T. R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF COMPUTER ENGINEERING

PIANO TEACHING MOBILE APPLICATION WITH AUGMENTED REALITY

Master's Thesis

Ismail Mohamed JAMAL

Supervisor
Prof. Dr. Erdal KILIÇ

SAMSUN
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ÖZET

ARTIRILMIŞ GERÇEKLİK İLE PİYANO ÖĞRETİMİ MOBİL UYGULAMASI

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Bilgisayar Mühendisliği Ana Bilim Dalı
Yüksek Lisans, Ocak/2022
Danışman: Prof. Dr. Erdal KILIÇ

Piyano, müziğin en önemli alanlarından biridir ve dünyanın her yerindeki müzik mekanları, piyano öğrenmek isteyen çok sayıda insanı ağırlamaktadır. Bu yoğun talebe rağmen müzik kurumları öğrencilerden piyano dersleri için yüksek ücret almaktadır. Bu konuyla ilgili yapılan çalışmalar, kurulumu pahalı cihazlar gerektirdiğinden öğrenme maliyetleri sorununu çözememiştir. Bu çalışmanın amacı, hayatımızın vazgeçilmez bir parçası haline gelen akıllı telefonlar gibi temel artırılmış gerçeklik cihazlarıyla herkesin kullanabileceği uygun fiyatlı, basit, kurulumu kolay ve erişilebilir bir mobil piyano öğretimi uygulaması oluşturmaktır. Bu çapraz platform uygulaması, Android veya iOS akıllı telefonlara yüklenebilir. Oyuncu, orijinal bir MIDI klavyenin önünde oturur, uygulamayı başlatır ve bir müzik parçası çalmak için uygun modu seçer. Uygulama, doğru zamanda dokunulması gereken piyano tuşlarını kullandığı akıllı telefonun ekranında görüntüler. Ayrıca oyuncunun el hareketlerini izlemek için de akıllı telefonun kamerasını kullanır. Her şarkının, oyuncunun elde etmesi gereken ağırlıklı bir puanı vardır. Oyuncu oynamaya devam ettikçe, kazanılan puan ekranda görüntülenir. Oyun tamamlandıktan sonra, nihai puan, oyuncunun performansı hakkında paylaşılan geri bildirim olarak ekranda görüntülenir.

Anahtar Sözcükler: Artırılmış Gerçeklik, Piyano Öğretimi, Unity, Vuforia, Mobil Uygulama.

ABSTRACT

PIANO TEACHING MOBILE APPLICATION WITH AUGMENTED REALITY

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Institute of Graduate Studies
Department of Computer Engineering
Master, January/2022
Supervisor: Prof. Dr. Erdal KILIÇ

The piano is one of the key fields of music, and music venues worldwide welcome a huge number of people interested in learning it. Despite this high demand, music institutions charge students a high price for piano lessons. The conducted studies related to this topic didn't solve the issue of learning costs since they required expensive devices to set up. The purpose of this study is to create an affordable, simple, easy-to-set-up, and accessible piano teaching mobile application that everybody can use with their basic augmented reality devices, such as smartphones, which have become an essential part of our lives in the last decades. This cross-platform app can be installed on Android or iOS smartphones. The player sits in front of a genuine MIDI keyboard, launches the app, selecting a music track and the proper mode to play in. The app displays the piano keys, which must be touched at the right time, on the screen of the smartphone. It also uses the smartphone's camera to track the player's hand movements. Each song has a weighted score that the player should achieve. The earned score is displayed on the screen as the player continues playing. After the game is completed, the final score is displayed on the screen as shared feedback on the player's performance.

Keywords: Augmented Reality, AR, Teaching Piano, Unity, Vuforia, Mobile Application

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To begin with, I thank Allah, the Almighty, for giving me such enormous strength, opportunity, patience, courage, and capability to move forward and finish this research successfully. Furthermore, attaining a goal like this requires the support of genuine people who can encourage you and push you ahead when you're feeling down or fatigued. My supervisor, who is also the head of the department of computer engineering Prof. Erdal KILIÇ deserves my gratitude and heartfelt appreciation for his invaluable assistance, never-ending encouragement, and unwavering faith in my talents. I owe him huge respect and gratitude for everything he has done for me during this research. Without his assistance, I would not have been able to finish my thesis. I also want to express my appreciation to all of my lecturers who helped me throughout my educational journey.

My deepest appreciation goes to my loving family: mom Maryama, dad Mohamed, my wife Maria, my two lovely daughters Fatima and Maryama, and my siblings, for their love, moral, and technical support. I'd like to thank all of my remaining family members as well as everyone who helped me throughout my education. I'm sorry I won't be able to list them all on this page. Finally, I am thankful to my soulmate friend Mohamed Kader Hajiwali for his endless motivation and support specially for waking me up every morning to pray the morning prayer together in the masjid. Also, thanks to all my friends. Their generous assistance and support made my education and living in Turkey an unforgettable experience.

Ismail Mohamed JAMAL

CONTENTS

ABBREVIATION OF TERMS

ADEPT	Augmented Design to Embody a Piano Teacher
AR	Augmented Reality
BCI	Brain Computer Interface
CPU	Central Processing Unit
GPS	Global Positioning System
GS	Gained Score
HMD	Head Mounted Display
iOS	iPhone Operation System
MEMS	Micro Electro-Mechanical System
MIDI	Musical Instrument Digital Interface
MR	Mixed Reality
OS	Operating System
PS	Pressed Note
VR	Virtual Reality
RAM	Random Access Memory
SDK	Software Development Kit
UI	User Interface

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1. INTRODUCTION

The direct and indirect effects of technology on our daily lives and behavior patterns have increased dramatically during the last three decades. It has affected almost every aspect of our daily life, including medical, business, education, and research. Many previously tough tasks that required a lot of time and energy have been simplified and quickened due to technological innovations. This development has led to a significant increase in the number of people who rely on technology. The smartphone is the most commonly used everyday device, at least in the pockets of everyone in the world today. Technology has facilitated and improved traditional teaching methods in the field of education, allowing students and teachers to simply participate in research-related experiments in a comprehensive, visual, and imaginative manner. One of the fastest developing areas of technology today that has had a significant impact on education is Augmented Reality (AR). This chapter will briefly present the history of augmented reality (AR), motivation and contribution, the difference between AR and virtual reality (VR), augmented reality architecture, different types of devices used in AR, types of AR systems, and areas of AR applications. Finally, the chapter will conclude by outlining the organization of the thesis.

The first demonstration of AR can be traced to the 1950s, when cinematographer Morton Heilig envisioned cinema as an activity that could successfully bring the audience to the on-screen action using all of their senses. Heilig created a Sensorama prototype based on his vision, which he articulated in "Cinema of the Future" in 1955 and which predated digital computing in 1962 (Carmigniani et al., 2011). In 1966, as Figure 1.1 illustrates, Ivan Sutherland introduced the head-mounted display. Also, he was the first to develop an AR application and use an optical transparent head-mounted display In 1968 (Laurence et al., 2005). Myron Krueger developed the Video Place in 1975, a room that for the first time allowed audiences to interact with virtual objects.

Later, while assisting personnel in the assembling of wiring and cables for an airplane, Boeing's Tom Caudell and David Mizell came up with the term "augmented reality" They also started to discuss the benefits of AR over Virtual Reality (VR), including the use of less electricity due to the use of fewer pixels (Laurence et al., 2005). After a while, L.B. Rosenberg developed Virtual Fixtures, which was among the first working AR applications, and illustrated how it managed to improve human performance, while Steven Feiner, Blair MacIntyre, and Doree Seligmann proposed an AR application prototype called KARMA, which became the first major paper in the field of AR (Milgram and Kishino, 1994).

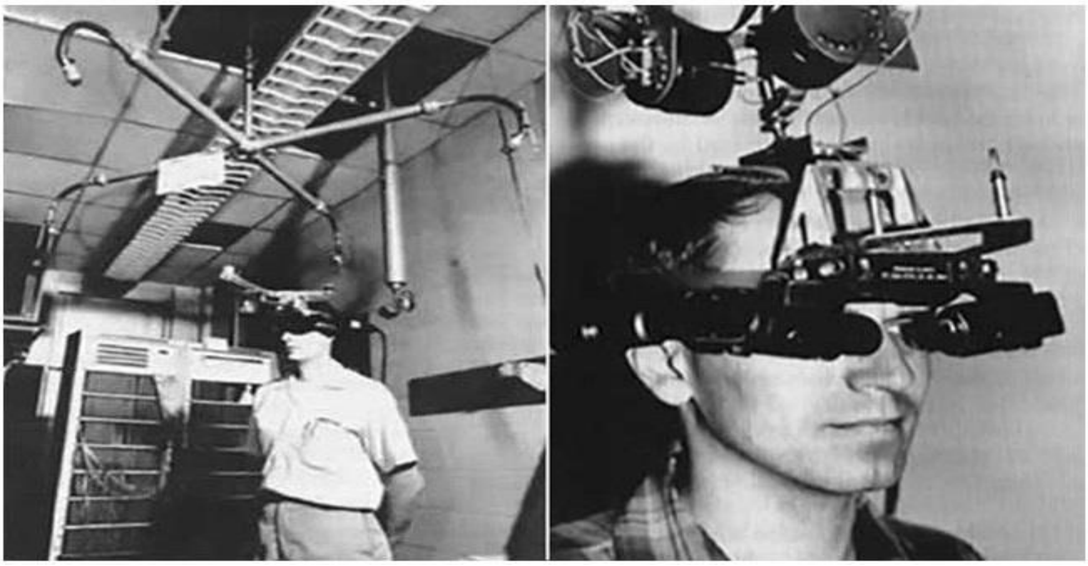

Figure 1.1. Sutherland's Head-Mounted-Display (Carmigniani et al., 2011)

Ronald Azuma conducted the first AR survey in 1997, describing it as a merger of real and virtual worlds that are both tracked in 3D and interactive in real time (Laurence et al., 2005). In 2000, Bruce Thomas demonstrated ARQuake, the first outdoor mobile AR game, at the International Symposium on Wearable Computers. In 2005, the Horizon Report (Anonuymus, 2010) predicted that AR technologies would experience rapid growth in the next 4–5 years, and in the same year, camera systems were developed that could analyze physical environments in real time and correlate positions between objects and the environment. These camera systems participated in the growth of the AR technologies and evidently proved the Horizon Report's prediction because they have been the cornerstone for integrating virtual objects with reality in AR systems.

In the years followed, alot of AR applications were created, especially for mobile devices, such as Wikitude AR Travel Guide, which was launched in 2008, but also for medical applications in 2007. A vast number of AR applications and systems are just being developed as a result of technological developments. However, the field of AR has flourished and improved tremendously in the past few years and continues to do so (Anonymous, 2009). Since then, the field has significantly expanded. The International Workshop and Symposium on AR is one of the conferences dedicated to this topic that have been started. Figure 1.2 depicts the evolution of AR over time.

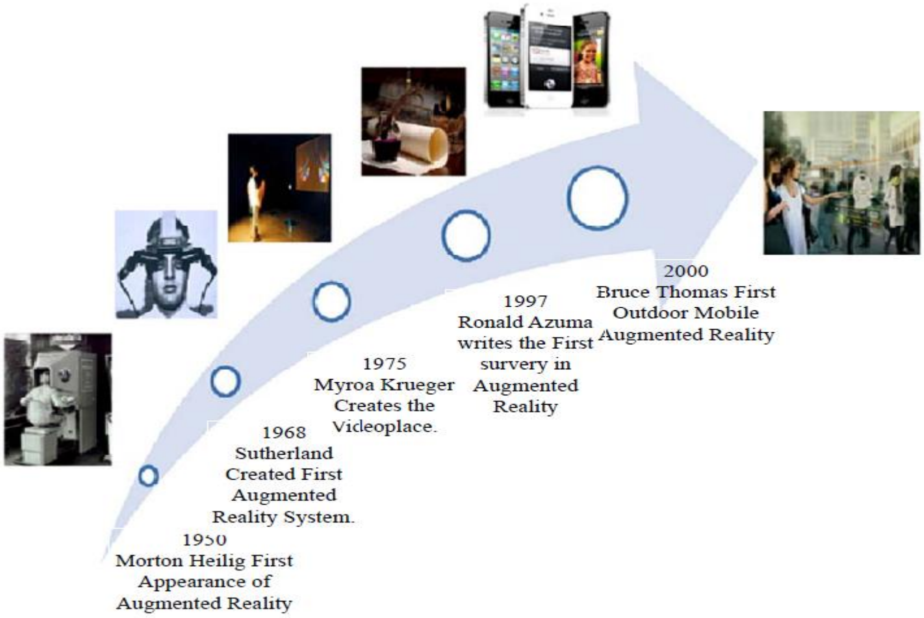

Figure 1.2. Evolution of AR (Alkhamisi and Monowar, 2013)

AR become a hot topic and rapidly evolving field of application in recent years, from industrial market segments to mainstream technology, it can be defined as one of the leading technologies that will produce a "next generation reality-based interface". It is related to the concept of "Mediated Reality," where the computer transforms the current view of the user's surrounding real environment (Graham et al., 2012). As a result, AR is opposed to conventional computer interfaces that take the users into a world that is entirely different from the current real world on the screen. Modern AR technologies such as computer vision and object recognition give the user the ability to interact with and control the information and contents of the real environment around them by displaying them, this information can be virtual or real (Azuma, 1997), such as viewing other real-world sensed or measured data, such as electromagnetic radio waves, presented in precise alignment with their actual position in space (Mann, 2015; Mann, 1992). In AR, various senses such as smell, touch, and hearing can be superimposed.It can also be used to supplement or replace missing sense organs in people employing substitutional sensory devices, such as delivering audio cues to help blind or low-vision people see, or visual cues to help deaf people hear.

The information transferred by the virtual object can assist the user in performing daily tasks such as teaching someone to play the piano or demonstrating digital objects through a headset (Chow et al., 2013). AR applications include education, medical visualization, entertainment, advertising, maintenance and repair, explanation, robot path planning, etc. The music world, is one of the fields that is used to teach and learn with AR technology, such as piano, guitar, and violin.

1.1. Motivation and Contribution

Music is an important part of every culture and society (MacDonald, 2013). It is also a powerful stimulant that has an impact on the human brain. When listening to music, the human brain begins to generate widespread emotional processing, attention, and past memory processing (Sarkamo et al., 2008). The piano is one of the most popular musical instrument families in the world. It has a significant role in the composition of various sorts of songs, ranging from classical to rock. It's also noted for being loud, having a wide range of sounds, and being intense (Jin Yang, 2016).

The demand for piano lessons is high, and while many institutes throughout the world offer traditional piano lessons with human instructors, the rates are prohibitively expensive for pupils. With the rapid advancement of technology, developers have already done some work and created piano learning support applications employing AR and Mixed Reality (MR) technologies. As a result, by sitting in front of a real piano and seeing to-do lists through AR devices such as head-mounted displays (HMDs), smart eyeglasses, and so on, these applications provide piano learners guidance and instructions. Most of the developed applications till date make use of pricey AR gadgets like Microsoft HoloLens, which are out of reach for most people, while others require the use of supplementary equipment like external webcams, projectors, and so on, making them difficult to install or set up. Furthermore, the existing mobile versions of these applications are insufficient for the situation that we are constructing.

This become a good enough motivation to propose an application to increase learners' experience and motivation by providing unlimited practice hours. We develope an economical, simple, easy-to-set-up, and accessible piano teaching mobile application that teaches students how to play the piano without the need for a pianist. The application is cross-platform and anyone can download it to their mobile phone, whether it is an Android or an iPhone. The reason we chose the mobile application as an augmented reality device is that it become an indispensable part of our lives in recent decades. There were about seven billion users in 2016. The growth of cellphones, along with their ever-increasing capabilities, empowers applications in a wide range of fields (Fadi, 2016).

Smartphones are more cheaper and much easier for everyone to access compared to other devices used for augmented reality like head-mounted-displays (HMD) and so on. Even more importantly, the mobile is a device that is equipped with all the various necessary devices to create a complete augmented reality application, such as cameras for tracking and identifying, a screen for displaying virtual augmentations, and speakers for generating audio. The user will be seated in front of a real MIDI piano keyboard for playing. As will be seen in the literature review, most of the applications created are based on head-mounted-displays, which are difficult for everyone to access, while other applications do not give the ability to launch real pianos.

1.2. VR versus AR

Both virtual reality and augmented reality are in the mixed reality world, In this section, the difference between them is explained.

1.2.1. VR

To begin with virtual reality (VR), is a technology that takes the viewers to an entirely artificial environment, which can be fully fictional, which is different from the viewers current real environment or a close replica of it. It's feasible to have visual, audio, and practical experiences. Virtual reality immerses the viewers totally in an artificial environment while preventing them from seeing the current real environment.

1.2.2. AR

Regarding AR, it is different from virtual reality because it only improves the viewers sense of reality by superimposing virtual content and cues on the real environment in real time. The viewers engagement in the virtual world isn't full since they can always see and follow the events in the real environment around them. The main objective of AR is to improve the viewer's life by delivering virtual information into his immediate surroundings as well as any indirect perspective of the nearby real-world environment, including a live video stream. As a result, AR is so close to the real world, whereas virtual reality (VR) is closer to a complete virtual environment, as illustrated in Figure 1.3. (Cai et al., 2012).

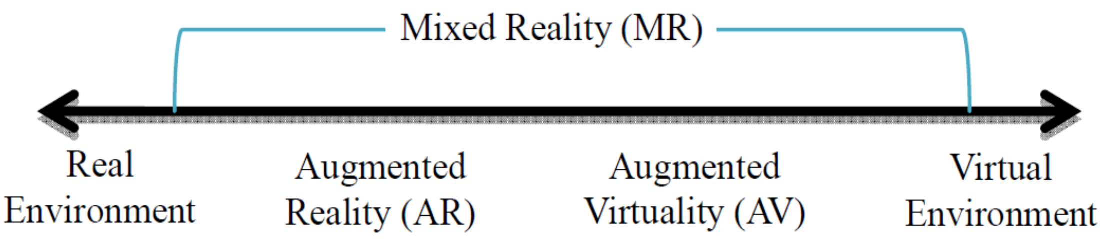

Figure 1.3. Reality-Virtuality Continuum (Milgram and Kishino, 1994)

1.3. AR Archıtecture

The architecture of AR is based on the activities performed, these activities include: scene capturing, then identifying the captured scene to superimpose, processing the scene, and displaying the augmented scene (López et al., 2010). Following are the detailed descriptions of these activities:

1.3.1. Scene Capturing

Scene capturing is the first step to do in AR, scene capture devices are physical components that are used to capture/record the surrounding real environment that should be improved. Scene-capture equipment is divided into two categories:

- Video-through devices: such as video cameras and smartphones, these devices capture reality in a different way than other AR visualization devices.
- See-through devices: such as head-mounted-displays, these devices capture reality and provide it with augmented information (Grasset et al., 2012).

1.3.2. Scene Identification

After capturing, next step is to identify the scene, thus, scene identification is one of the most important components of reality augmentation architecture, they are used recognize by comparing the captured images/videos with those stored in the system. There are two types of scene identification techniques and they are explained below:

- Marker-based AR: the marker-based technique employs markers in the form of visual tags embedded inside the real-world scene that the AR system perceives (Grasset et al., 2012). Figure 1.4 illustrates a marker in action.
- Marker less AR: the marker less technique does not utilize markers and instead rely on technology for scene identification. For example, the AR browser employs tags to assist users in visualizing and surfing digital material in a real-world setting. E.g, as you walk around, the browser may readily provide information about your position, such as the location you are interested in, clinics, restaurants etc (Metz, 2012). Figure 1.5 illustrates this.

Figure 1.4. Marker-less AR (Sheldon et al., 2019)

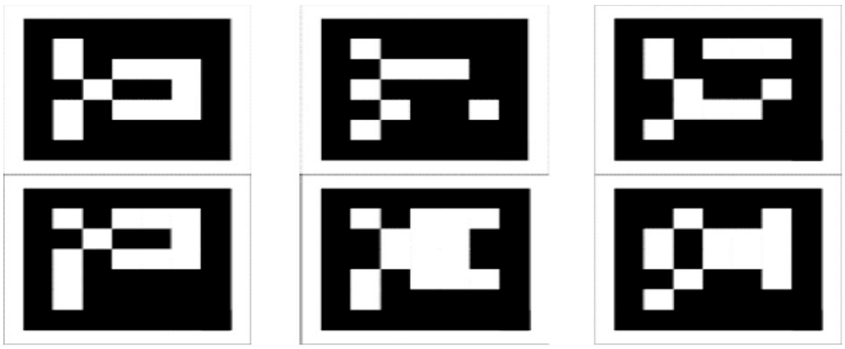

Figure 1.5. Marker-based AR (Takahashi et al., 2018)

1.3.3. Scene Processing

When the scene is identified by the system, the next step is to process the system, the system looks for the corresponding virtual model for each marker in 3D after estimating the place of a given marker in real space using the camera's inner and outer parameters.

1.3.4. Scene Visualization

The last step in AR architecture is to visualize the scene, in this step, the system generates an image of the projected 3D object in real space, and when using non-marker scene identification approaches, it generates a scene image that combines reality and virtuality and conveys digital information (López et al., 2010).

1.4. AR Devıces

AR Devices include display devices, input devices, tracking devices, and computer. Today's mobile devices, such as smartphones and tablets put all the devices we mentioned together in one place. Next subsections explain AR devices.

1.4.1. Display Devices

There are three approaches to display in AR, and they are: head-mounted displays (HMD), handheld displays, and spatial displays.

- A Head-Mounted-Display (HMD): is a device that is mounted on a headset, such as a harness or helmet, they display visuals of both the actual world and virtual objects in the user's field of view. HMDs have six degrees monitoring sensors that allows them to align virtual information with the physical world & adjust to the user's head motions. Figure 1.6 illustrates the HMD displays.
- A handheld display: is a lightweight computing device with a display that the user may hold in their hands. For their six degrees of freedom tracking sensors, they use digital compasses and GPS units, as well as marker-based systems (Bimber et al., 2007). Handheld devices for AR include smartphones, PDAs, and tablet PCs. Figure 1.7 illustrates the handheld display.
- Spatial AR: employs video projectors, optical components, holograms, radio frequency tags, and other tracking technologies to project graphic information directly onto physical objects without the user having to wear or carry the

display. Figure 1.8 illustrates the spatial display.

Figure 1.6. Head Mounted Display (Martín-Gutiérrez et al., 2017)

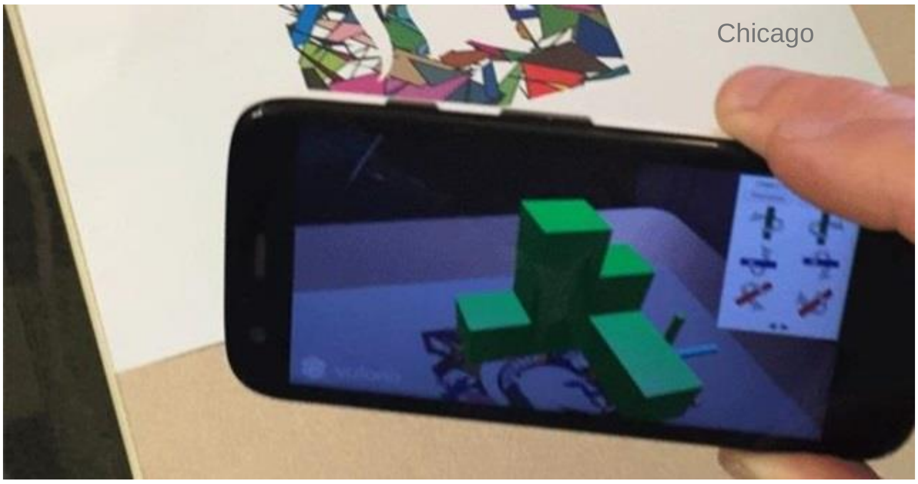

Figure 1.7. Handheld Display (Bell et al., 2018)

Figure 1.8. Spatial Display (Jin, 2017)

1.4.2. Input Devices

Input devices used in AR contain several types of sizes and designs. In some AR systems, gloves are utilized as an input device. To give an instance, Reach Media (Lee et al., 2010) employs a wireless wristband. When it comes to smartphones, however, they can be considered as pointing devices. For instance, on the Android phone, Google Sky Map needs the stars or planets' directions on the phone to be pointed at in order to learn their names. The sort of application for which the system is being designed and the type of the selected display devices mostly determine the type of input devices that will be employed for the system. If a user needs to be hands-free, for instance, the selected input device will be one that allows the user to use his or her hands for the applications without needing additional awkward motions or being held by the user. Gaze engagement or the wireless wristband utilized in the game are instances of these input devices (Reitmayr and Schmalstieg, 2003) (Lee et al., 2010). Similarly, if a system uses a handheld display, developers can use a touch screen input device.

1.4.3. Tracking Devices

Tracking devices used in AR for scene tracking include digital cameras and other optical sensors, global positioning systems (GPS), accelerometers, solid-state magnetometers, and wireless sensors. Every approach has a different precision and accuracy, which is dictated by the system being constructed (Yi-bo et al, 2008).

1.4.4. Computer

Computer here means processors and memories, as a technology that deals with graphics, AR applications need a strong microprocessor (CPU) and a massive volume of memory (RAM) to analyze images taken. With the evolution of smartphone and iPad technologies, it is possible that this backpack format will be supplanted by a smaller, more modern-looking device. For stationary systems, a normal desktop with a powerful graphics card can be used. In this application, the smartphone is a core device for implementation..

1.5. AR Systems

There are two types of systems in AR: mobile and fixed systems. A mobile systems allows users to roam around independently and is not restricted to a certain area, giving the user the ability to travel around wirelessly. While fixed systems, as opposed to mobile systems, are stable or fixed to the position where they have already been installed, so users should utilize them wherever they find them without moving unless the complete system installation is being relocated. As a result, the developer should first consider and decide what type of system he will develop, because this will affect the type of system components that will be used, such as the user interface, tracking system, and display method. Fixed applications, for example, do not use global positioning system (GPS) tracking, while mobile applications do. Our system, by the way, is the fixed application.

1.6. AR Applications

AR applications have grown progressively in the last few decades, with benefits seen in a variety of fields such as health care, business, education, and entertainment. This section summarizes previous research that makes use of AR applications.

1.6.1. Medical

The desire to visualize medical data and the patient inside the same physical location is the driving force behind medical AR. This would necessitate in-situ viewing of co-registered heterogeneous data in real time, which is likely the goal of many medical AR technologies. As aforementioned, Sutherland introduced a tracked head-mounted display as a breakthrough human-computer interface for viewpoint-dependent visualization of virtual elements in 1968. Only two decades later, Roberts et al. developed the very first medical AR application (Bajura et al., 1992). In the medical field, ultrasound imaging is also another AR application (Blum et al., 2012). Through the use of an optical see-through display, the user can see a volumetric projected view of the baby superimposed on the pregnant woman's belly. When the user moves, the picture appears to be inside the belly and is displayed accordingly (Sielhorst, 2008).

Moreover, Blum et al. demonstrated the first stages towards a Superman-like X-ray vision, where the viewer controls the AR visualization through the use of a brain-computer interface (BCI) device and a gaze-tracker (Wen et al., 2014). Wen et al. (2008) suggested a collaborative surgical approach directed by hand gestures and enhanced by an AR-based surgical field. The authors created a system-assisted natural AR guiding technique that considers the advantages of AR visual guidance information and surgeon experience and manages to help with surgical precision (Chang et al., 2013).

1.6.2. Education

In the educational sector, AR is introducing lots of new teaching and learning capabilities to the mainstream. In mixed reality, students can envision complicated spatial relationships and abstract concepts (Billinghurst and Duenser, 2012), discover patterns that would be difficult to observe in the real world (Thomas et al., 2010), deal with virtual entities in two and three dimensions (Yuen et al., 2011), and practice important skills that would be hard to learn or practice in other learning environments that technology has developed (Johnson et al., 2010). As a result of the potential educational benefits above-mentioned, AR was predicted to be among the most important fast-growing technologies in educational sector over the next five years (Cavallaro, 1997).

1.6.3. Entertainment and Games

In the field of entertainment and gaming, AR is playing an important role in creating a lot of popular games, such as Kings of Pool, Knightfall AR, and Pokemon Go. AR is also used for displaying game objects that are used for superimposing live sports broadcasts. AR can assist companies by projecting virtual advertisements and product promotions after a large audience has been reached. Swimming pools, race tracks, and various athletic arenas such as football stadiums are some of the most typical and popular venues to set up simply for video-through augmentations employing monitored camera feeds (Krevelen and Poelman, 2007). One example is the Fox-Trax system (Azuma et al., 2006), which is used to show the location of an invisible moving hockey puck as it travels quickly across the ice. AR, on the other hand, can be used to highlight other activities such as car racing, tennis ball trajectories, and live swimmer movements (Cavallaro et al., 2011). Because of the prediction techniques such as chroma-keying, the comments and annotations are projected on the field rather than on the players (Spies et al., 2009).

1.7. Organization

Chapter II presents some of the most recently conducted researches that is related to piano teaching application with augmented reality, followed by an explanation of the system proposed in this study.

Chapter III explains the proposed system's conceptual framework, including the architecture design, which includes hardware components, and the user interface (UI) design. The system's features, such as piano roll, which shows how virtual augmentation are displayed on the screen, and final score calculation, are discussed under the UI design.

Chapter IV outlines the hardware devices as well as the software tools and libraries utilized to implement the proposed system, also tracking setup, creating image targets for the AR camera, and generating piano audio.

Chapter V presents the results of the system evaluation as well as the proposed feedback, suggestions, and recommendations for the system. Finally, Chapter VI concludes with a conclusion as well as future work suggestions.

2. RELATED RESEARCHES

This chapter reviews some of the most recent undertaken researches and developed applications that is related to piano teaching mobile applications using augmented reality, such as HoloKeys, Mr. Piano, ADEPT and so on. The chapter concludes with an overview of the proposed system.

2.1. AR-Based Individual System for Piano Training

(Guo et al., 2020) proposed an AR-based individual system for piano training that can automatically generate hand action animations and show them on actual pianos using head-mounted displays (HMDs) (Guo et al., 2020). Given a piece of music as input, the system uses a hidden Markov modal to predict the relationship between target keys and fingers. They used musical prior knowledge to construct a generating mechanism for hand actions based on the prediction results, intending to coordinate arm and finger motions while keeping naturalness and convenience in mind. As a result, it solely teaches how to play the piano.

2.2. HoloKeys Application

(Hackl and Anthes, 2017) developed HoloKeys as a prototype implementation of an AR teaching piano application (Hackl and Anthes, 2017). HoloKeys is a virtual piano that runs on a head-mounted display that the user wears while sitting in front of a real piano. The application displays virtual keys overlaid on the physical keyboard to indicate which notes should be played. The HoloKeys application was also implemented using Microsoft HoloLens, and a tablet device as hardware.

2.3. Augmented Design to Embody a Piano Teacher (ADEPT)

(Gerry et al., 2019) suggested the Augmented Design to Embody a Piano Teacher (ADEPT) system, is a mixed reality application that students use under the supervision of a piano specialist. The specialist demonstrates how to utilize the fingers, move the hands, and configure the torso properly to sound out the piano using the embodied perspective (Gerry et al., 2019). It practically overlays a video recording of the teacher's hands on top of the student's hands in the students' head-mounted headset. The embodied music cognition inspired the ADEPT system by emphasizing the music perception and performance role of human body movement.

2.4. ARPiano Efficient Music Learning

(Trujano et al., 2018) introduced the ARPiano Efficient Music Learning (Trujano et al., 2018). a mixed reality experience that employs a MIDI piano keyboard and a multifunction knob to improve the learner's music experience visually. ARPiano uses AR to enlarge a physical piano and find a physical keyboard so that various items can be overlaid on the keyboard and certain notes. HoloLens was used to implement this application.

2.5. AR-Supported Piano Learning System

(Cai et al., 2019) proposed the AR-Supported Piano and the AR-Based Supporting Live Group System for piano learning (Cai et al., 2019). AR-Supported Piano Learning System allows the teacher and student to watch each other's activities through their HMDs (Cai et al., 2019). The technology takes into account instruction mapping between the music sheet and the keyboard to make learning actual note position easier for the student. The system uses Microsoft HoloLens as the Head-Mounted-Display and does not provide any feedback on the player's performance at the end of playing.

The AR-Based Supporting Live Group System has two options: the first is the Formal Learning Mode, which allows students to see the teacher's key pushing and finger movement directly from their HMDs during the learning process to increase mutual comprehension (Cai et al., 2019). The second option is the Group Competition Mode, which was created to encourage students to compete with one another to boost their desire to learn the piano.

2.6. Marker-less AR-Based Piano Teaching Application

(Huang et al., 2011) proposed the Piano AR, a marker-less AR-based piano teaching application (Huang et al., 2011). The application recognizes the configured keyboard from the taken image by identifying all conceivable keyboard outlines and matching the number of black keys. They created a three-dimensional coordinate system based on the keyboard after tracking it and then calculated the position of each piano key. Virtual fingers can play on the real keyboard according to the imported piano score. Learners can play the keyboard by following the virtual fingers.

2.7. Portable Piano Tutoring Mobile Application (Mr. Piano)

(Sun and Chiang, 2018). Presented the Portable Piano Tutoring Mobile Application (Mr. Piano), is a portable piano tutoring mobile application that allows users to practice at numerous locations (Sun and Chiang, 2018). It has virtual keys that are the same size as those on a traditional piano. Within the limits of permissible visibility and the field of view obtained by the webcam, the projected piano can cover up to four full octaves in standard size. A portable micro-projector, a wireless video streaming device (Chromecast), an external webcam, and a smartphone or a tablet are all required for the system to work (or a tablet).

2.8. Proposed System (EasyARPiano)

EasyARPiano is a cross-platform application that works on both Android and iOS smartphones. The player sits in front of a physical MIDI piano keyboard and starts the application by choosing one of the tens of music songs available, as well as the appropriate playing speed (beginner, medium, or expert). The application uses the smartphone's screen to provide clues by displaying falling notes on the piano keys that must be pressed at the exact moment. It also tracks the player's hand movements using the smartphone's camera. Each song has a weighted score that the player should score. The gained score is displayed on the screen while the player keeps playing the song. The final score is presented on the screen when the game is finished as shared feedback on the player's performance.

3. CONCEPTUAL FRAMEWORK

This chapter presents the conceptual framework of the proposed system, including the architecture design. The architecture design outlines the hardware devices used for the system and the user interface (UI) design. Under the UI design, the features of the system are covered, such as the piano roll, which demonstrates how virtual augmentations are displayed on the screen, as well as calculating the final score of the user.

3.1. Architecture Design

This section discusses the hardware components that make up this system. The MIDI keyboard and Smartphone, which are required hardware for this system, are described in the following subsections.

3.1.1. MIDI Keyboard

A real physical MIDI keyboard is a core device in our system, because the player will be playing the piano. We designed the system to work with both 25-note keyboards (15 white and 10 black) and 37-note keyboards (22 white and 15 black). We hung a marker labeled with the key name, such as C4, D4, E5, G5, on each key. We've drawn some little square textures around the key names for better tracking. These sorts of MIDI keyboards were chosen for two reasons: First, they are the most often utilized keyboards for learning the piano nowadays due to their excellent instrumental compositions and their light and size weightiness, making them extremely portable. Second, it is of a size that allows it to be fully positioned inside the camera range of the tracking smartphone.

3.1.2. Smartphone

Smartphone is another core device in our system since it is used to perform multiple tasks at once. After downloading the app on the smartphone (Android or iOS), the player sits in front of the physical MIDI keyboard and opens the system. The smartphone’s camera is used to scan the MIDI keyboard first to identify it and then track the player's hand motions. The smartphone's screen is used to display the augmented falling virtual notes, the player's updated score while playing the song, and the ultimate score after playing it. As well as, the smartphone's speaker emits the music sound of the pressed keys on the piano. Because our system is a fixed projection type, a smartphone holder such as a tripod should be used to adjust the camera with the piano and maintain its stability. Figure 3.1 illustrates the architecture design of the system, which includes the MIDI keyboard and the smartphone.

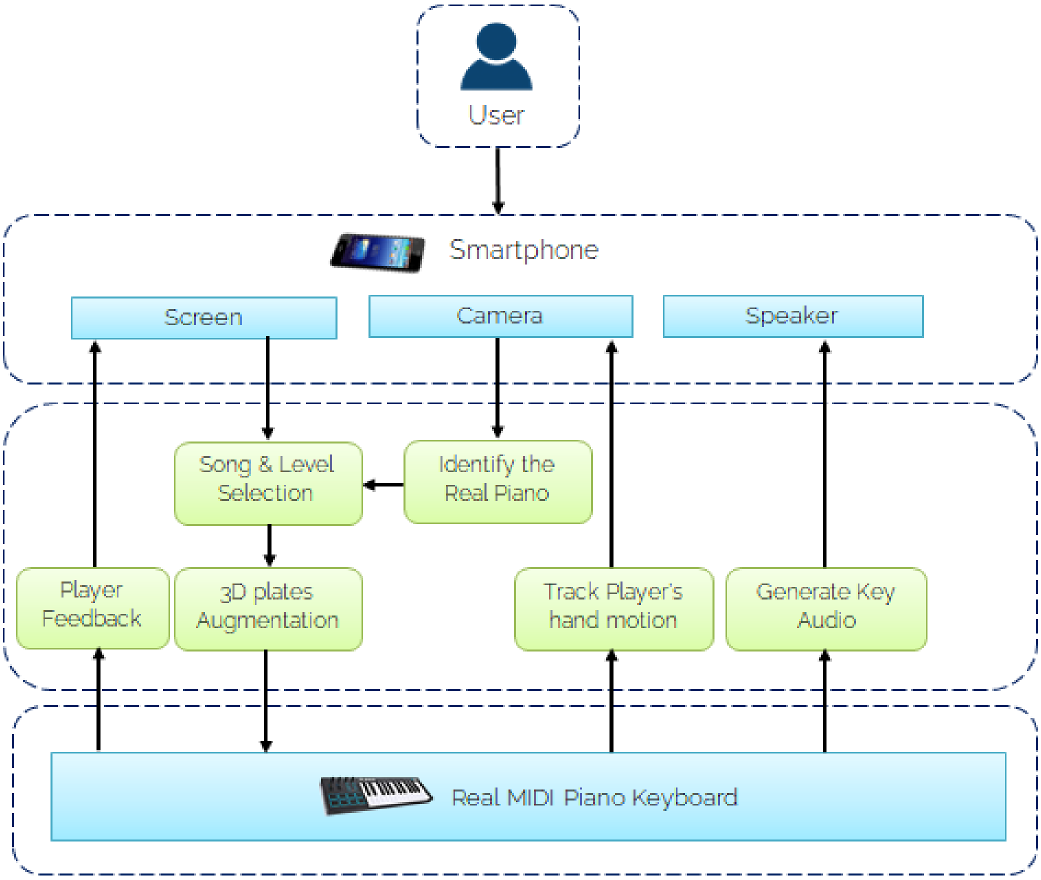

Figure 3.1. System's architecture design

3.2. User Interface (UI) Design

We designed a simple and attractive user interface (UI) to manage player actions by configuring and toggling between the system settings. From selecting the system language to quitting the system, the player can go through the various sub-menus grouped in the main menu. The flowchart of the application's user interface operation is shown in Figure 3.2.

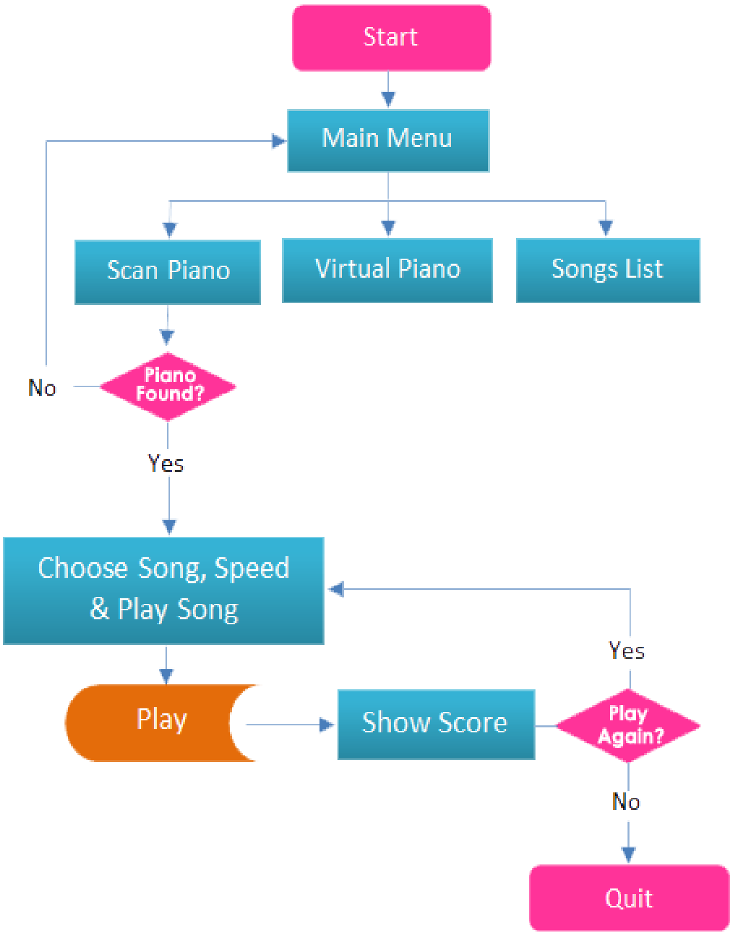

Figure 3.2. User Interface (UI) operation flowchart

3.2.1. Main Menu

The main menu is the application's first scene, it consists of four submenus. "Scan Piano", "Virtual Piano," "Songs List", and the last submenu "Quit" submenu. Figure 3 illustrates the submenus under the main menu.

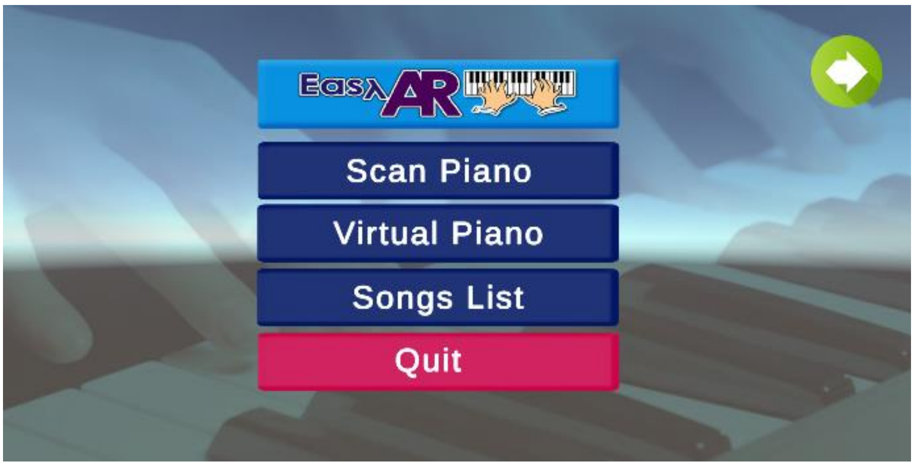

Figure 3.3. Submenus under the main menu

When the Scan Piano submenu is selected, the system opens immediately and uses the smartphone's camera as the primary AR camera to track and identify the corresponding piano in front of the player. Following the piano's identification, the details of the piano are displayed, and the player is given the option of selecting a song from the "Choose Speed" dropdown list, as well as adjusting the song's speed mode, and then starting to play the song by clicking on the "Play Song" button as shown in figure 3.4. There are three-speed levels to choose from: For new players, there is a beginner mode with a 60-beat per minute speed. The intermediate level offers a 90-beat per minute tempo and is aimed at players with a basic familiarity with the piano. The fastest of the three, with a 120-beat per minute tempo, is the Expert mode, which is suited for advanced players. When no piano is identified, the screen displays a notification that there is no piano found, followed by a button that allows the player to scan the piano again, as seen in Figure 3.5.

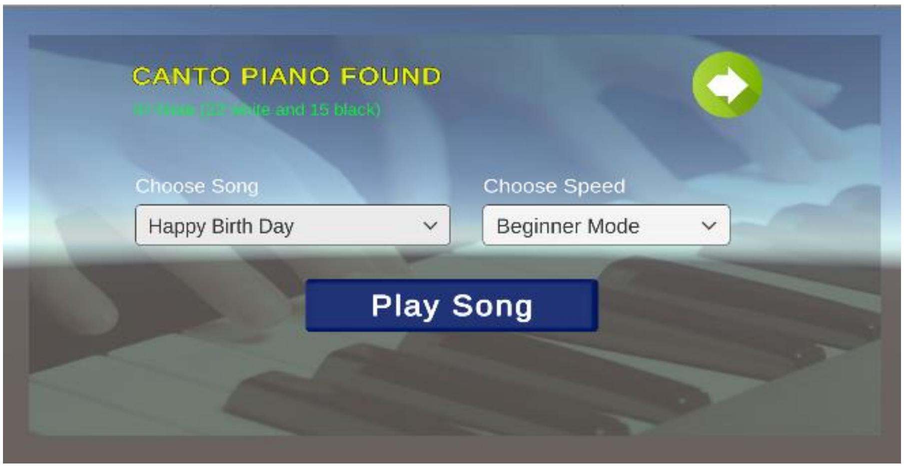

Figure 3.4. Piano Found

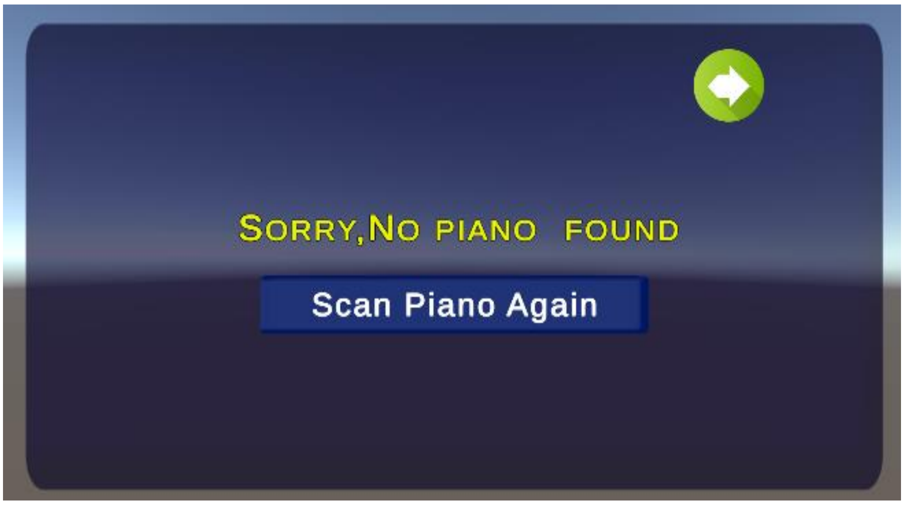

Figure 3.5. No Piano Found

The remaining are the "Virtual Piano" and the "Songs List" submenus. By selecting the virtual piano submenu, the player will be presented with a virtual piano that can be played on their smartphone. The list of songs accessible in the system is displayed when the player selects the "Songs List" sub-menu as seen in figure 3.6; the songs are usually updated by the system administrator.

Figure 3.6. Songs List

3.2.2. Piano Roll

As the user starts playing the song, blue rectangular virtual game objects (planes) fall from the top screen. Every game object goes on the line straight to the piano key, which must be pressed at the appropriate time by the player. The speed at which these objects fall is dependent on the player's chosen speed mode. The gained score is displayed on the left side of the smartphone screen when playing, as seen in figure 3.7.

Figure 3.7. Falling Notes Scene

3.2.3. Final Score

The final score is displayed on the screen once the player has finished playing the song, as seen in figure 3.8. The following is how the final score is calculated: Each falling note is worth 100 points; therefore if this song comprises 20 notes, it is worth a total of 2000 points. When the user taps the correct key at the exact time, the score is increased by 100, and when the key is missed or an erroneous key is touched, the score is increased by 0 as shown in Table 3.1.

Table 3.1. Final Score Calculation

Correct Note	C4	C4	D4	C4	F4	E4
Pressed Note	C4	C4	D4	C4	E4	E4
Gained Score	100	100	100	100	0	100

The total number of points earned by the player ∑ (Gained Score) is divided by the total number of points allocated for the song ∑ (Pressed Note), and the result is multiplied by 100.

$$\textbf{Final Score} = \frac{\sum(\textit{Gained Score})}{\sum(\textit{Pressed Note})} \times \mathbf{100}$$

Based on the information provided in Table 3.1, the total notes score are 600, the player lost 100 by missing 1 note and got 500 for correcting 5 notes, thus, the final score will be 83.3%.

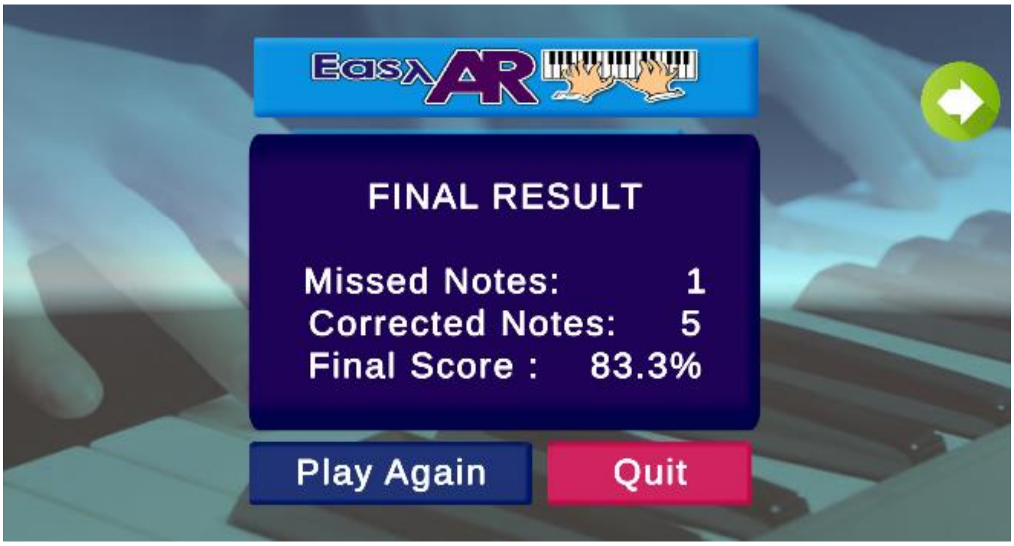

Figure 3.8. Player's Final Score

4. IMPLEMENTATION

In this chapter, the implementation of the system is explained. In the following sections, the hardware devices as well as the software tools and libraries utilized to implement the proposed system are described, along with tracking setup, creating image targets for the AR camera, and generating piano key sounds that are coupled with the player's real piano key pressing.

4.1. Hardware Devices

The subsections below describe the Impact LX25 + MIDI keyboard and the Samsung Galaxy A51 hardware devices used to implement this system.

4.1.1. Impact LX25+ MIDI keyboard

Impact LX25+ MIDI keyboard is used to implement this application. The Impact LX25+ MIDI controller is small and portable, yet it's packed with clever and expressive performance control that is not found in many high-end products. This keyboard consists of 25 keys (15 white and 10 black).

4.1.2. Samsung Galaxy A51

Samsung Galaxy A51 is used to test this application. The Samsung Galaxy A51 is a touchscreen smartphone with 6.50-inch screen size and a resolution of 1080x2400 pixels. It has a front camera with a 32-megapixel and a rear camera with a 48-megapixel, which is employed as the primary augmented camera for tracking in this application. Because our system is a fixed projection type, the Syvo WT 3130 Aluminum Tripod is used as a holder to maintain the stability of the camera.

4.1.3. Hardware Specifications

The developer should have these hardware devices which meets the system meets the following requirements to develop the proposed system.

Table 4.1. Hardware specifications

Computer		**Smartphone**	
CPU	Core i5	RAM	4 GB
HDD	250 GB	Screen Size	6.5"1080x2400 pixels
RAM	12 GB	CPU	Octa-core
MIDI Keyboard (25-key)		HDD	64 GB

4.2. Software Tools and Libraries

Software tools and libraries used to implement this system includes: Unity gaming engine, Vuforia tracking library, and Visual Studio Code for scripting C # programming.

4.2.1. Unity Engine

Unity is the ultimate cross-platform real-time 2D, 3D, AR, & VR development engine game engine developed by Unity Technologies (Anonuymus, 2021)., was first revealed at Apple Inc.'s Worldwide Developers Conference in 2005 to allow cross-device support. The engine can be used on a variety of devices, including desktops, mobile devices, and virtual reality headsets. It's a popular platform for producing iOS and Android mobile games. Unity includes a C# programming API as well as drag-and-drop functionality.

4.2.2. Vuforia Library

Vuforia is a software development kit (SDK) for mobile AR that allows developers to develop AR applications (Anonuymus, 2021).. Using computer vision technology, it recognizes and tracks planar graphics and 3D objects in real-time. Users can assess the tracking and stability of current area targets in their relevant settings using Vuforia.

Figure 4.1. Unity Logo (Unity, 2021)

Figure 4.2. Vuforia Logo (Vuforia, 2021)

4.2.3. Microsoft Visual Studio Code

Microsoft Visual Studio Code is a source code editor for Windows, Linux, and macOS (Anonuymus, 20021). It supports to development of many programming languages, including C#, Java, JavaScript, Python, C++, and others. For editing and debugging C# scripts in-game files in the Unity environment, Visual Studio Code is an excellent partner. Unity offers built-in support for launching scripts as an external script editor in Visual Studio Code. When Visual Studio Code is selected as an external script editor.

4.2.4. Software Specifications

The developer should have these software tools and libraries to develop and implement the proposed piano teaching system.

Table 4.2. Software specifications

Computer		**Smartphone**	
OS	Windows 10, MacOS 10	OS	Android 10, iOS 11
Unity	Unity 2020.3.21 Personal		
Vuforia	Vuforia Engine 10.2.5		
VS Code	Microsoft Visual Studio Code-x64-1.62.2		

4.3. Tracking & Visualization

As mentioned previously, tracking is one of the most important functions of augmented reality. It means recording the object in the real world and comparing it with the existing image targets that have been already stored in the system so that the corresponding virtual elements are augmented or visualized if the object is being identified.

4.3.1. Image Target

An image target should be created for the AR camera to track an object in the real world. A JPG or PNG image target can be created in Vuforia using the Vuforia Target Manager. The width of the image target should not be less than 320 pixels and the size should not exceed 2.25 MB. The collected features are later saved in a cloud or device database. They will later be downloaded as a Unity Asset Package and imported into Unity. The Vuforia engine assigns a star rating to each image target based on its quality, the better the quality, the higher the rate. The image target should be rich in detail, have good contrast, and have no repetitive patterns to maintain the best experience. As shown in Figure 4.3, our piano image target has a good rating feature. By comparing extracted natural features from the AR camera image to a known target resource database, the engine detects and tracks the image. The Vuforia engine will monitor the image and augment the content whenever the image target is identified.

Figure 4.3. Image Target Features

4.3.2. Tracking Setup

In the system, there is a list of songs that have been uploaded by the administrator. Every song has its own scene. Every scene has planes, which are 3D game objects with a blue rectangle shape. These planes are stored in an array sequentially and are used as falling virtual 3D objects for augmentation and superimposing. When the players start playing the song, the planes will begin to fall from the top of the smartphone's camera and travel in a straight line to the piano key to be pressed by the player. Planes have Rigidbody and box collider components. The rigidbody puts the plane's motion under the control of Unity's physics engine and pulls it downward by gravity. The drag property and the AddForce method of the rigidbody are used to increase and decrease the speed of the falling planes. As a result, the user can choose between beginner, intermediate, and expert mode. Virtual buttons have been put on every piano key on the image target. So, the AR camera tracks the player's hand movements and senses the pressed virtual button when the player hits the corresponding piano key on the real piano. The player cannot see the virtual button. To get a better and clearer tracking technique, we hung a marker with the key name, such as C4, D4, E5, G5, on each key and put some small square textures around the key names as shown in Figure 4.5. Box collider components define the shape of the plane for the purposes of physical collisions. When the plane collides with the virtual button, Unity calls the "OnTriggerEnter" method. While the player is playing the song, the gained points are displayed in the left bottom corner of the screen.The player can win points by hitting the piano key. While the plane is colliding with the virtual button, because when the plane leaves the virtual button's area, the "OnTriggerExit" method is called and the player loses those points. Under the virtual buttons, there are game objects used as target elements. With the help of the Vector3 class, every falling planes will travel directly in a forward straight line from their source position to the target elements, passing through the desired virtual button to be pressed. Finally, a UI canvas that contains the final points gained by the player is displayed on the screen. Figure 4.4. illustrates the tracking algorithm for the our system.

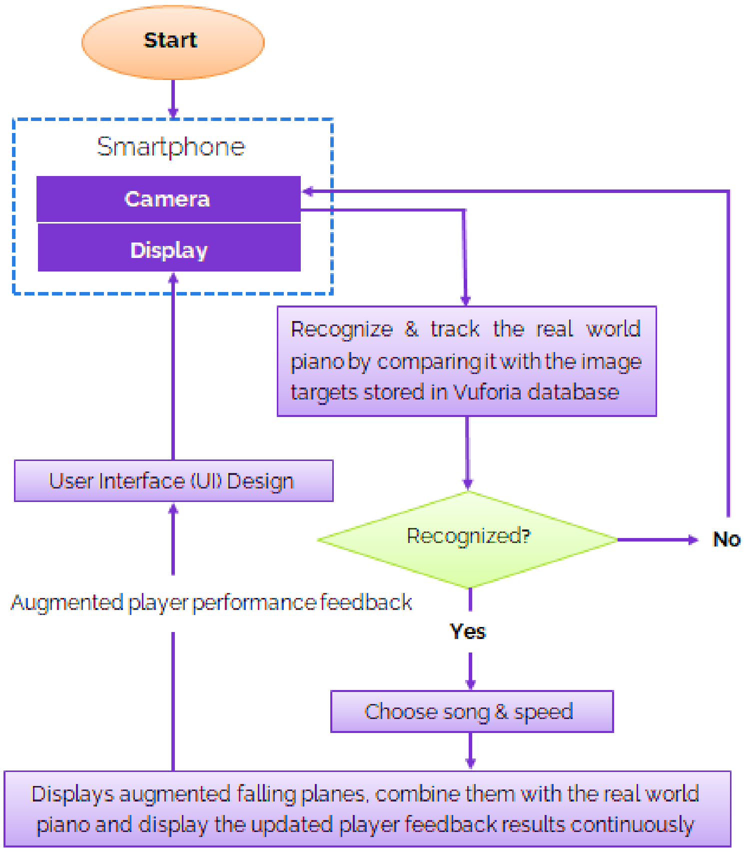

Figure 4.4. Tracking algorithm of the system

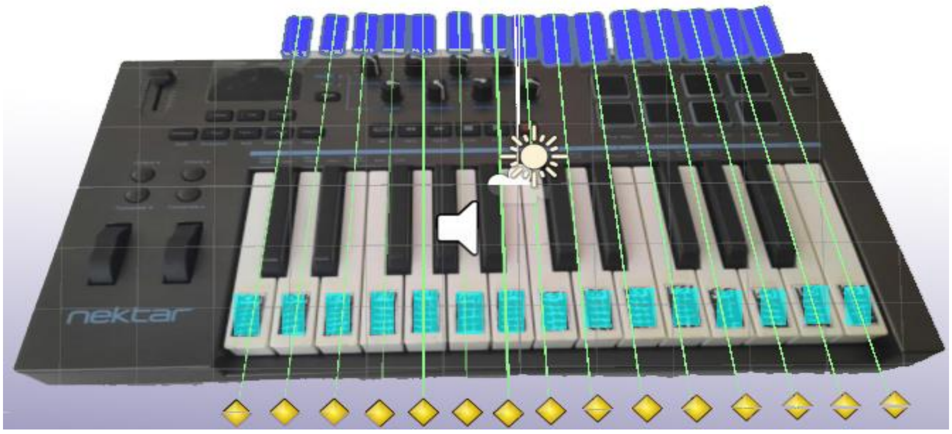

Figure 4.5. Falling notes, destination positions, and colliders

4.3.3. Audio Generation

As a result, each of the piano keys has its own music melody that sounds when the key is pressed, the application generates the melody of the key that has been pressed by the user while playing the song. These audio tracks were downloaded from GitHub before being uploaded to the application (Anonuymus, 2021).

5. EVALUATION AND RESULTS

Following the implementation, we made an evaluation to see whether the EasyARPiano mobile application presented a valuable educational experiences and how much it improved piano practice. This chapter summarizes the results of the system evaluation as well as the proposed feedback, suggestions, and recommendations for the system.

The evaluation examined how much our piano teaching application made learning and practicing the piano easier. In the evaluation process, we divided them into two groups by applying two methods to them. In the first method, we gave the participant a letter in which we wrote the script for playing one of the songs in the application and asked him to practice on the real piano. Every participant was given 30 minutes to practice the song, and then we reviewed their performances by playing the same song on the system's virtual piano. In this method, only 20% of the students were able to score 100%, while the remaining 80% of students scored an average of somewhere between 70% and 80%.

In the second method, we first explained to the user how to use the application and then asked them to take training and practice the song on the real piano using our system. Similarly, as we did in the first method, we then reviewed their performances by playing the song on the system's virtual piano. In this method, 40% of the students were able to score 100%, while the remaining 60% of students scored an average of between 80% and 90%.

Table 5.1. Evaluation Result

Method	**% of participant**	**Score (%)**	**% of participant**	**Score (%)**
Method One	20	100	80	(70 - 80)
Method Two	40	E4	60	(80 - 90)

As shown in Table 5.1, when comparing the results of the two methods, we found that the second method, in which the system was used to practice, doubled the number of 100% scorers by 100% and also increased the performance of the remaining students by 25%. Thus, the concept of our piano teaching mobile application was well received. All participants described the system as being easy-to-use, interesting, and fun, and they were able to understand and interact with it quickly.

While most of the feedback was positive, the participants recommended the following suggestions:

- The size of the falling virtual notes is not adjusted to the key, which means that there is a little bit of a size difference.
- The directions of the falling notes are not 100% aligned with the destination real key.
- Since the tracking is not accurate, it is sometimes difficult to decide which key to press.

6. CONCLUSION AND FUTURE WORK

This thesis proposed the EasyARPiano, a cross-platform AR mobile application that augments a physical keyboard. It simply requires a Musical Instrument Digital Interface (MIDI) keyboard and a smartphone to deliver a perfect visual mediated reality piano learning experience without the need for a piano instructor/trainer, as well as increase learners' experience and motivation by providing unlimited practice hours. The player sits in front of the physical MIDI keyboard and opens the system. The smartphone’s camera is used to scan the piano keyboard first to identify it and then track the player's hand motions. The smartphone's screen is used to display the augmented falling virtual notes, the player's updated score while playing the song, and the ultimate score after playing it.

In the future, we would like to improve our application by allowing the player to move the smartphone around while playing the piano. Right now, we are using a tripod to maintain the stability of the camera; otherwise, it will lose focus and stop tracking the piano keys properly. Thus, it should stay in a fixed position. Also, we would like to take the application to a new level by adding a multi-player feature that allows different users of the application to challenge and conduct competitions among themselves to motivate and improve their piano skills.

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