Media Engineering and Technology Faculty
German University in Cairo

DatAR

Bachelor Thesis

Is Augmented Reality able to enhance the Data Visualization experience

Author: Andrew Ayman Alfy
Supervisors: Prof. Dr. Slim Abdennadher
ENG. ElHassasn Makled

Submission Date: 30 July,2020

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This is to certify that:

(i) the thesis comprises only my original work toward the Bachelor Degree

(ii) due acknowledgement has been made in the text to all other material used

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Andrew Ayman Alfy
30 June, 2020

Acknowledgments

I would like to express my sincere gratitude to my supervisors Professor Dr. Slim Abdennadher and my TA ENG. Hassan Makled, for all the help and the continuous support they gave me during my bachelor study, And without whom I wouldn't have that experience of exploring new fields in Augmented reality and Data visualization.

To the memory of my friend, Abanoub A.Saad

Abstract

Through the past few years, Augmented Reality has become one of the fundamentals in the field of Data visualization. This study aims to derive a three-dimensional representation of the two-dimensional data with the help of the Augmented Reality technology to enhance the user experience in Data visualization. At first, Python is used to generate QR codes to store the values of the data. Then by using mobile Augmented Reality, A Three-dimensional model of the user's data is shown. As a result, the user can examine the Data in a three-dimensional form.

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Chapter 1

Introduction

Data visualization has always been an important field in research throughout all ages. Methods to improve data visualization have evolved throughout the years. These methods vary from mobile applications to AR and VR. Since nowadays nearly everyone has a smartphone, Augmented Reality (AR) is more accessible to most of the users. Applying AR in the field of Data visualization is an attempt to help data analysts to make decisions based on concrete knowledge. Also, enhance two-dimensional/printed data visualization by extruding the third axis and allows users to uncover trends and patterns that may not be noticed and that is the main goal for the DatAR system.

AR/VR are noticed to take on Big Data. Although some users prefer using the old fashioned approaches for analyzing data and examining data-sets, the world is giving a better approach, which is graphic representations. Also, Augmented Reality and Virtual Reality data visualization are heading to be equally important as the natural virtual collaborations. Nowadays users around the world use the AR/VR in their daily meetings, which is better than meeting in a real meeting room, that is also because of the COVID-19 danger[7], the DatAR system will help in these circumstances. Augmented Reality technology can enhance the user's experience in the field of data visualization. There have been many attempts to achieve a good way to visualize data in a clear way using Augmented Reality. One of these attempts is IBM's data visualization. This attempt will be mentioned in the background section in more details.

The DatAR system is a developed approach towards enhancing user's data visualization. This approach allows the user to examine and study the data in a three-dimensional way by extruding the third axis of the data. Augmented Reality was chosen for the DatAR system for many reasons, among them we can find that Augmented Reality is more pleasing to be used by many users, the user would prefer to deal with an Augmented reality image, that would trigger some action even if this action is not expensive than a normal image[37]. Also, since Augmented Reality is more accessible to more users more than VR, the decision was that the way to enhance user's experience in data visualization will be done by using Augmented Reality.

In this thesis, the DatAR system is presented, which as mentioned before, will take us a step forward towards enhancing user's experience in the field of Data Visualization. The DatAR system will give a clear example of how to use Augmented Reality in the field of Data Visualization. To make it clear, the DatAR system is a system that shows the user's data in a simple and a clear way using the Augmented Reality technology.
At first, many problems were faced, especially during the COVID-19 pandemic, among them was that a way had to be found to make the user able to examine the data, without having the CSV file. The solution to this problem was to develop a Python application to generate a QR code, that holds all the data in the CSV file and by using the DatAR software, the data will be represented in the surrounding environment

using the Augmented Reality technology. The DatAR gives the user the ability to examine the data in a three-dimensional representation and moving the resulted data in the surrounding environment, without interacting with any paper. The user uses his mobile and laptop, which can be listed under the personal stuff. Of course, this doesn't give the user complete safety, but at least the user will be comforted when examining the data and safe from being infected by the Corona virus.

The aim of this study is to investigate the impact of using Augmented Reality in the field of Data visualization. The research questions for this study were as follows:

- What is the effect of using Augmented Reality in the field of Data visualization?
- How can the DatAR application be used in a way to enhance the user's data visualization experience?
- Does DatAR software provide the user with extra information and capabilities more than the old-fashioned data visualization techniques?

Chapter 2

Background

2.1 Data Visualization

Some people prefer using the old fashioned methods for analyzing data and examining data-sets, The world is giving a better approach, which is graphic representations. Data visualization is the way by which the relationship between images communicate. This relationship is the connection between the data and the viewer. The communication between the user and the data is achieved through many things, among them is the use of a systematic mapping between data values and the marks used in the graph.To achieve that communicate, Data visualization uses many methods. Among these methods, there are statistical graphics, information graphics, and plots. In data visualization, data can be in many forms, among them are dots, bars, and lines. When this data is represented in a clear form, It is called effective data visualization. Effective visualization helps the user to understand the relationship between data in the graph and analyze the reason for data and evidence.[8]

Data visualization can be described as the science which is the crossroad of many fields including mathematics, computer science, cognitive and perception science, and Engineering [40]. Data visualization importance appear in making the data easier to understand and remember. Where According to studies seeing the thing makes the human more capable of understanding[10], where 90 percent of the information transmitted to the brain is visual[11]. As a result, data visualization helps the user to visualize relationships and patterns quickly.

Data visualization is part art and part science[42]. However, the main challenge comes when this art is used to represent the data without getting the science wrong. To make it clear about the art part, this is an example. If data visualization is used there are three scenarios, the visualization is pleasing to the user and is showing the data properly, the visualization is pleasing but it is not precise, and The graph is not pleasing or precise. Proper data visualizations are created when the collision between communication, data science, and design happens[9].

2.1.1 Data visualization History and attempts

Data visualization has been around for many years. It began in the late 1700s with William Playfair.Data visualization has been around for many years. It began in the late 1700s with William Playfair, Who is credited with inventing the line, bar, and pie chart.
Charles Joseph Minard, who created one of the most well-known historical figures. Minard was a famous French civil engineer, who is famous for his representation of numerical data on maps. One of his famous works is the map pf Napoleon's Russian campaign in 1812. Where he displayed the dramatic loss of Napoleon's army over the advance on Moscow.[9]

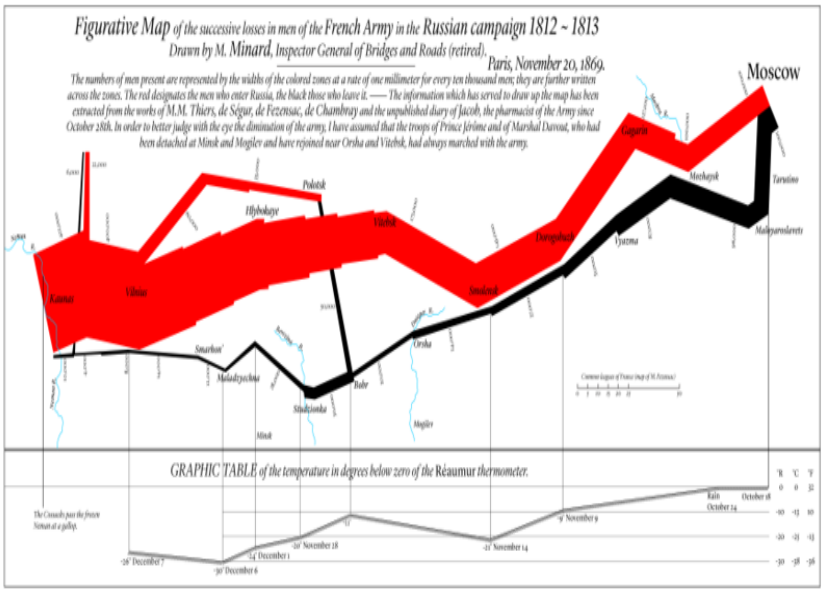

Figure 2.1: Charles's map

2.1.2 Data visualization Techniques

To get a well-crafted data visualization, there are some techniques to be followed to fulfill that desire. The first and most important technique is to know the audience, which is also known as the most vital concept. This technique represents a problem for many companies. Every company needs to find a suitable data visualization chart type. Some stakeholders may be happy with a simple pie chart. However, others will be looking for a deeper way to get into the insights you have gathered. Another thing is that some of the accomplished entrepreneurs find it difficult to get deeper and digest more than a pie chart, bar chart, or even a presented visual. As a result, ensuring that the content of your data is inspiring is the most essential data visualization technique[11].

The second technique for getting perfect data visualization is to set the goals of the data visualization, which means that with the visualization of the data, the efforts are effective when the strategies behind them are effective too. As a result, to efficiently use this technique, a logical narrative must be created. Also, drill down into the insights that matter the most[11].

The third technique to be followed is to choose the right chart type. The right chart is selected according to many things including the project, the audience, and the purpose. First of all, when the user is looking

to show an immediate and interactive overview of a particular key performance indicator. The best thing is to use the number charts. When the user is looking to inspire engagement in a board meeting or a presentation, maps are the best choice. The user will choose maps for two reasons. First maps look great. The second reason is that they are a quick, easy, and digestible way to represent large sets of geographical information. The third chart type is the pie chart, pie charts form a useful visualization tool to serve up valuable metrics in a simple format way. Pie charts prove their importance when demonstrating the proportional composition of a value over a static period. The fourth type is the Gauge chart, which can is best used with a single value or a data point. Gauge charts can also be used in financial reports to display progress against performance[11].Simplicity is the key is the main slogan for data visualization Because the user can not be distracted by any additional elements from the data[9]. This what was followed in the DatAR application.

The fourth technique to be followed is to take advantage of color theory. The most straightforward data visualization technique is selecting the right color scheme for the data visualization, Which will enhance the data visualization significantly. The right way to follow is to try to keep the color scheme consistent throughout the data visualization, Which is done by using contrasts between colors to distinguish between the elements of the data[11].

The fifth technique to be followed is to handle the big data in the correct manner. To deal with the big data correctly and break it down for the most focused and logical visualization, there are some rules. The first rule is to discover the type of data that is available for you and your organization and label each type of information to make it easy to analyze and decipher. The second rule is to make sure that all your team members know the source of the data and how to access it. The third rule is to keep the data protected and updated to make the visualization process as intuitive as possible. The fourth and last rule is to make sure to use business dashboards to present the most valuable insights in one place[11].

The sixth technique to be followed is to use ordering and hierarchy to prioritize. Creating a labeled hierarchy of the data will enhance data visualization by making the data visualization simpler, speedier, and more successful[11].

The seventh technique to be followed is to utilize word clouds and network diagrams. The user should consult the services of network diagrams or cloud words to handle decidedly sets of data. Network diagrams are used to draw graphical charts of networks. Word clouds give means of presenting complex sets of unstructured information. A word cloud is an image developed with words. The size indicates it's frequency and importance in the context of information[11].

The eighth technique to be followed is to include comparisons. When the user is presenting information, the user should add as many tangible comparisons as possible. This comparison is done by showing two graphs, charts, or diagrams, each of them showing contrasting versions of the same information over a particular time. By using comparisons, the user will provide a clear-cut guide on the impact of the user's data[11].

The ninth technique to be followed is to tell your tale. When presenting the data in a visual format, telling a story behind the data will engage the audience and make it easy to understand the purpose behind visualization with minimal effort. To do so, the user should collate the information, establishing a clear-cut speech, and building tension during the narrative to add maximum impact to the visualization[11].

The tenth and last technique to be followed is to apply visualization tools for the digital age. Using digital tools will help the user while gathering the data to make the best decision. Digital tools offer a digestive and interactive means of collecting and presenting data. This will ensure that the user will have the best impact while taking up the minimum time[11].

2.1.3 Enhancing Data Visualization using AR/VR

In the past few years, there have been some attempts to improve data visualization using Augmented Reality. Before getting into details, there are some learnings for data visualizations in Augmented Reality that must be known [6]. First of all **Finding a meaningful use for the AR is difficult.** As known, the biggest advantage for the AR is not just simplifying the user's problem and providing a simple solution, but it is the physical space around the user.As a result, it is hard to come up with a new idea or a new use that benefits the most from that advantage. The second thing to be known is that **Interactive experience in AR is fun.**The interaction with the AR content in the real world is supposed to be fun. That is because the user can be immersed in the data in the desired comfortable environment. The last thing is that **The environment matters.** Augmented reality needs to have a suitable environment including light conditions, the user's position, and having a suitable place for the augmented outcome to be shown in. Using AR in data visualization is like telling a story you can not tell with numbers alone. There has been some attempts to enhance the data visualization using AR/VR[20]. The first technology that used VR in data visualization is Brexit. The user can put on goggles and see a map of Europe and see questions related to each European country. There is also a technology that enables the user to visualize all the data about the solar system using custom AR/VR software solutions. AR/VR technology now allows the users to swim with the whales. Whereby using AR/VR goggles, the user will be swimming next to whales and discovering new information related to the anatomy of the whales. The last technology that enhanced data visualization using AR/VR is turning any image into an adventure. Google allows users to be part of any image, where the user can use the Google Cardboard. By using Google Cardboard, the user can be part of the graph or even go on a helicopter tour over the Grand Canyon.

2.1.4 Future of Data Visualization

Nowadays, applications and devices are collecting a lot of information, which needs revisions maintenance. For example, two and a half quintillion bytes of data every day. Data analysts can't revise this amount of data or derive some insights from it using pie or bar charts. Briefly, the old traditional methods for data visualization are no match for machine learning, which is getting more powerful and faster. However, in the future, all these data will be presented in a more interactive way, which is the AR/VR charts to communicate faster and give the analysts a clear view of the data. Viewing and examining the data like any ordinary object in the surrounding physical environment Gives the user a clear focus on the data, improves the data interpretation, and reduces the time needed to get the necessary information from the data. Using Augmented Reality to enhance the data visualization field will have an impact on many businesses, especially in the industry and communal services, where the analysts can examine the data in the real surrounding environment. The data will be more comprehensive and will give a new way to be organized into new patterns.

2.2 Augmented Reality

A fine thread is between reality and imagination. Augmented Reality technology is the one to make imaginations and dreams come true. It is the technology that mediates between humans and computers[39]. Augmented Reality makes human life easier using computer technology by bringing information to the user's real-life environment. For an Augmented Reality application to work, there are two steps. The first step is determining the real-time state of the physical world and the current state of the virtual world. The second step is to display the content of the virtual world in the real one. This display has to be in a way that makes the user feels that the content of the virtual world is a part of the real one. Briefly, Augmented Reality is the medium where the physical world is overlayed with information from the virtual world.

The privilege of Augmented Reality technology over the other ones, is that AR is accessible for ordinary users. Augmented Reality [41] gives us the ability of enhancing the real-world environment by real-time direct or indirect views. It aims at simplifying user's life by bringing virtual information to the user's surroundings and also bringing any indirect view of the real-world environment. AR can also be used to augment or substitute user's missing senses, especially to users with missing senses. Some AR applications require removing real objects from the user's environment. This is done by covering real-time objects with virtual information so it cannot be seen by the user in the augmented world. The information can vary from having an entertainment purpose, such as Wikitude, to having a main role in making the user's daily life easier, such as guiding workers through electrical wires in an aircraft.

2.2.1 Difference between AR, VR, and MR

Some users can not differentiate between Augmented, Virtual, and Mixed Realities. As a result, in this subsection, an abbreviated explanation for each technology will be given and explanation to the differences between the three of them. Virtual Reality (VR) is the technology that immerses the user in a completely virtual environment[29]. The computer is responsible for the generation of this environment. Some advanced VR technologies even allow the user to move freely in the virtual environment without constrains. The tools used in Virtual Reality technology vary from hand controllers to VR headsets. Some VR headsets and controllers have to be connected to the computer, but others are standalone. Most standalone Virtual Reality headsets work with the help of smartphones, where the user puts the phone in the headset to experience the virtual world.

Augmented Reality (AR) is the technology that allows the users to interact with the real physical environment while adding extra digital content to it[29]. Augmented Reality also has many tools that vary from smartphones to AR headsets such as Google Glass and Microsoft HoloLens. This chapter will talk in a detailed way about Augmented Reality. This subsection will focus on VR and MR.

Mixed Reality (MR) technology is the most recent development in the technology of reality[29]. In Mixed Reality, there are two forms of reality technology. The first form is when MR starts with the real-world. Virtual objects do not just overlay the real objects in the physical environment. The user can also interact with these objects. The user remains in the physical environment and can experience virtual objects. One famous example is how users use Skype in HoloLens. The second form of reality is when the MR starts with the Virtual world. The MR completely immerses the user in the virtual environment, and the real world is blocked. One famous example of this form is the Windows mixed reality headset.

In conclusion, the difference between the three real technologies can be stated as follows. In Virtual Reality, the environment is digital. Also, the user is enclosed and has no sense of the outer world. In Augmented Reality, the surrounding environment is part digital and part real. The real world is still the surrounding environment. However, digital information enhances the real world with data. In Mixed Reality,

the MR device intertwines the real and virtual worlds. Also, the user can interact and manipulate in both the physical and virtual environments.

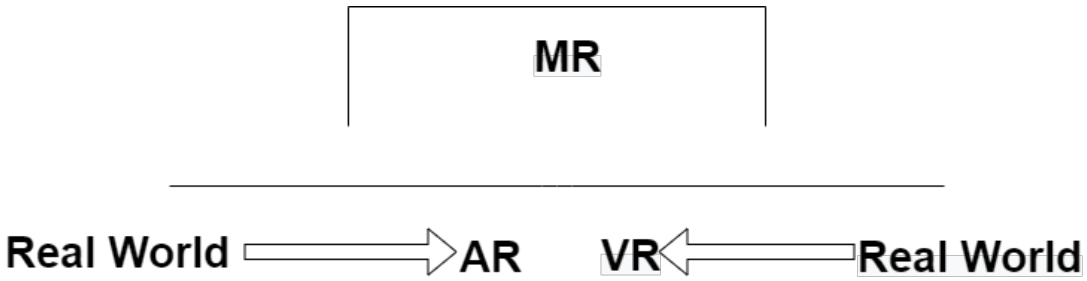

Figure 2.2: The First AR system

2.2.2 History

This subsection will talk about the history of the Augmented Reality technology. The first Augmented Reality system was developed in 1968 at Harvard. This was when Ivan Sutherland created the first AR head-mounted system (Fig.2.3). Those systems were used in simulations that were used for aviation , military, and industrial purposes. However, they were not for the public users[33].

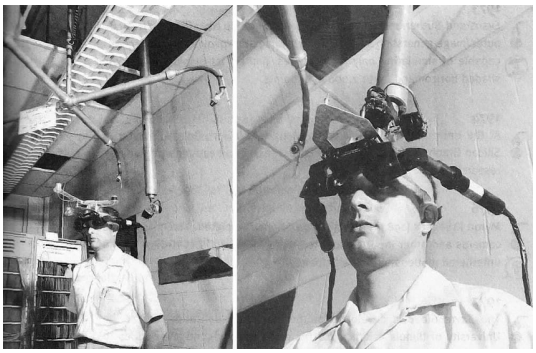

Figure 2.3: The First AR system

The first commercial AR system appeared in 2008. It was deployed and advertised by some German agencies in Munich, where they designed a printed ad of a BMW car model, which appeared on the screen when held in front of the computer's camera. This was one of the first marketing campaigns in the field of AR that allowed interaction with a digital model in real-time[33].
This idea was adopted later by other brands. By 2011 users started seeing more advanced versions such as National Geographic, which showed rare and extinct animals as if they were walking through a shopping mall. And there is also one more famous example which is Disney, in 2011 Disney showed in The Times Square some cartoon characters, they were interacting with people on the street on a large screen[33]. And that was the end of phase 1.
Phase 2 started in the early 2010s, which was trying products at home. So some companies especially watch and jewelry ones started their AR marketing campaigns. One famous example was the campaign of the apple watch, which let the customer try the watch before buying it.This phase continues to advance. The last one was by the London-based AR agency Holition and agency Coty, which recently launched an AR app. This

app lets the customer scan any make-up from a person or an image and try it using AR. The consumer's ratings for these apps keep increasing [33].
Phase 3 is using Ar apps in a broader range of uses, which shows that AR apps can be used in exploring cultures, historical sites, and geographic aspects. In the 2000s these types of apps were developed for tourism purposes. One example is the Museum of London app, which shows the user how a specific street looked like in the past. One other example is the Google Lens app, which is developed by Google and it has many AR features, such as scanning texts and translating them on your screen [33].
According to researches, users are not looking for robotic digitization of their daily life. However, what they truly desire is technologies that weave themselves in their activities[33].

Briefly, this subsection will mention the years at which a remarkable Augmented Reality event happened[26]. As mentioned before, the first head-mounted Augmented Reality display appeared in 1968 by Ivan Sutherland. The second remarkable event was the establishment of the first dedicated Augmented Reality laboratory in 1974 by Myron Krueger. The third remarkable event was the creation of the term 'Augmented Reality' by Thomas P Caudell in 1990. The fourth remarkable event was the creation of the first advanced Augmented Reality system and the creation of the virtual fixtures in 1992. The fifth remarkable event was using the Augmented Reality technology in theatres and for entertainment in 1994. The sixth remarkable event was using the Augmented Reality technology to power the NFL's first and tenth line in 1998. The seventh remarkable event was using the Augmented Reality technology in NASA's hybrid synthetic vision system in 1999. The eighth remarkable event was using the creation of the first open-source Augmented Reality library in 2000. The ninth remarkable event was adding the Augmented Reality technology to sports aerial camera in 2003. The tenth remarkable event was using the Augmented Reality technology in printing media in 2009. The eleventh remarkable event was using the Augmented Reality technology Automotive industry in 2013. This type of AR is called leverage Augmented Reality. 2014 witnessed the launch of the first wearable Augmented Reality technology. This technology was Google Glass. In 2016, Microsoft also launched another headset which is called Microsoft HoloLens. 2017 was the first year that witnessed the first use of Augmented Reality in the retail field.

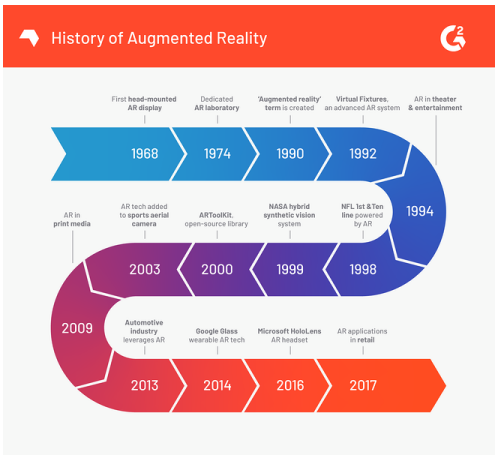

Figure 2.4: AR History diagram

2.2.3 Augmented Reality categories

Augmented Reality has many usages in many fields, and this chapter will mention these fields. Each one of them uses a specific type of Augmented Reality technology according to the field's needs. This subsection will get into details about Augmented Reality types, their uses, and the pros and cons of each type of them.[32].

- **Marker-Based AR:** Its a type of Augmented Reality and its also called Image Recognition[32], This type of AR gives information to the user after recognition of the objects (Fig.2.5). Marker-based Augmented Reality needs a target. This target is called an AR marker, that has to be a photo the created especially for the project. This image has to be unique and has many graphical images and contrasts to ensure it is unique. Briefly, Marker-based Augmented Reality allows the device to scan physical images, and accordingly will perform a specific action. Marker-based Augmented Reality has some pros and cons[27]. First, the pros include. Marker-based AR content provides a quality experience and a stable tracking if the marker image is a well prepared one. The second thing to mention is the smooth use of marker-based applications. Users who use it for the first time do not need instruction. However, Marker-based technology has three cons. The first one is that the Augmented Reality experience disappears when the mobile's camera moves away from the marker. The user has to scan the target image again to show the AR result again. The second point in the cons, scanning the target image will not work if the marker reflects light in certain situations. The third and last point is that the image target has to have contrasted colors to make tracking stable.

Figure 2.5: Marker-Based AR

- **Marker-Less Augmented Reality:** This type of AR is the most implemented applications in the industry. It is also called Location-based AR. This type has many common usages, such as helping travelers and discovering interesting locations, and it is all done according to the user's current location using the mobile's GPS (Fig.2.6). Briefly, Marker-less Augmented Reality denotes an AR application that does not need previous knowledge of the user's surrounding environment to overlay content into the scene[21]. Augmented Reality has achieved the 'dead reckoning' transition. This transition is to move from image or Qr based activation to marker-less AR experience. Using the marker-less Augmented Reality technology, the user can place virtual objects in the surrounding environment without the need for a QR code or image target. Marker-less Augmented Reality has many fields of usages[21]. The first field is the gaming one. The world witnessed the biggest impact of Augmented Reality in gaming with the AR-enabled Pokemon GO back in 2016. ARKit and ARCore made it possible for the AR technology to create the three-dimensional content of the game that remains fixed in place for users to

interact. The second field is the Retail product. By using marker-less Augmented Reality technology, the user can now try any products in the surrounding environment. The third field is advertising. By using marker-less Augmented Reality technology, the user can now scan any three-dimensional character, and an advertisement will appear on his mobile. Many companies started to apply the marker-less advertising like WayFair, the NBA, Sephora, and Gucci. The fourth field is education. By using marker-less Augmented Reality technology, Digital information overlays in the real world to educators. This technology allows students to understand complex concepts. Among these applications, there is Anatomy 4D, where students can learn Anatomy, Elements 4D, where the students can learn chemistry. Also, museums started to enhance their exhibit tours with this technology. The visitors can see additional information about the museum's piece using Augmented Reality. With the help of the Hololens, companies also began to create training sessions for the trainees on everything, starting from repairing engines to surviving in combat. Marker-less technology has a privilege over marker-based[27]. This privilege is that once the user puts the AR content in the desired place, it is more flexible and stable than marker-based alternatives. However, Marker-less technology has two cons. The first one is that the Augmented Reality experience may not make sense in certain conditions. The second point is that it requires that the surface has a texture, to make the computer vision able to recognize it.

Figure 2.6: Marker-Less AR

Figure 2.7: Marker-Less AR

- **Projection Augmented Reality:** This type is the simplest one of AR, which represents the pro-

jection of light on a surface. It is done by touching the projected surface with hand. This one can be used to create deception about the user's position, depth of the object, and its orientation (Fig.2.8). Projection Augmented Reality technique eliminates the need for a hard copy or monitor-based instructions. Projection-based AR is flexible, scalable, and customizable. It also has many benefits over other AR systems. First, it avoids headset problems such as restricted field of view and poor fit. Second, it does not deliver the isolation like the headsets, where projection creates a simultaneous shared Augmented Reality experience, and it is highly efficient. The benefit of projection mapping is accuracy. For example, if aircraft assembly workers used projection, they would find the holes to drill without effort. In contrast, if these workers used Augmented Reality headsets, they would struggle to find the exact spot to dig the required hole. However, there are some issues, considering projection mapping technology. One of these issues is the cost and mobility of the projectors. The cost of the projection technique is an issue because to make a precise projection, the user will need more than one projector. Having multiple projectors will cost a lot of money[22].

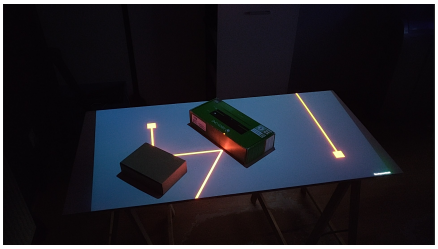

Figure 2.8: Projection AR

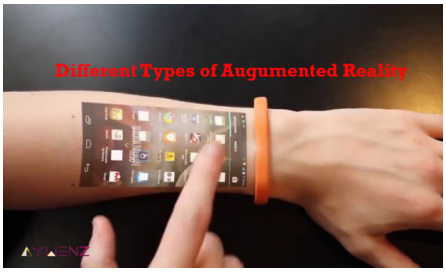

Figure 2.9: Projection AR

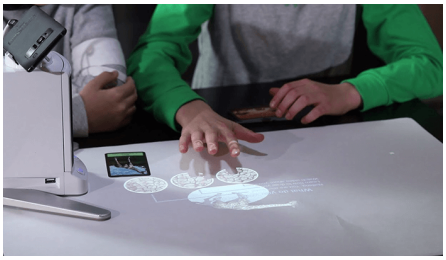

Figure 2.10: Projection AR

- **Superimposition Based Augmented Reality:** This type of AR is my favorite, as this one allows

you to provide a replacement view of the current object in focus. This is done by changing the user's real-time view with an augmented view of the object(Fig.2.11). The superimposition Augmented Reality technology mainly depends on object recognition. If the application could not find what it is looking at, it can not replace the desired object or scene with the augmented one. This technology can is used in many fields and for multiple purposes[23]. The first field that uses the superimposition Augmented Reality technology is the medical field. Doctors can use this technology to examine their patients using the X-Ray, which helps the doctors to examine the patients from different angles on the real image to provide a better understanding of the damage to bones. Doctors use the application in two different ways. The first way is to use the headset or goggles. The second way is to display the feed directly on the screen. The second field that uses Superimposition Augmented Reality technology is the military field. It provides multiple views of any target object to the soldiers without showing any extra information that would block the soldier's vision. Also, the Superimposition of infrared views of an area can save lives and help win wars. The third field that uses Superimposition Augmented Reality technology is to use it over ancient pictures, where it can provide multiple views of historical places. Also, a broken monument can come back to life. Briefly, users can re-live ancient eras using the AR. The fourth field that uses Superimposition Augmented Reality technology is to train people to face their fears. It can bring a tiger or a snake in front of the user and make him respond to this situation accordingly. The fifth field that uses Superimposition Augmented Reality technology is the study. As mentioned before, studying using the Augmented Reality technology provides an entertaining environment for students to understand complex lessons. Superimposition Augmented Reality technology has pros and cons. One of its pros is that it eases the user's job and makes it more fun and interactive. However, this technology might be a danger to the user in some activities. When these activities are related to driving and surgeries, This technology can cause distraction of the user from the goal.

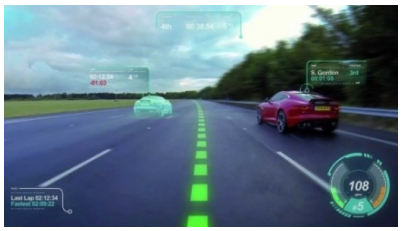

Figure 2.11: Superimposition Based AR

Figure 2.12: Superimposition Based AR

Augmented Reality has reduced the gap between imagination and reality.

2.2.4 AR usages

Augmented reality is now one of the main drivers of the technology economy. The value of the AR market is expected to reach one hundred billion dollars by the end of 2020[12]. Augmented Reality has many usages in many fields. This section will talk about some of the fields that use Augmented Reality to develop.

The first and most important field is the medical training, where operating MRI equipment and performing complex surgeries can now be performed using Augmented Reality. For example, the user can delve into the human body in an interactive three-dimensional format using an Augmented Reality headset. This will allow medical students to study anatomy easily[12].

Figure 2.13: Augmented Reality in medicine

The second field for using Augmented Reality is the retail field. Shoppers can now use their smartphones to compare prices and look for additional information. One famous example is the Harley Davidson motorcycle brand. Harley developed an AR application that can view a motorcycle in the showroom. The buyer can also customize any motorcycle using the application to see which features and colors they like[12].

Figure 2.14: Augmented Reality in retail

The third field for using Augmented Reality is the repair and maintenance field. Maintenance and repair staff are beginning to use Augmented Reality glasses and headsets during the repair and maintenance process to provide them with useful information. The information can be in the form of suggested fixes and point out potential trouble areas[12].

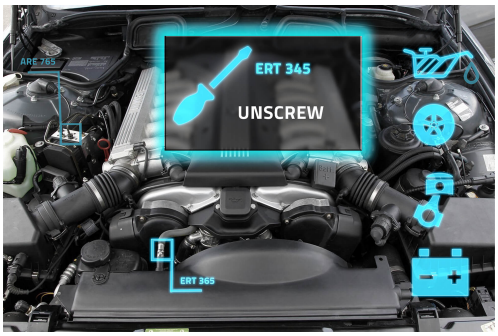

Figure 2.15: Augmented Reality in repair and maintenance

The fourth field for using Augmented Reality is the design and modeling field. AR is used to design interior architecture and help to visualize the final products during the creative process. Using AR headsets gives engineers and architects the ability to step into their buildings and see how their designs might look like when completed. AR headset visualization can also be used by urban planners to model how an entire city will look in the future[12].

Figure 2.16: Augmented Reality in design

The fifth field for using Augmented Reality is the business logistics field. AR gives many opportunities to increase efficiency and cost savings for business logistics. This includes route-optimization and transportation. DHL shipping company has already implemented this technique, where DHL implemented smart Augmented reality glasses in some warehouses, where the lenses show the workers the shortest route to take to locate and pick any item to be shipped. This technique saved DHL time and money[12].

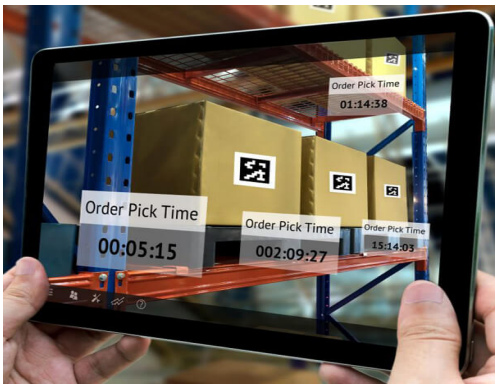

Figure 2.17: Augmented Reality in logistics

The sixth field for using Augmented Reality is enhancing the tourism industry field. Nowadays, especially during the COVID-19 danger, travel brands give the tourists a huge opportunity to have an immersive experience even from home and before they decide to travel anywhere. Imagine walking around the beach in Hawaii before booking a flight ticket using an AR headset only. The user can also point the camera at a famous monument or building, and information about it will appear. Using AR in this field makes selling trips and traveling much easier[12].

Figure 2.18: Augmented Reality in tourism

The seventh field for using Augmented Reality and is considered the most important one, especially these days, is the classroom education field. Students can view and attend their classes via a smartphone or tablet for a more rich learning environment. Students who learn about astronomy can now see a full map of the solar system using the AR glasses. Students who love music can now see the music notes in real-time as they play their favorite instrument. Students who loves Geology can now see active figures of volcanoes for example.[12].

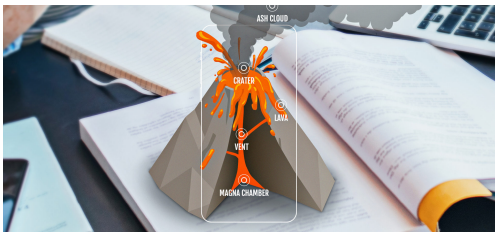

Figure 2.19: Augmented Reality in education

The eighth field for using Augmented Reality is the entertainment. The entertainment field is one of the most desired ones of all ages. Using Augmented Reality technology and merging it with entertainment is fun. One famous example of using Augmented Reality in the entertainment field is Pokemon GO, where the player can see Pokemon characters in the real-world environment in real-time[12]. The users also can see dinosaurs in real-time using AR.

Figure 2.20: Augmented Reality in entertainment

The ninth field for using Augmented Reality is the data visualization one. This field is the one that was chosen to work on in this project. The user can see the data in real-time in the surrounding environment in a clear way, which will give the user a wider view of the data and give the user the ability to make decisions according to the data.

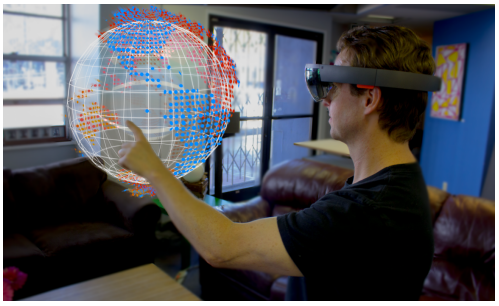

Figure 2.21: Augmented Reality in data visualization

2.2.5 Development frameworks

Many libraries,Packages, and frameworks allow you to work with augmented reality platform and develop AR apps. Some of them are [3] :

- **Vuforia :**
  Vuforia is an augmented reality SDK that sits near the top of most "Top AR" lists, Its used to create immersive, engaging AR experiences. It uses mobile vision to recognize and track images and show the outcome on the mobile camera in real-time. Vuforia also provides APIs in C++, Java, and objective-C++, This way it can be used in IOS, Android, and UWP development. and most importantly it also enables the development of AR applications in Unity that are easily portable to both platforms[2]. To activate the Vuforia Engine in Unity, The user has to go through some steps[25]. The first step the user has to make is to replace unity's camera with the Vuforia ARCamera. The second step is to open the Vuforia Configuration Inspector and add the Vuforia's license key. The third step is to activate the Vuforia's target database. The user activates the target database by opening the Vuforia website and adding the desired image targets to the target database. The last step is to add an image target from the database uploaded on the site.

- **AR Foundation**
  AR foundation is a set of APIs and Mono-Behaviours for dealing with devices that support the concept of world tracking, Plane detection, Reference points, Object tracking, and Light estimation[34]. It enhances the low-level API with additional utilities, and it is considered one of the main packages in AR development.

- **ARCore**
  ARCore is a platform developed by Google for building AR experiences. It enables your phone to sense your surrounding environment and interact with information. It also integrates the virtual content with the real environment as seen by the user's camera by using three key capabilities, which are[35]:
  - **Motion tracking :** Which allows your phone to track its position relative to the world
  - **Environment understanding :** This capability allows your phone to detect the size of any surface detected by the camera and it works on all types of surfaces.
  - **Light Estimation :** This one allows your phone to estimate the current light conditions

- **ZXing :**
  ZXing is a barcode image processing open-source library implemented in Java. It forms the basis of Android's Barcode Scanner apps[36].

- **OpenCV :**
  OpenCV is a library of programming functions developed by Intel, Its main aim is real-time computer vision. The library is a free cross-platform for both academic and commercial use. And hence written in C/C++, it can take advantage of multi-core processing. So it can be used in many fields including interactive art, Augmented Reality, Human-Computer interaction, Motion tracking, and mines inspection.[1].

- **Raycast Manager**
  Raycast Manager is used to detect tarckable object, where it detects features in the physical world.[31]

2.2.6 Augmented Reality best practice tools

As mentioned before, Augmented Reality is a tool that aims at simplifying user's life by bringing virtual information to the surroundings, However, Augmented Reality needs to be used correctly to fulfill that desire. To fulfill that desire, the user must choose a suitable Augmented Reality solution and tool according to what the business need. If the user needs to improve the efficiency of the sales team, for example, The user is likely to choose a solution like Augment. If the user wants to add and integrate a new Augmented Reality feature in any AR app, The best solution is to integrate the app with an Augmented Reality.

This subsection will talk briefly about the components needed in Augmented Reality usage[28]. The first technology is the cameras and sensors, where they are essential as they collect data from the user's surrounding real-time environment and use it in the AR application accordingly. The camera is to scan the surroundings and extract information. The sensors are for locating the current location of the user and the physical objects and generate the three-dimensional models. The second technology is the processing, where the Augmented Reality devices need to have a GPU, GPS, RAM, WiFi, and a CPU. These components are to be able to measure the speed, direction, and angle of the device or the desired object. The third technology is the reflection, where some Augmented Reality devices have mirrors to help the user to view virtual images. The reason behind this reflection is to make propper image alignments.

2.2.7 Augmented Reality potential dangers

Augmented Reality application has begun to merge in nearly every industry in the user's daily life. No one can deny the importance of Augmented Reality in human's life. However, AR brings some risks and hazards to some users[24]. The first thing to mention is the information load problem. Nowadays, social media has led to exponential growth in information. The availability of mobile technology and its spread has made it easy for anyone to access different kinds of information from various sources. Especially nowadays, the smart Augmented Reality glasses technology is spreading. This information overload can cause stress to some of the users, indecisiveness, and can lead to inaction. Briefly, Augmented Reality's purpose is to access real-time information and allow the user to take quick actions according to the displayed information. However, with the exponential growth of data, AR's purpose is getting harder and harmful to some users. The second thing to mention is the problem of perception impairment. Augmented Reality glasses are one of the keys to this technology. However, these glasses compromise people's safety if they do not match the highest standards. They can cause impairment in the perception of the user and may lead to other consequences. As a result, the user must ensure that the Augmented Reality glasses compliance the quality of the highest standards to be safe. The third problem to mention is the distraction the user will get while wearing the AR glasses or even using an AR application. Dealing with the Augmented Reality technology at first causes distraction from the main purpose and information. Using AR applications in some activities is dangerous especially when these activities are like driving or surgeries. The fourth problem to mention will cause an obstacle to Augmented Reality technology when it gains mass adoption, the privacy problem. Augmented Reality applications require to collect data from the user's surrounding environment before overlaying it with extra visual information. Augmented Reality applications do not collect the user's data only, but also, the people viewed through the device. Some people might find this problem a major one. They consider that their privacy is not preserved. The fourth problem to mention will cause a problem to Augmented Reality technology when it gains mass adoption, the privacy problem. Augmented Reality applications require to collect data from the user's surrounding environment before overlaying it with extra visual information. Augmented Reality applications do not collect the user's data only, but also, the people viewed through the device. Some people might find this problem a major one. They consider that their privacy is not preserved.

2.3 Related Works

This section will mention some related projects, which also use real technology (AR, VR) in enhancing data visualization.

2.3.1 Augmented Reality in data visualization

One of the attempts to achieve a proper outcome in Data visualization using the Augmented Reality technology is IBM's data visualizations, which utilize an open-source data framework to load data in real-time. Although developers and companies rarely use machine learning in the field of Augmented Reality, they are aware that there are projects that started to work on merging the AR field with the Data Visualization one.[38]. This technology will give analysts and users the ability to examine data efficiently and clearly. Briefly, IBM Immersive Insights gives the user the ability to study the desired data using Augmented Reality technology. However, IBM Immersive Insights requires an Augmented Reality headset, and it can not work on mobile phones alone. This point is what was developed in the DatAR application, where now the user can examine the data using the mobile phone application only, without the need for any special types of equipment.

2.3.2 Virtual Reality in data visualization

In contrast to Augmented Reality, Virtual Reality has many attempts to enhance data visualization. The first company [30]. This company released a demo version of their application DatavizAR to Steam, which gives the user a chance to experience data visualization using Virtual Reality. The second one is BadVR, where it presents data in new ways. BadVR parses large datasets with the help of artificial intelligence and machine learning. It also focuses on collaboration and real-time filtering. The Third provider is Virtualitics, where it offers a DataViz VR solution combined with machine learning and collaboration. Virtualitics's technology is based on researches at NASA/JPL and Caltech. The fourth provider is Ulysses, where it offers data visualization solutions using Virtual Reality technology. Nowadays, Ulysses website allows the user to explore COVID-19 Data with the VR Ulysses. The fifth company is Virtual Cove, where it offers big and complex data visualization solutions using Virtual Reality technology. The sixth company is Nanome, where it offers more than the rest companies. Nanome offers the experience of scientific visualization, where it gives the user the ability to interact and design molecular data in a three-dimensional representation. The seventh company is Kineviz, where it develops special tools for exploring high dimensional data sets. The company's main tool is the GraphXR, where they focus on having VR as their main platform. The eighth company is Datavized, where it develops data-driven tools for the immersed web. One of these tools is Geometric, which allows the user to build and visualize three-dimensional geospatial data maps. The ninth company is VR-VIZ, whereby using React JS library, they developed a list of components to generate three-dimensional representations in webVR.

Chapter 3

Functionalities

This chapter will be the guide for the user to be able to use the DatAR software. The first thing to mention is that the DatAR software consists of two parts. The first part is the generation of the QR code. A developed Python application is the one responsible for generating the QR code. The second part is the generation of the three-dimensional representation, which represents the data of the user saved in the mentioned QR code. This part is developed using Unity and is divided into two scenes, one scene for scanning the QR code and another scene for generating the three-dimensional representation. More details about the Python application and the DatAR application will be mentioned in the implementation chapter.

3.1 Steps to represent data in three dimensions using DatAR

In this section and its subsections, the steps to operate the DatAR software will be mentioned. After following these steps, the user will be able to represent the data in a three-dimensional way.

3.1.1 Creating the QR code

The first step in the DatAR system is to create QR codes that contain the user's data. As mentioned before, a Python application was developed. This python application needs the CSV file to be uploaded by the user from the computer. This is done by entering your CSV file into the program. Then your data will be saved in QR codes. The python application is also user friendly, even if the user does not have any experience with coding or dealing with Python. Allowing the user to access the console not the code makes the application more secure, more efficient and easy to be used by users with no experience in Python. Briefly, the steps to generate the Qr code is as follows. First the user has to open the python application, which is in the exe extension, then by dragging the required CSV file into the console. This will generate an SVG picture in the place where the user uses the application, this picture contains the QR code to use in the DatAR application. A sample of the result QR code can be seen in (Fig.3.1).

Figure 3.1: Resulted Qr code

3.1.2 DatAR application

The DatAR application consists of two scenes. The first scene is the one responsible for showing the 3d representation for the data. The second scene is the one that performs the QR reading using ZXing.

To describe the first scene briefly. There is a button in the lower-left corner responsible for moving from the first scene to the second one. There is also an image of a cube in the upper right corner. This cube is to represent the outcome and show the user the name of the three axes and their location in the generated representation. The generated three-dimensional representation is displayed when the phase of reading of the QR code and scanning the environment is complete. Until then nothing more is displayed on the screen.

The first step for the user is to press the mentioned button in the first scene, which will open the second scene to start the phase of scanning the QR code. In the second scene, the user now has to scan the QR code by using the mobile's camera. The scanning process will take an average of 2-4 seconds, so the user has to make the camera stable focusing on the QR code to be scanned efficiently. After scanning the QR code, it is time to return to the first scene to generate the three-dimensional representation, so the user has to press on the button located at the upper right corner in the second scene, which will take the user back to the first scene.

On returning to the first scene, the user has to scan the surrounding environment. On every scanned plane, the AR default plane appears on top of the plane, indicating that this plane is detected and is available for placing the representation. Now it is time for placing the three-dimensional representation. On any plane detected by the AR default plane, the user can touch this place on the screen. This action will result in two actions. The first one is the generation of the representation. The second action is the generation of a yellow quad, which will be described and mentioned later.

In the figure 3.2, A yellow indicator, which allows the user to relocate the three-dimensional representation's position, can be shown. This indicator changes the position according to the user's touch on the mobile screen. In the figure 3.4 and 3.3, The three-dimensional representation, generated after scanning the QR code in the second scene, can be shown. This representation does not appear unless the QR code is read in the second scene and the ZXing QR code reader extract the information stored inside it.

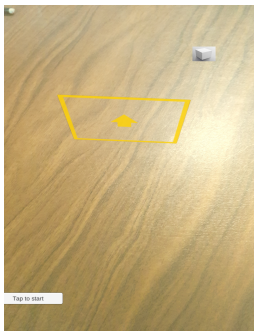

Figure 3.2: yellow indicator to adjust the outcome position

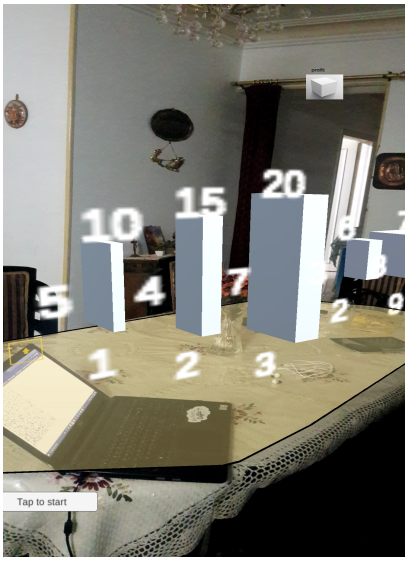

Figure 3.3: Sample of three-dimensional representation

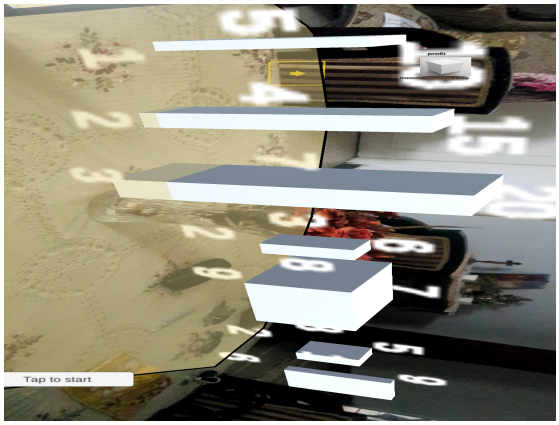

Figure 3.4: sample of outcome from the first scene

3.1.3 Application Flow for the user

This subsection will describe the application flow for the user. The first step is that the user has to use the laptop to insert the CSV file in the python application. The second step is to open the DatAR application on the mobile phone and press the start button to start the ZXing Qr code reader to scan the QR code. The last step is when the user finishes scanning the QR code and presses the show result button. When the user presses this button, this action will take the user back to the first scene to display the generated three-dimensional representation, which represents the user's data where the user can change it's location using the mentioned yellow quad.

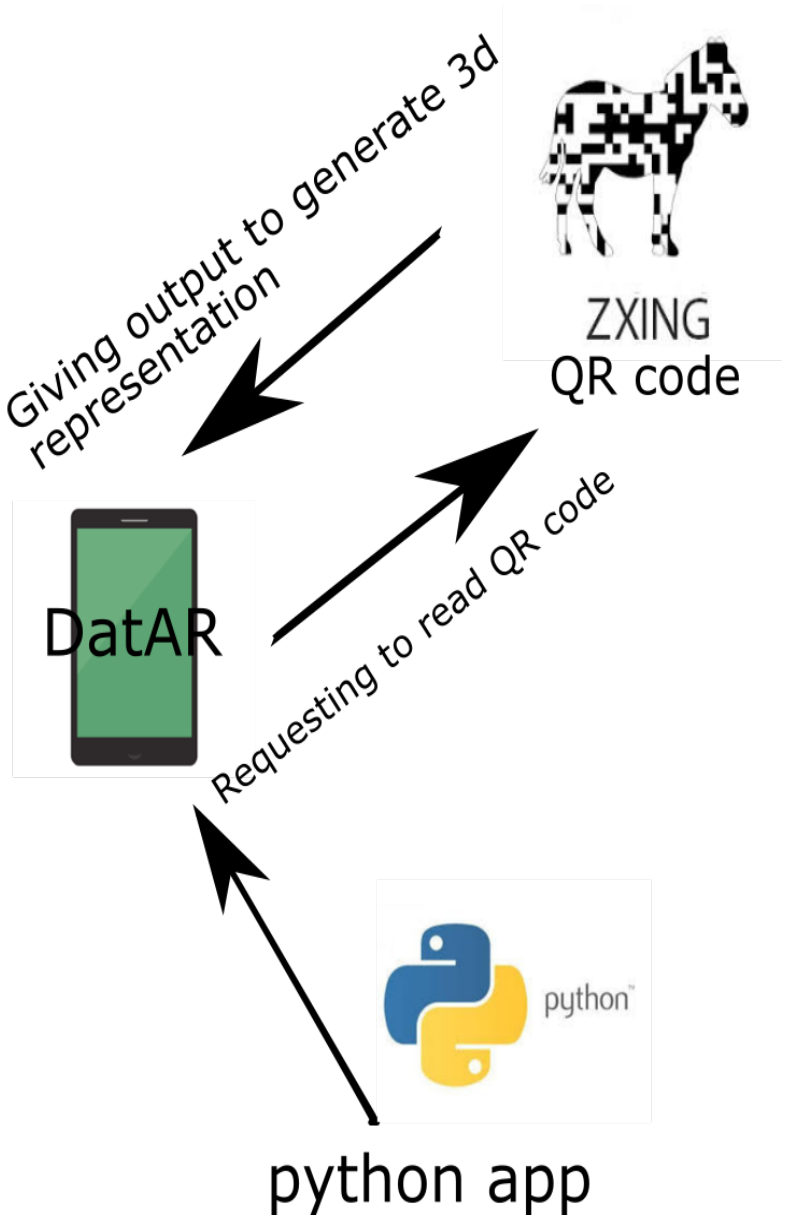

Figure 3.5: How the DatAR system components communicate.

Chapter 4

Implementation

This chapter will present the implementation of the DatAR software. A general overview of the DatAR software will be given in the first section. Where the section will start with an introduction to the development tools used in the DatAR and why Augmented Reality is the best fit for DatAR. Then, an introduction to a general overview of the Python application and its architecture and main components and how they communicate with each other. Then, the same for the DatAR application. At last, this chapter will explain how the whole system communicates and how the flow for the DatAR application goes

4.1 DatAR general overview

The main purpose of the DatAR, the reason behind choosing Augmented Reality, and the development tools used in the DatAR system will be discussed in this section.

4.1.1 DatAR main purpose and why using Augmented Reality was preferred

The DatAR project provides an opportunity for the user to view the data in a three-dimensional representation. This opportunity will give a complete view of the user's data and enhance the user's experience in the field of data visualization. With the help of the python application and Unity game engine, DatAR is now able to improve the data visualization user's experience. Thanks to the python application, the user first creates the QR code responsible for holding all the user's data. Also, thanks to Unity, using the DatAR application, the user can now scan the generated QR code and study the data using the resulted three-dimensional representations. Unfortunately, since the DatAR application uses ARCore, It can only work on high Android devices. As a result, DatAR is not compatible with all Android devices, only the ones working with new versions of Android operating systems.

There are five main reasons behind choosing Augmented Reality rather than other real technologies. As mentioned in the background section, the first reason is that Augmented Reality is more accessible to ordinary users, where most user now uses smartphones which makes them able to use AR easily. The second reason behind choosing Augmented Reality is that many companies have already developed techniques to enhance data visualization but by using other real technologies like virtual reality, as mentioned before. However, IBM Immersive Data is the only technique that tried to improve the user's experience in the field of data visualization, and it was by using Augmented Reality headsets. As a result, the decision was that the DatAR application will only use the mobile Augmented Reality technology to be more accessible and

smoother. The third reason behind choosing Augmented Reality is that the user will still be interacting with the surrounding environment so the user will not be distracted by extra information from the virtual world. As mentioned before, Virtual Reality and Mixed Reality takes the user from the real world to the virtual one. However, Augmented Reality is the only technology that keeps the user's environment and enhances it with digital information. The DatAR needed the user to be in the surrounding environment to prevent any distraction from the main purpose, which is studying the data. The fourth reason behind choosing Augmented Reality is the cost. When dealing with real technology, Augmented Reality is the least costly. Where Virtual Reality requires some VR headsets and controllers, which the background sectioned mentioned. Also, Mixed Reality requires the headset, and in some cases, a controller. However, using Augmented Reality in the DatAR application costs nothing, only the user's smartphone to have a high Android version. The fifth reason behind choosing Augmented Reality is saving time. As mentioned above, other real technologies require some special equipment like VR headsets. However, Augmented Reality is on the user's phone in the DatAR's case, where the user will not waste time on preparing any pieces of equipment or the headsets.

4.1.2 DatAR Development tools

Python which is a high level general-purpose programming language. Its object-oriented approach helps programmers write clear and logical codes[4]. As a result, it was the best choice to make an app that reads CSV files and generates QR codes.

Unity is a cross-platform game engine. It gives the user the ability to create experiences in both 2D and 3D. It is also a cross-platform engine that extends more than 27 platforms.It also allows the user to develop AR and VR apps[5]. As a result, the DatAR application is developed using Unity. It also allows the user to export the project for both android and IOS systems. As a result, it was the best choice.

AR Foundation is a set of Monobehaviours and APIs for devices that support some concepts. Among these concepts, there is the "World Tracking" concept, the "Object tracking " concept, and the "reference point" concept[34]. These three concepts were the most important concerned with the DatAR project. That was to locate the point of origin to show the resulted representation. Also, to track the generated three-dimensional representations.

ARCore is a software development kit developed by Google, It allows the user to build their AR applications[35]. And since the testing phase was by using Android devices to test and implement the DatAR app, ARCore was the best option.Unfortunately, ARCore is still not supported On all Android devices, only for the higher Android devices only.

ZXing is a barcode image processing library. The unity project uses ZXing to read the resulted QR code from the Python app. Then as mentioned above, the resulted list is used to generate the three-dimensional representations.

Raycast Manager
As mentioned before, Raycast Manager is used to detect tarckable object, where it detects features in the physical world[31]. As a result, Raycast is used to detect planes and surfaces where the user can show and change the location of the three-dimensional representation.

4.2 Python QR code generator application

4.2.1 System Architecture

First of all, The interaction between the python application parts will be shown in this subsection. This application mainly depends on three python libraries, which are CSV, pyqrcode, and pandas. The flow is as follows, First of all, iterating over the first row extracts the main three axes from the CSV file . Then another iterate is done over the CSV file completely. After reading the data of each row, this row's data is saved in a variable. After iterating over all the CSV file rows and saving them in them mentioned variable, PYQRCODE is used to save these data in a QR code. Another version was implemented for the DatAR application, That creates a QR code for every row in the CSV file. However, a problem appeared, which is the lag of the DatAR application. As a result, the first version is the one to be chosen, which creates one QR code to hold the whole data is the best approach.

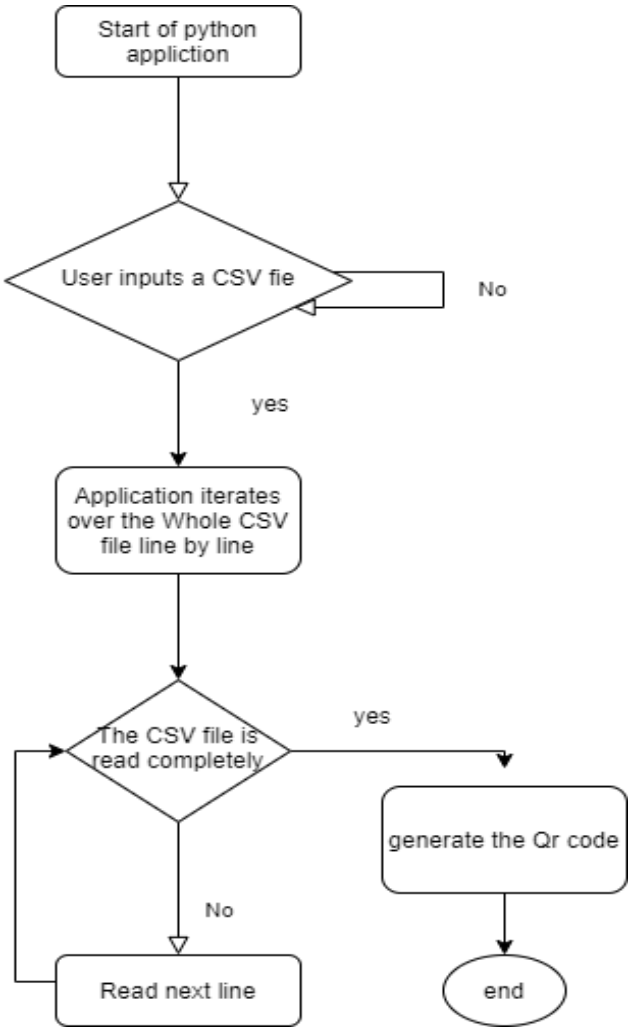

Figure 4.1: Python application code flow

4.2.2 QR code generator modules

In the python application (QR code generator), some modules and packages are used to achieve the DatAR's goal. The first module used in the QR code generator is the CSV (Comma Separated Values) module. The CSV module is the most common import and export format for databases and spreadsheets. This module implements classes to write and read tabular data in CSV format. It also allows programmers to write the data in Excel format or read data from an Excel generated file without knowing the precise details of the CSV format used by Excel[13]. In the QR code generator, the CSV module is used to read the CSV file of the user to be able to generate a QR code that contains this data.
The second module used in the QR code generator is the pyqrcode. The pyqrcode module is one of the simplest ways to generate QR codes. It is written in pure Python. This module can create a QR code using only two lines of code. The generated QR codes can be saved as SVG, PNG, Or as plain text format[14]. The pyqrcode is used in the DatAR project to generate the QR code that contains the user data extracted from the CSV file.
The Third package used in the QR code generator is Pandas. This package provides fast, flexible, and expressive data structures. It eases the use of structured (tabular, potentially heterogeneous, and multidimensional) data. Pandas package aims to become the most powerful and flexible open-source data analysis. It is also one of the fundamental high-level building blocks for doing real-world data analysis in python[15].

With the help of these modules and packages, the QR code generator application can read the user's CSV file properly and generate a QR code that holds the CSV file's data. This QR code will be later used in the DatAR application, where the data will be extracted from the QR code to generate the three-dimensional representation of the data.

4.3 DatAR application

4.3.1 DatAR System Architecture

In this section a general overview of the DatAR software system architecture and how the components interact with each other will be mentioned. DatAR is implemented using Unity, Unity is one of the best software engines for developing AR applications, which made the implementation of the DatAR application much easier. Once you have the QR code, Its time for generating the three-dimensional representation for your data. ZXing is used to read the QR codes. But it needs to use the camera in a separate scene, the DatAR consists of two scenes. The first scene is the one to show the 3d representation for the data. The second scene is the one that performs the QR reading using ZXing as mentioned before. The coming subsections will give more details about the two scenes.

The two scenes in the DatAR used some namespaces in both of them. The first namespace is System. This namespace contains some base and fundamental classes. That defines the reference data types, events, and event handlers. Also, It contains commonly-used values and processing exceptions[16]. The second namespace is 'System.Collections'. This namespace contains some classes and interfaces that are to define various collections of objects[17]. The third namespace is 'System.Collections.Generic'. This namespace contains some classes and interfaces that are to define generic collections. This namespace allows the user to create a strongly typed collection. A well-typed one provides better type safety and performance for the user[18].

4.3.2 DatAR application first scene

The first scene uses AR Session origin, which is responsible for making your mobile's camera relative to the resulted 3d representation. Ar default plane is used to locate the scanned places where the user can show the representation at. AR camera, AR session origin's child, is used instead of the main camera to give the user the AR experience.Also, AR Session is used. Which coordinated the processes that ARKit performs to create Augmented Reality experience. Therefore, after scanning the QR codes, the user returns to this scene again, and by using the mentioned tools, the user scans the surrounding environment to locate the representation's required place in a clear way using Augmented Reality. After scanning the surrounding environment, a yellow quad appears, this quad allows the user to relocate the representation in any desired place. The only problem is that the representation can be shown at planes only, the ones scanned by the Raycast manager.

The first scene uses extra namespaces. The first extra one is 'UnityEngine.UI'. This namespace is the one responsible for the user interface collections, and because the button and the text components are used in the first scene, this namespace is added in the first scene script. Raycast manager is also used to scan the surrounding environment to show the places where the user can place the representation at. The third extra one is 'System.IO'. This namespace is the one responsible for reading and writing to files and data streams[19].

4.3.3 DatAR application second scene

The second scene is responsible for extracting data from the QR code using ZXing. Unity's main camera and Augmented Reality's camera are overwritten with a webcam texture. This is done in order to make ZXing able to read the QR code. After reading the available QR code, there is a button to switch the current scene to the other one. That will clearly show the data representation(Fig.3.4). At the upper right corner, the cube represents the three axes names.

The second scene uses extra namespaces. This extra one is 'ZXing.QRcode'. This namespace is the one responsible for reading any QR code once detected on the screen.

To describe the second scene briefly. 'GUI. Draw' is used to draw a webcam texture over the main camera to overwrite it so ZXing can be used properly. Also, by using 'GUI. Draw' the button is drawn at the upper-right corner, which is responsible for moving from the second scene back to the first one. By using the webcam texture, the scene is displayed rotated ninety degrees clockwise, so in the update section, a rotation ninety degrees anticlockwise is performed.

4.3.4 DatAR code flow

This subsection will talk briefly about the code flow of the DatAR application. At first, the cube image at the upper right corner and three empty text meshes are created once the application starts. The DatAR application opens at the first scene, where the three-dimensional representation will appear later.

When the user clicks on the start button, this action will open the second scene, the one responsible for reading the QR codes. As mentioned before, the second scene only contains a button at the upper right corner. This button is responsible for switching to the first scene. In the second scene, a webcam texture is drawn, which will allow the second scene to use the ZXing Qr code reader, and a scale to this texture to fit in the user's screen is done. When the second scene starts, the ZXing QR code reader begins collecting information displayed at the screen from the camera. If a QR code is detected, ZXing starts decoding this Qr code and saves the data saved inside it as long as the second scene is open. Once the user finishes scanning the required Qr code, the user will press on the button mentioned earlier, which will take us back to the first one.

Once the user returns to the first scene again after scanning the Qr code, now it is time for generating the three-dimensional representation. The first thing to do now is to get the list contacting the data extracted from decoding the QR codes from the second scene. After getting the required list, there is a method that iterates over the list to check for duplicates and removes them, because the QR code scanner can scan the same QR code multiple times. The next step is to check for the name of the three axes. There is another method that iterates over the list to extract the three axes' names. When this method finishes the iteration, the three empty text meshes will now show the names of the three axes to show the user what the resulted numbers represent.

Now it is time to generate the representations. There is a cube prefab that will represent the data in the first scene. Now, a method iterates over the mentioned list for the last time. This time after reading every line of data, a cube prefab is instantiated and resized according to the numbers in each row, until the counter reaches the end of the data in the list. After instantiating each prefab and resizing it, It is time to write the value of each side of the cube on it. A text prefab is used. This time the text prefab is the one that will be over each cube to indicate the value of the data. The process of generating three-dimensional representations is complete once the iteration finishes. Now, it is time for the user to show the representation. The process is as follows. The user first scans the surrounding environment and then clicks on the desired place to show the three-dimensional representation. A yellow quad and the representation appear to the user. This yellow quad allows the user to change the location of the representation.

In the below figure The sequence of events in the DatAR app can be more clear(Fig.4.2).

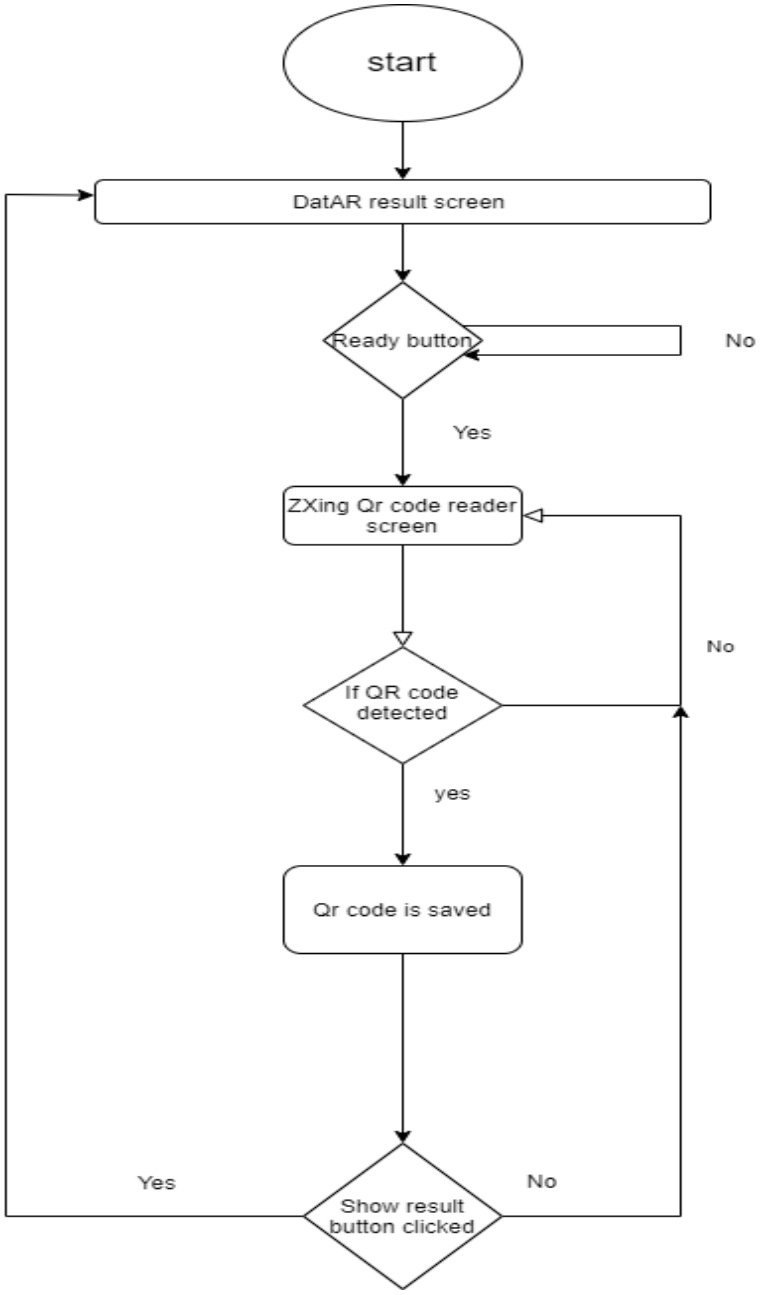

Figure 4.2: Flow chart showing DatAR application sequence of events

Chapter 5

Evaluation and results

As mentioned in the introduction section, the main aim of this study is to test the impact of using Augmented Reality in the field of data visualization. As a result, this chapter will discuss the study's experiment design, preparation, and results.

5.1 DatAR functionality test

5.1.1 Participants and Experiment Phases

Experiments are conducted to test the functionality and the usability of the DatAR app. Due to the current circumstances, The testing phase was with the help of a limited number of participants. Ten participants helped in testing the DatAR functionality. The age of the participants ranged from 21 to 51. five medical students, one accountant, a businessman, and three engineering students.

The first phase of the conducted experiment, was to explain what is the benefit of the DatAR application and the steps to make the DatAR work. The second phase was to make a challenge between two of the participants, one of them had three graphs representing the XY, YZ, and XZ axes, which represent the time, income, and profit for a company over a certain period of time. A sample of the three graphs can be seen at the figures 5.1 5.2, and 5.3. The other participant used the DatAR application. The competition was to ask the two participants to get some information like the value of the profit when the income was maximum, the value of income when the time was lowest, and the value of time when the value of adding profit and income is the least. The timing of the participant's answers was recorded after each question.

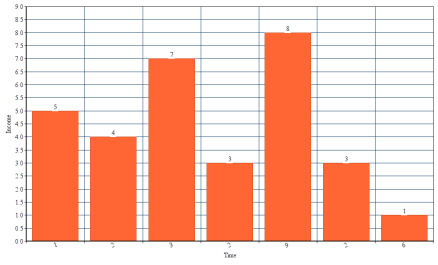

Figure 5.1: XY Graph

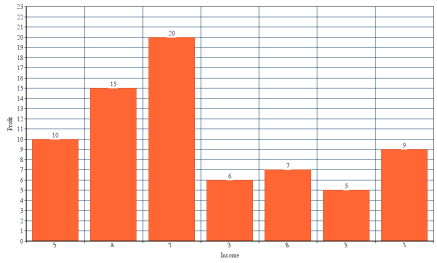

Figure 5.2: YZ Graph

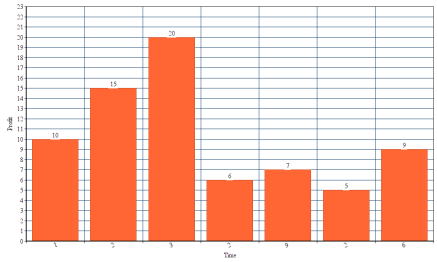

Figure 5.3: XZ Graph

The participants were divided into two teams A and B. Team A is the team who used the three graphs. Team B is the one who used the DatAR. The last phase in the experiment was to get feedback from the participants on the application. The feedback from the participants was in the form of two questions, the first one was If the application is user friendly and easy to use. The second Question was about the importance of the DatAR application in improving the user's data visualization experience and if there were any improvements to be done to make the DatAR application more efficient.

5.2 Results of experiment

5.2.1 Questions related to two-dimensions

The result of the experiment was as follows. For the questions that are related to two-dimensions only, team A answered them faster than team B. The participants were asked questions such as : getting the time value when the profit was at maximum, getting the profit value when the income was the lowest, and getting the profit value when the time was minimum. As mentioned, team A were better at these types of questions, with an average of timing 1.84 seconds. However, team B in this type of question did it with an average of 2.3 seconds.

To make it more precise, one participant from team A and one participant from team B, are asked the same question at the same time. The timing of the answer for each participant is recorded. The first type of

testing questions consisted of five ones related to the two-dimensions. The first question was to ask the two competitive participants to get the value of time when the profit was at the maximum. The second question was to ask another two competitive participants to get the income value when the profit was the minimum value. The third question was to ask another two from team A and team B to get the profit value when the time was at the maximum one. The fourth question was to ask another two participants to get the income value when the time was at the minimum one. The last question was to ask another two participants to get the profit when the income was at the maximum value. The following table shows the timing for each team at every question.

Questions	Team A timing (sec)	Team B timing (sec)
Question 1	1.4	1.7
Question 2	2.0	2.7
Question 3	1.7	2.0
Question 4	2.2	2.5
Question 5	1.9	1.8
Average timing for each team	1.84 seconds	2.14 seconds

5.2.2 Questions related to three-dimensions

For the questions that are related to the three-dimensions, Team B answered them faster than Team A. The participants were asked questions such as: getting the time value when the summation of the profit and income values were at maximum, getting the profit value when the summation of income and time values were the lowest, and getting the profit value when the summation of time and income values were minimum. As mentioned, team B were better in these types of questions, with an average of timing 5.18 seconds. However, team A in this type of question did it with an average of 5.6 seconds.

To make it more precise, one participant from team A and one participant from team B, are asked the same question at the same time. The timing of the answer for each participant is recorded. The second type of testing questions consisted of five ones related to the three-dimensions. The first question was to ask the two competitive participants to get the value of time when the summation of profit and income values is the maximum. The second question was to ask another two competitive participants to get the income value when the summation of profit and time values is the minimum. The third question was to ask another two from team A and team B to get the profit value when the summation of time and income values is the maximum. The fourth question was to ask another two participants to get the income value when the summation of time and profit values is the minimum one. The last question was to ask another two participants to get the profit when the summation of time and income values is the maximum. The following table shows the timing for each team at every question.

Questions	Team A timing (sec)	Team B timing (sec)
Question 1	5.6	4.7
Question 2	6.7	4.6
Question 3	5.8	4.9
Question 4	5.0	6.0
Question 5	4.9	4
Average timing for each team	5.6 seconds	4.84 seconds

5.3 Engagement test

A test is conducted to tests the ability of the DatAR software to serves the aim of the research question, enhancing user's data visualization experience by using Augmented Reality. In this subsection, this section

will explain the steps of the mentioned test. The answers for this test was to answer with strongly agree, agree, neutral, disagree, or strongly disagree as shown in(FIG.5.4).

The first question to test the aim was about the importance of the DatAR application, in improving the user's data visualization experience. The answers to this question were, none of the participants strongly disagreed, two of the participants disagreed, one of them answered with a neutral response, four of them agreed, and three of the participants strongly agreed that the DatAR is a step forward towards improving data visualization using Augmented reality. However, as mentioned before, some of them complained that the QR code reader is a bit laggy.

The second question to test the study's aim was to ask the participants, if there were any improvements to be do to make the DatAR application more efficient. Four out of ten participants agreed on enhancing the QR code reader is a required step to enhance the DatAR application. Two out of ten participants suggested merging the python QR code generator with the DatAR application. One out of ten participants suggested providing the user with a manual when the application opens, to make the DatAR experience smoother, especially when the user will not have a guide for the first time. One out of ten participants suggested giving the user the ability to readjust the three-dimensional representation. This suggestion's purpose is to make the user move freely when the DatAR is running. Two out of ten participants did not give any suggestions and said that they do not have any ideas.

The third question to test the study's aim, is to ask the participants if the DatAR provides the user with more information than the traditional data visualization techniques. According to the participant's answers and the testing outcomes, it is concluded that. The DatAR does not give the user mush help when related to questions about two dimensions. However, when it comes to three dimensions questions, the DatAR provides the user with a clear view of the data and is more efficient than the traditional data visualization techniques.

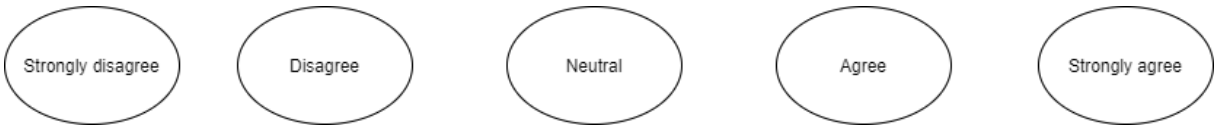

Figure 5.4: Evaluation answers

Chapter 6

Conclusion

As stated earlier in this thesis, the main aim of the DatAR project, this data visualization platform, is to help the users derive conclusive data, relationships, and context from the resulted three-dimensional representation. DatAR makes it easier to derive relationships between the three main axes. It also gives the user the ability to analyze data in a fast and easy way and gives the analysts a clear cut about the data. That is by enhancing the two-dimensional data visualization by extruding the third axis.

The DatAR application mainly depends on three technologies, the AR Foundation, ARCore, and the ZXing barcode reader. These three technologies mainly allowed a smooth interactive experience for the user with studying data and concluding results. The importance of the DatAR application appears in these days. Especially in the COVID-19 ones. Where now the user can examine the data from his mobile without interacting with any paper or charts. Also, at the same time, the user will have a clear view of the data from the three-dimensional representation. Also, the user doesn't need to understand the relationship between data from the CSV file or from the three graphs representing the three axes. Thanks to the three-dimension output the user can now compare between data, determine the best one, and study the data in an efficient way that saves time.

After conducting the experiments, The DatAR software proved that it is a better approach than the old data visualization techniques, especially when it comes to dealing with three-dimensional data, where the data is previewed clearly and simply. Also, the DatAR showed that Augmented Reality is able to enhance the user's data visualization experience.

6.1 Limitations and Future work

In the current circumstances, especially during the COVID-19 pandemic. The DatAR software could not be tested by many participants. As a result, the number of participants in the testing phase was not enough. As mentioned before, the number of participants was only ten. This problem was the main limitation faced in the DatAR.

Taking about future work, many goals need to be achieved to make the DatAR system more efficient and smoother. Among these goals is to find a smoother QR code reader than ZXing, this will make the process much easier. The ZXing QR code reader works perfectly on the laptop's camera. However, it is a bit laggy on the Android's camera. This was one of the main complaints in the testing phase. As a result, if a smother QR code reader is found, the process will be much easier.
The second goal is to merge the python application with the DatAR system. Merging the QR code generator

with the DatAR system, will save the user's time and the process will be much easier.
The third goal is to provide a user manual at the beginning of the application. Providing the user with a manual when the DatAR application starts, will give the user a clear view of how the application works and will make his first trial a smooth one.
The last thing is that the number of participant in further research should be a large number to infer more conclusion in this field.

Appendix

Appendix A

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