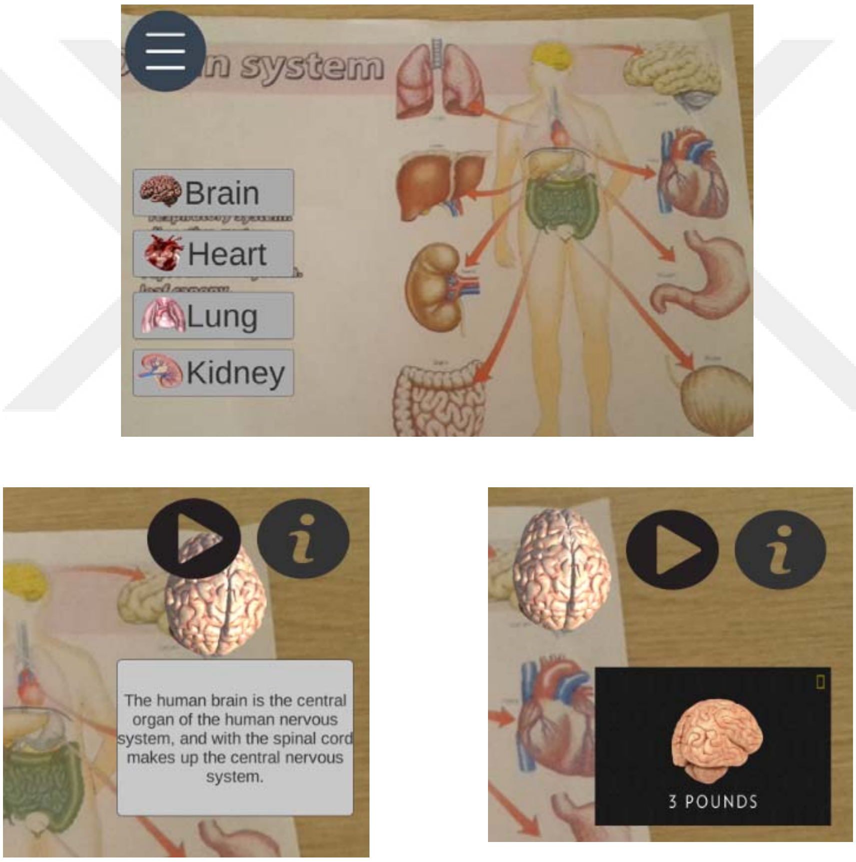

Figure 3.14. Screenshots of the Final Prototype

In summary, the prototype that was developed for this thesis provides some features to its users. First, users can select from a list of human organs via the menu of the prototype. Second, users can read information and watch a video about the selected organ. Third, users can interact with the selected human organ by canonical manipulations such as rotation, scaling and translating. It is aimed to assist anatomy students in learning human anatomy.

4. CONCLUSIONS AND FUTURE WORK

The purpose of this thesis was to explore the potential use of Augmented Reality Technology in human anatomy education. In order to test this, a prototype application was developed. Different types of manipulations were investigated and integrated into the prototype. As a result, a simple Android mobile AR application has been produced. The AR technologies used in this application has been explained and discussed.

The aim of this thesis is partially achieved. Although the aim was to build an application that supports human anatomy teaching, results do not contain verified results for the questions formed for this thesis. It was mainly because some difficulties and obstacles have been encountered during the thesis process. One of the obstacles was related to obtaining original 3D human organ models from the medical school of a local university. These original 3D models could not be acquired due to the legal issues. Therefore, the process of obtaining 3D models was delayed. The second difficulty that was encountered during this thesis process happened in developing phase. Rotation could be done on one axis only. Rotation cannot be applied on two or three axes at the same time. In other words, rotation on different axes at the same time cannot be assigned to one 3D model. For example, a 3D model neither can be rotated both on x and y axes nor on an xy-plane. When both axes are taken into consideration in rotation, the object can disappear from the view of the display.

Is AR a good option for teaching human anatomy?

Augmented reality has a potential to replace some elements that are in use of today's human anatomy education. Using the computer graphics to visualize human body parts with AR can also help students to study independently

During the process of developing the prototype, verbal feedback was taken from medical doctors. Their reaction was positive, and they stated it could be more exciting and more comfortable to understand human anatomy. However, they also stated that models must include more details. In addition to that, their general opinion is that it has a potential to replace atlas of anatomy, but it unquestionably cannot replace dissection because of the emotional impact of dissection.

What are the benefits and drawbacks of Augmented Reality to teach human anatomy?

One of the most critical benefits of using Augmented Reality is the dimensional perception increase when compared to 2D pictures in the textbooks. Understanding how anatomy actually looks like can be considered as the essential benefit of using Augmented Reality.

The primary drawback of Augmented Reality is to acquire 3D objects. Most of the time, 3D objects that have free or free for non-commercial use license are not the best in terms of quality. Another issue is that sometimes interaction with 3D objects can be nonresponsive and cumbersome.

This study should be considered to be the first step to figure out how Augmented Reality can be implemented in human anatomy teaching. Next step can be applying the prototype in the classroom environment with the large group of students. Data obtained from students can be used to create more perceptible research in the field of human anatomy teaching.

Other ideas for the future works are adding more functionality to the prototype that is developed for this thesis. For instance, different layers of the organs can be displayed. In addition to that, animations can be added to the specific organs such as heartbeat animation, breathing mechanism animation for lung. Moreover, it can be turned into an AR atlas of human anatomy.

Finally, it can be an interesting study to compare Augmented Reality and Virtual Reality for comparing both technologies advantages and disadvantages. It would be interesting to see how many common advantages and disadvantages these two technologies have.

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