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Augmented Reality Card Game Based On ArUco Marker Detection

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Abstract/Resümee

Augmented Reality Card Game Based On ArUco Marker Detection

ArUco is a fiducial marker detection library that uses a square marker system for identifying different patterns with unique values. This thesis explores the possibility to use those markers as an AR element in video games so, that any physical marker may represent any virtual object that is assigned to it in the software. Such system could be used for purposes, where the cost or volume of game specific cards is too high.

First and second part of the thesis give a brief overview of AR/VR-, mobile- and overall video gaming industry. Third part looks into fiducial marker detection and more specifically ArUco technology. Fourth part describes the development process of a mobile application and fifth part presents the results of the carried out user testing.

CERCS: T111 Imaging, image processing; T120 Systems engineering, computer technology.

Keywords: Computers, video games, card games, augmented reality, virtual reality, image processing, marker detection, artificial intelligence.

ArUco Märgiste Tuvastusel Põhinev Liitreaalsuskaardimäng

ArUco on märgiste tuvastuse teek, mis kasutab ruuduliste märgiste süsteemi unikaalsete mustrite ja väärtuste tuvastamiseks. See töö uurib võimalust kasutada neid märgiseid liitreaalsuselemendina videomängudes nõnda, et iga füüsiline märgis võib kujutada ükskõik millist virtuaalset objekti, mis on sellele tarkvaraliselt määratud. Taolist süsteemi võib rakendada kohtades, kus mängupõhiste kaartide hind või kogus on mängija jaoks liiga suur.

Antud töö on kirjutatud ArUco märgistel põhineva mobiili kaardimängu arendusprotsessist ja sellega seounduvast uurimusest, tehnoloogiatest ja kasutajatestist. Esimene ja teine peatükk annavad lühikese ülevaate liit-, virtuaal-, mobiili- ja üldisest videomängude turust. Kolmandas peatükis vaadeldakse lähemalt märgiste tuvastust ja konkreetsemalt ArUco märgiseid. Neljas peatükk käsitleb mobiilirakenduse arendusprotsessi ja viies antud rakendusega läbi viidud kasutajakogemustesti tulemusi.

CERCS: T111 Pilditehnika; T120 Süsteemitehnoloogia, arvutitehnoloogia.

Märksõnad: Arvutid, videomängud, kaardimängud, liitreaalsus, vrituaalreaalsus, pilditöötlus, märgiste tuvastus, tehisintellekt.

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Acronyms

AI - Artificial Intelligence

AR - Augmented Reality

HMD - Head-Mounted-Device

PC - Personal Computer

RTP - Return To Player

TCG - Trading Card Game

UI - User Interface

UX - User Experience

VR - Virtual Reality

1 Introduction

Conventional card games have been used for entertainment and wagering for more than a thousand years. The style and types of cards vary, but most commonly the cards and games can be divided into two bigger groups. The first group is a universal deck of cards, that is used for many different games. For example the conventional 52-card French deck is widely known in English speaking countries [1, 2].

The second group would be games, that require a game specific deck of cards. A popular branch of that is for example collectable- or trading card games. The key difference is that there is no universal deck, that can be used to play different TCGs and specific cards are required for specific games. While a regular deck of cards can be acquired for just a couple of euros [3] and it can be used for hundreds of different games, then popular TCG starer kits alone may cost multiple times more. The most popular TCG Magic: The Gathering has over 19 000 distinct cards. This would get very expensive very quickly for a user, who does not want to spend this much on playing cards. Thus an alternative that would allow the benefits of regular card games, while still being able to enjoy any other card game could be looked for [4–6].

The current value of the entire video game industry is estimated to be worth around 120-140 billion USD [7]. This includes arcade, console, handheld, PC, mobile and VR branches. The last two are the youngest platforms in that list and both have shown notable growth rates since their birth. Mobile gaming has grown to nearly around one half of the entire industry over the past 20 years. VR video gaming has also shown notable share in the industry since 2015 and has grown to about 5% of the total industry value since then. This has happened due to a constant rise of the awareness, popularity and availability of VR hardware and VR-compatible games and other software. It is also reasonable to note, that the term VR goes often hand in hand with AR and in some cases, the latter may even be considered as a subclass to VR [8–10].

As the popularity of mobile games is already very high and VR gaming is on the rise, it is reasonable to assume, that more and more users and companies start showing interest in VR and AR technologies and their applications. Regardless of the actual future outcome, this paper explores the potential to integrate conventional card games into a

mobile AR platform, that would allow to use a single deck of cards for any game that is built on the platform.

In the first part, a brief overview of the VR/AR, mobile and card game industry and technologies is given. The second part of the paper takes a closer look into specifically ArUco markers and includes an overview of a development process of an Android mobile application that utilises the named markers. The application is to be a proof of concept, that ArUco markers can be used as an element in VR- or AR gaming. To further learn about the possible impact or effect on the market, a user testing process is also carried out.

The survey results of the developed application testing should give some overview of how general population sees and values AR elements in video games. Additionally, if AR games may possibly become a competitor or an alternative to conventional card games and what are the main lacking points of the proposed and developed demo application.

2 Overview

Overview chapter covers the main definitions, uses and devices of VR and AR. In addition to that, video gaming in general and on mobile devices is looked into more specifically. Lastly a brief overview of the separation between two types of card games in this paper are explained and the requirements for the developed application are set.

2.1 Virtual Reality

While virtual reality can have different definitions depending on who interprets it, in this paper, we use it in the form of a summarising term for the technological field of virtual reality [11–13].

The word "virtual" itself originates from 14.-15. century and is defined as "being something in essence or effect, though not actually or in fact" according to Online Etymology Dictionary. In computing, the term was specified in 1959 as "not physically existing but made to appear by software" [14].

The term "virtual reality", according to Cambridge Dictionary is "a set of images and sounds produced by a computer that seem to represent a real place or situation" [15].

Commonly it is referred to as the virtual reality set, that usually includes the headset and its auxiliary devices [16].

2.1.1 Devices

The most popular and relatable VR device is the aforementioned headset, which looks like oversized goggles. The headset has a screen, where the image is displayed for the user and is usually also accompanied by headphones for audio output. Depending on the headset, they may also include a gyroscope, accelerometer and other extras [17].

The user's vision is completely isolated by the goggles and no or little outside light reaches the eyes. If headphones are used as well, then user's hearing can also be isolated. The price range varies greatly and depends on the hard- and software capabilities, production quality, accessories and other factors. Budget devices, that are meant for mobile use can cost as little as less than 10 EUR or be even hand made [18–20].

Mid range devices include mostly hard- or software specialised devices or higher quality

universal phone cases. The price range is anywhere around 70-140 EUR. An example is Samsung Gear VR which is a device, that is built and designed to be compatible with Samsung's newer mobile phones. There are other examples, but the general idea stands, that they are developed and produced for either some specific smartphone models and model ranges or are similar to low end devices, but have higher production quality and possibly additional input methods [18, 21, 22].

The price of high-end devices can average around 500-1500 EUR, depending a lot on the additional equipment that comes with the package. High end devices also require external computer or gaming console to run the games themselves and this price is not included here. For example HTC Vive prices start from 600 EUR and Vive Pro full kit end at 1400 EUR. For this group of VR devices, majority of AAA title VR games are developed [18, 23–26].

2.1.2 Uses

While by far the largest use for VR is gaming and entertainment, then there are also other fields that have found useful applications. Some of the biggest markets include retail/shopping, real estate, education, military and engineering. There is no clear-cut limit, where the applications can be expanded to as the technologies are improving and new possible uses are created. Parallels can be brought out with PC, smartphone and tablet usage popularity rises, where continuous development and hardware price drop surged the userbase [27, 28].

2.2 Augmented Reality

Augmented reality is closely related to VR, as they share similar properties and characteristics. AR can also be considered as a subclass or a variation of VR and thus AR can sometimes be hidden under the name of VR. While in essence, they are alike, then AR takes a step further and attempts to lessen the obvious presence of technology from the real world. The virtual elements, creations or additions are not strictly isolated from the surrounding world and are instead merged or blended in. The keyword often used is "seamless" integration, which is a goal to allow the user to adapt quickly and not be confused or hindered by new and unknown environment that may be caused to a inexperienced user by VR solutions [29, 30].

2.2.1 Uses

AR solutions and applications can be used anywhere, where adding virtual elements to real world may enrich or benefit user experience. These include for example heads-up

displays for wearable devices and vehicle windows screens [31]. Different solutions have been developed for schools and education, that help to create more immersive studying objects [32]. There are options to use AR as a learning or general assistance in different fields of medicine, military, manufacturing and entertainment. Often the main purpose is to assist the user with different visualisations or annotations to real world objects, that are displayed on a screen in front of user's eyes [30].

2.3 Video Gaming

As this paper focuses on the use of AR solutions in gaming industry, then it is apt to bring out some additional information about the uses of different technologies in both global and mobile gaming.

2.3.1 Global

As mentioned earlier in the introduction, global gaming market value is estimated to be worth around 120-150 billion USD. The largest contributors to that are mobile, console and PC gaming with all their subclasses, where mobile takes up around one half of the market and PC and console gaming split the other half. This does not take AR/VR gaming into account as separate class, since here they are based on PC, console and mobile platforms [33]. If AR/VR is also considered as a separate class, then its market share is estimated to be somewhere around 5% with approximately 170 million active users worldwide in 2018 [27, 34].

2.3.2 Mobile

The popularity of mobile gaming has risen very fast during the past years and the total value has doubled during the past 4 years from around 35 billion USD to current 70 billion USD [35]. The number of smartphones sold had been growing every year until 2018, which was the first year, where total amount of shipped new smartphones did not exceed the one of previous. The global smartphone vendor shipments total of 2018 was between 1400-1500 million units. These numbers are still huge, considering that this means one new phone a year for every 5th person on earth [36]. So fast rise of the availability of smartphones gives more and more people access to the use of smartphones and thus mobile gaming. There are already around 3 billion smartphone users with around 2.2 billion of them playing mobile games [37–39].

2.4 Card Games

Card games are one of the most popular tabletop games and there are countless different types of cards and games that are played with them. Here we separate card games into two different categories; games played with standard playing cards and games played with game-specific cards. The latter combines all the more and less known card games, that use a set or deck of cards dedicated specifically for a single type of game. This includes mainly collectable card games and dedicated deck card games [40].

2.4.1 Standard Playing Cards

Standard playing cards are a universal deck of cards, that can be used for many different card games. The number and style of the cards in the deck is not fixed and depends on a region. In the modern Western world, the most common deck is the standard 52-card deck of French playing cards. As the name suggests, the deck consists of 52 cards. Each card has a suit and value. There are four suits: clubs, diamonds, hearts and spades. The values range from 2-10 as numbers and face cards jack, queen, king and ace. Every card is unique and value-wise does not differ of a card from another deck. The art-styles and card sizes may however vary, making the cards look different. The cards are played as either social- or wagering activity. Some of the most commonly known card games include Blacjack, Poker, Bridge, Gin etc. with different popularities among regions and people groups [41].

2.4.2 Game-specific Playing Cards

There are many countless kinds of card games, which use a deck especially dedicated to one single game and they will not be brought out here separately. One big part of game-specific playing cards are collectable card games. These are card games, where the deck is specifically designed for a themed game. The games usually have official rules and communities where the games or tournaments are held. Some of the more notable titles include Magic: The Gathering, Pokemon TCG and Yu-Gi-Oh!. These games can have massive amounts of unique cards with prices ranging from anywhere between some cents to hundreds of dollars for a single card. The trading and card acquiring process however is one of the main parts of the entire TCG community [40, 42–46].

2.4.3 Casino Card Games And Card Counting

Card games are also a popular way of gambling in casinos. One of the most popular games of chance is Blackjack, where the players try to beat the dealer, by scoring as close to 21 points as possible without going over it. In general, the game rules favour the casino, but under right circumstances and depending on the amount of face and ace cards left in the

deck in relation to other cards, the player can gain an advantage over casino. To achieve that, some players can use card counting methods.

Card counting is a technique used by players in casino, to gain an advantage over the house. There are multiple different card counting techniques, that do not require superhuman skills and under right conditions can give the player a RTP of over 100 per cent. This is especially common in Blackjack games, where a small amount of cards is used and the cards that have already been in the play are discarded.

To counter this, most casinos use more decks of cards, to reduce the efficiency of card counting. In addition to larger amount of cards in the shoe, some cards may also be burnt (discarded without anyone seeing the cards) throughout various stages of the game. More time consuming option is to shuffle the deck or use a new, pre-shuffled shoe, but this requires the assistance of a 3rd person, to not slow down the game pace [47].

2.4.4 The Universal Deck

This brings us to the main point of this thesis: to develop an AR deck, that would allow any physical card to be any virtual card. The deck would implement AR technology to display the player an overlay image of a 3D designed card on the screen, where live video feed is being shown. This is to explore possibilities of using one deck similar to standard playing cards deck for games, that may usually require a specialised deck.

The requirements for the developed solution are as follows:

1. Allow any distinguishable and detectable physical marker to be assigned any 3D object.
2. Allow instant re-assignment of IDs and objects.
3. Be designed for mobile use.
4. Have at least one fully working well known card game using physical markers as input.
5. Have at least basic level AI opponent in the game.

3 Fiducial marker detection and identification

Fiducial markers are used in AR as a reference point in the real world that can be translated into virtual or digital space. They help and allow to estimate the position, rotation and orientation of the video source and do it in real time. The main use is to have a device, that is equipped with or carries a camera, that provides live video stream to a computer. The software running on the computer is using a fiducial marker detection algorithm and detects markers, respective to the software from the live video feed. The information from the detection allows to estimate the position in relation to the markers in 3D real world.

The applications for marker detection vary, but is commonly used in AR. Other examples also include robot movement or navigating in either open or closed space. Also any other system, where tracking of a visual object is required [48, 49].

There are many different algorithms for detecting fiducial markers and not all of them will be covered or event mentioned in this paper. The main focus will be on a library called ArUco.

3.1 ArUco

ArUco is a fiducial marker detection library written in C++ and based on OpenCv. The system utilises square markers that can be generated for different dictionaries that vary in size and number of bits. The markers are generated so, that the inter-marker distance would be as high as possible. High inter-marker distance allows lower confusion between markers and is thus more accurate in identifying a specific marker. ArUco allows to use a variety of marker dictionaries. In every dictionary a unique marker has a unique binary pattern. Depending on dictionaries, they can have more or fewer bits. The amount of bits affects mainly two things: confusion rate and necessary camera accuracy and resolution. A dictionary with lower amount of bits allows the marker to be detected at lower resolution, since the patterns are simpler, but this also results in higher confusion rate within the

dictionary [50].

3.1.1 Choosing and designing the cards

Standard playing cards come in two different standard sizes known as the Bridge and Poker size. Bridge cards are narrower at 2.25×3.5 *inches* and Poker cards are wider at 2.5×3.5 *inches* (5.715×8.89 *cm* and 6.35×8.89 *cm* respectively). The names of the card sizes do not limit them to specific games [51]. Since ArUco markers are square, it is more reasonable to use the wider cards, so the square can have larger edge length and the marker itself is bigger and easier to detect.

Since the markers need to have white or lighter background surrounding the black outline, then it is important to leave enough white space to every side of the marker. If placed to the middle, then the marker will definitely have plenty of free place to the shorter card edges. The shorter edge itself is 6.35 *mm* and when using 4x4 dictionary a total of 8 equally sized edges should fit there. That is 4 inside squares, 2 black outline border squares and 2 white outline border squares. When leaving some space for error (in this case the cards are handmade) of 0.25 *cm* on either side then the total edge length of the marker should be $(6.35 - 2 \times 0.25\ ) \times 6/8 = 4.7625$ *cm*. This results in a physical card as seen in Figure 3.1 [50].

The physical markers were created by using ArUco marker generator [1] and are 50×50 *mm* cubes. Downloaded as .svg files and converted to .png with a converter [2].

For testing and demonstration purposes, I have created a 53 card deck of 4x4 dictionary ArUco markers from ID 0 to ID 52 as seen in Figure 3.2. The total cost of the deck depends mainly on the quality and quantity of the cards. This specific example used some of the cheapest deck of regular playing cards found in supermarket (about 1-2 euros a deck). The printing can be done on a regular printer or in a printing shop. In this case, it was done in the latter and was 0.5 euros a page. One page could fit 9 cards, which was a total of 6 pages. Cutting out and taping all the stickers on cards depends on person's skill, but for me was roughly 2 hours.

The total size of the created deck should depend on how many cards can be displayed on the playing field simultaneously or how many cards need to retain a unique ID throughout the game. It should also be noted, that if cards are created that way, thicker paper should be used, because in the example deck, the old card values are slightly visible through the sticker.

[1] http://chev.me/arucogen/
[2] https://svgtopng.com

3.2 Alternatives to ArUco

While technically any library, system or technology, that allows the detection of physical world objects or markers and registers their location and pose sufficiently fast in live time, then in this paper, ArUco was chosen. The main reason for choosing ArUco for this project was its competitive performance, being open-source and availability of Unity asset package, that cuts out the need to study building plugins for Android devices and allow seamless compatibility between the library, Unity and the operating system. Below are brought out some more popular AR application development software options.

3.2.1 ARToolKit

ARToolKit claimed to be the most widely used AR tracking library in 2017 [52]. There are currently also some examples that allow it to be developed on Unity and built for Android devices. For example the ARToolKit+ Unity Plugin which shows promise to be used as an alternative [53].

3.2.2 Vuforia

Vuforia is partnered with Unity and is thus very well integrated into it. Vuforia would probably be the best alternative for someone, who definitely intends to develop an application on Unity platform. The main problem, however, is that the free version is limited and fully customisable version or license needs to be bought. This can be a limiting factor in applications (even prototypes), where high level of customisation is necessary [54, 55].

3.2.3 ArCore

ArCore is Google's product and has official guides how to set up with many different development environments. ArCore focuses more on motion tracking and environmental understanding. As their official examples show, they focus more on animated figurines being displayed in a certain room or on a plane. ArCore's main issue is that it sets hard supported device limits and most of the development and testing devices available during the making of this project and thesis are not supported. If hardware requirements were met, then ArCore could be also considered as a reasonable alternative to the chosen method [56, 57].

Figure 3.1: Handmade 4x4 dictionary marker

Figure 3.2: 53 card ArUco marker deck

4 Development of the application

The development process of the application can be divided roughly into three parts or stages. The first part was to learn the possibilities how to conveniently use the available software, plugins and packages to build the application on Android platform. The second part was mainly about the implementation and refining of selected software and handled the marker detection and interpretation. The last part was to design and visualise the use of the detectable data. That included the game design, AI implementation and UI/UX.

4.1 Development environment

When choosing the development environment components, most of the decisions were made based on the author's preferences and previous experience and compatibility with the rest of the chosen software.

4.1.1 Unity

The main development environment for the application is Unity. The primary reason for this choice was the author's prior experience with the game engine and thus basic knowledge, what can and what cannot be done with the engine. Unity is free for personal use and a very powerful professional game engine and development platform. About half of the world's games are developed on that platform [58].

For initial testings, version 5.6.1f1 was used, but due to OCVfU asset package requiring version 5.6.6 or higher, an update to 2018.3.5 was made. Release notes at [59]. During the development upgraded to Unity 2018.3.6 on 27.02.2019. Release notes available at [60]. At later stages upgraded to Unity 2018.3.11 on 07.04.2019. Release notes available at [61].

4.1.2 Blender

For designing 3D objects, Blender 2.79b was used. Unity and Blender work well together, since Unity allows to natively import Blender files while supporting all the key elements of .blend files [62]. Majority of the designed objects never made it to the final application and were used to test some concepts or ideas.

4.1.3 GIMP

GIMP 2.10.8 image editor software was used for creating textures for the 3D playing cards. It was also used in creating print sheets for ArUco markers to align them properly and leave plenty of cutting space.

4.2 OpenCV for Unity

To overcome the difficulties of integrating OpenCV contrib library to mobile device, "OpenCV for Unity" integration asset package by Enox Software is used. The package provides working .so libraries, that allow using OpenCV ArUco markers futures on mobile devices. In addition to .so libraries, the asset package also contains a good base for further development and has all the necessities for handling mobile specific camera feed handling and converting it to appropriate OpenCV Mat type [63].

In this project, all camera manipulation, including everything from starting the phone camera to converting the image to Mat type is already done in the asset package. Author's contribution starts with implementing marker detection using ArUco.

4.3 Development and test devices

1. Development on PC, Win 10 Pro 64-bit, AMD Ryzen 5 2600 3.4GHz, 8 GB RAM.
2. Main testing device (smartphone): Xiaomi Redmi 4X Android version 7.1.2.
3. Backup testing device (tablet): Lenovo Tablet YT-X703L Android version 7.1.1.
4. User experience testing device #1 Samsung Galaxy S7 Android version 8.0.0.
5. User experience testing device #2 CAT S60 Android version 6.0.1.

4.4 Detecting markers

The detection process is running all the time, when any possible detections are expected. If at least one marker is detected, actions with markers begin. All the visible markers are stored in a list and the list is updated during every Unity Update() cycle. Every ID has also a count, that counts the number of update cycles it has been visible for continuously. If the count reaches over 6 and is also visible on the 7. continuous cycle, it will be considered as detected.

The continuous visibility count was implemented due to high number of false detection occurrences. Most false detections happened with high contrast backgrounds and as a specific example, with keyboards. See Figure 4.1.

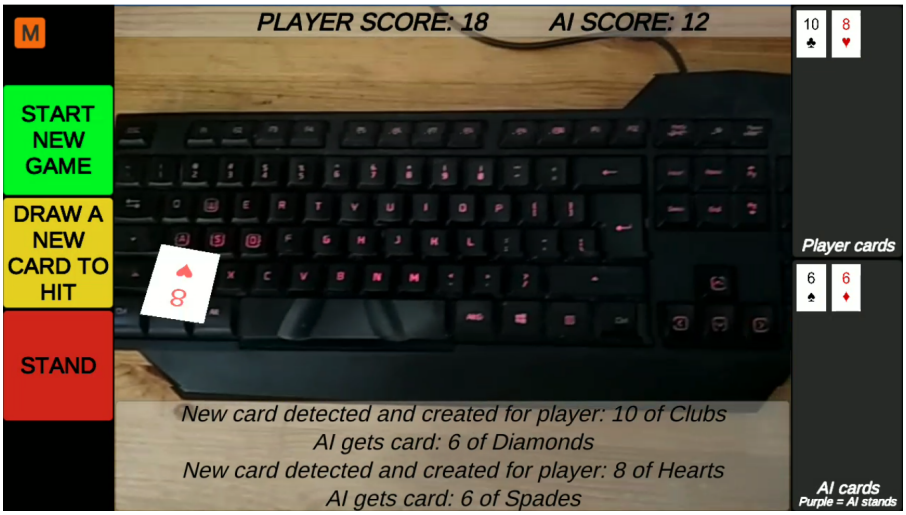

Figure 4.1: False card detection on keyboard

False detections can still occur, but are very rare. This can be improved by setting the consecutive update cycle visibility count even higher, but that results in longer detection delay. Alternatively a requirement can be fixed for the player, that the playing board should be a plain surface and not contain very high contrast patterns.

4.5 Playing cards

The virtually displayed game cards are Unity game objects. See Figure 4.2. There is a total of 52 objects and each one is a separate instance of a Unity prefab. The card positions are updated only, if the card is detected and visible. If the card is not visible, the object is set inactive and thus not displayed on the screen. When the cards are detected and visible, they are set back to active and immediately check for their new positions and rotations.

4.6 Random IDs and shuffling the deck

There are two approaches to take here, when it comes to assigning random values to marker id-s and shuffling the deck. One approach is to call the deck shuffling function at the beginning of a game round and have the function callable in case shuffling is required after the game has already started. This allows to assign each marker a specific game object and all the 52 cards would immediately have a unique id. Such solution would work well, when the game is entirely dependent on drawing the cards from the physical deck and there is no need to remove any id-s from the drawable pool or deck.

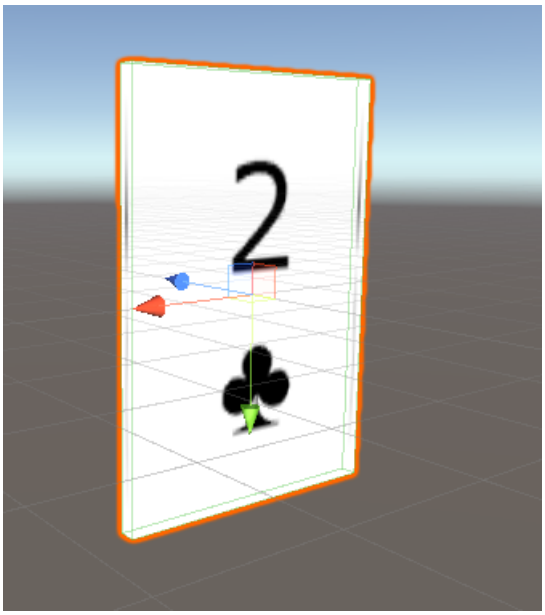

Figure 4.2: Virtually displayed card game object

The issue, that such method faces can be described in the following scenario:

Player plays against AI. Cards are shuffled at the start of the game or when shuffle function is called. Player draws cards from a physical deck and AI has cards assigned randomly, depending on which cards have not been drawn yet and are available in the deck.

A random card value X is assigned to a marker ID Y. AI starts and as a first card gets randomly card X. Player draws a card from the physical deck and the first card drawn has ID Y. If card duplication is not allowed, then such situation would result in a blank card, since it is in the play already and player needs to draw again, until they get a card with ID, that has not been drawn by AI yet. That would be unnecessarily confusing and unintuitive.

Thus I have elected to have the shuffling be done upon a new card being called or detected. When AI draws, a random card from the pool of available cards is selected. Player's physical marker card is assigned a virtual playing card upon the detection of a new, previously not detected marker. When a card is assigned, it cannot be drawn again, until it is moved back to the available pool.

4.7 Blackjack with 52 cards against AI demo game

"Blackjack" or also known as "21", is a card game, where the goal is to get a score as close as possible to 21, without going over the 21 point tally. Blackjack is a common

casino game, where players play against the dealer, but in this application, it is a one on one match between the player and the AI, where the cards are dealt one at a time and both parties always see each other's cards. There is no overall score to keep track of previous wins or losses and there is no real or game currency for wagering. There are also no limitations, when either side must draw or when they are allowed to stand depending on the current score or amount of cards.

Each card has a value from 1 to 11. Number cards are valued as their respective numbers, face cards jack, queen and king are worth 10 points each and ace is 1 or 11 points. The suit of the card does not affect the value and ace card's value is chosen automatically to give the best possible score for the participant [47]. The ace value X depends on participant's total score Y $\in \mathbb{N}$.

$$X = \begin{cases} 1 & Y > 21 \\ 11 & \text{otherwise} \end{cases} \tag{4.1}$$

The game starts with a coin toss, where player's starting condition X is decided by a random number Y $\in \mathbb{Q}, 0 \leq Y \leq 1$.

$$X = \begin{cases} 1 & Y < 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{4.2}$$

If player starts the round, then the game will wait for player's action. Every round, either participant can make one of two decisions: stand or draw. Standing means, that the participant does not want any further cards and settles with their current score. Drawing means having another card dealt. This is initiated by the player by bringing a physical marker in front of the phone's camera or moving the phone so, that a depiction of a marker is visible on the screen. Once a new valid marker is detected and it is player's turn, then it counts as drawing a card and a card is "dealt" for the player. After the player has made a decision and if AI has not chosen to stand, then it is AI's turn. Participants take turns until both have chosen to stand or at least one of the participants has gone over 21 points.

4.7.1 AI behaviour

AI makes its decision to draw a new card based on $Risk \in \mathbb{Q}, 0 \leq Risk \leq 1$ and a random number $Y \in \mathbb{Q}, 0 \leq Y \leq 1$.

$$Draw = \begin{cases} 1 & Y > Risk \\ 0 & \text{otherwise} \end{cases} \tag{4.3}$$

The risk is calculated depending on player's score $S_\text{p} \in \mathbb{N}$, AI's score $S_\text{a} \in \mathbb{N}$ and the chance $p \in \mathbb{Q}$, $0 \leq p \leq 1$ of drawing a card, that would not make the AI's score go over 21.

p = suitable/available

If player does not stand, then:

$$Risk = \begin{cases} 0 & (S_\text{a} < S_\text{p}) \wedge (S_\text{p} \leq 21) \\ 1 & S_\text{a} = 21 \\ 1 & S_\text{p} > 21 \\ \text{1-p} & \text{otherwise} \end{cases} \tag{4.4}$$

If player already stands, then:

$$Risk = \begin{cases} 0 & (S_\text{a} < S_\text{p}) \wedge (S_\text{p} \leq 21) \\ 1 & S_\text{a} > S_\text{p} \\ 1 & S_\text{a} = 21 \\ 1 & S_\text{p} > 21 \\ \text{1-p} & \text{otherwise} \end{cases} \tag{4.5}$$

AI calculates new risk every time a new turn for it starts.

4.7.2 UI design

Upon starting the application, user is taken to the game selection menu. In the demo application, there is just a single game, but there is the possibility to add additional ones. See Figure 4.3.

Once user has chosen the game, they are taken to it and initially the introduction with short helpful information is displayed. See Figure 4.4.

In Figure 4.5 all the UI elements are numbered and can be referred to in the list below:

Figure 4.3: Game selection page

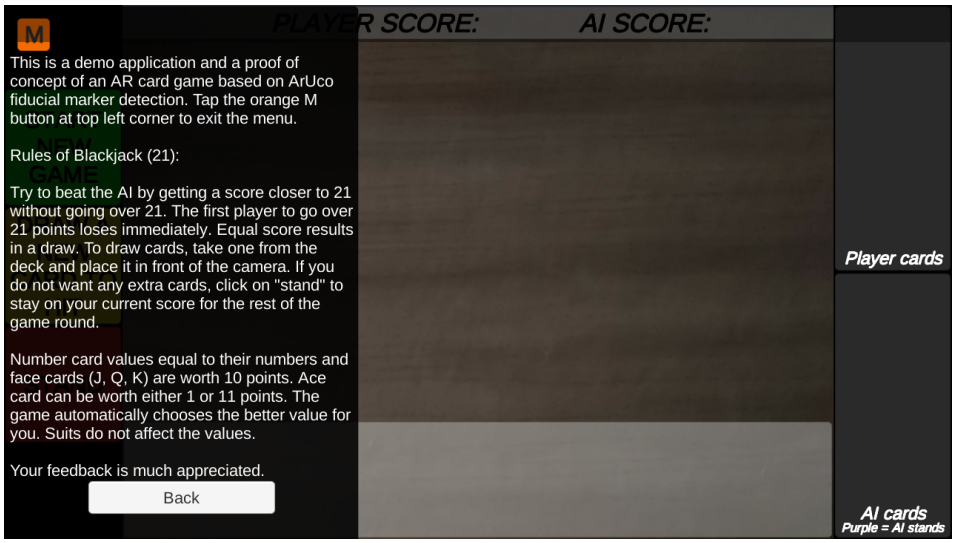

Figure 4.4: Start screen with introduction

1. Menu button.
2. Button to start a new game round.
3. Informative button about drawing a new card.
4. Button to stand and end your turn.
5. Player score display.
6. AI score display.
7. Player cards panel. These cards are always visible there, once they have been drawn and values have been assigned.

8. Similar panel, but for AI. If AI chooses to stand, then the background turns purple (normally it has the same gray color, as player's panel).

9. Event log. New card being drawn or detected, AI decision to stand and reminder to clear the board at the end of the round is brought out there. Initially it was used for debugging.

10. Game round end and winner notification.

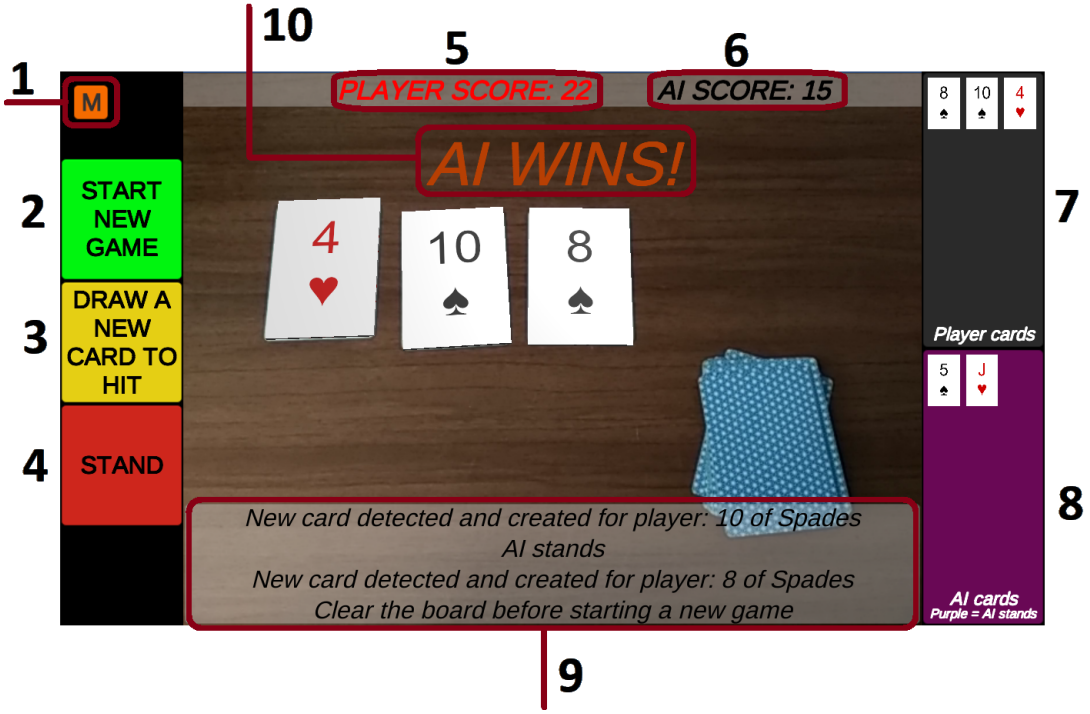

Figure 4.5: GUI guide

5 User testing

To test the application on different people and see their reactions and get feedback, a user experience testing was carried out between 17.04.2019 - 30.04.2019. The nature of the testing, survey questions and results are brought out in this chapter.

5.1 The testing

Users were given a mobile phone with the application running and half a deck (26 cards) of ArUco marker cards (see Figure 5.1 and Figure 5.2). They were briefed shortly about what the test is for and what they are going to do. After that they were given free hands to observe the cards and navigate around the application as they see fit. Users could ask questions throughout the entire testing and comment on any aspect of the application.

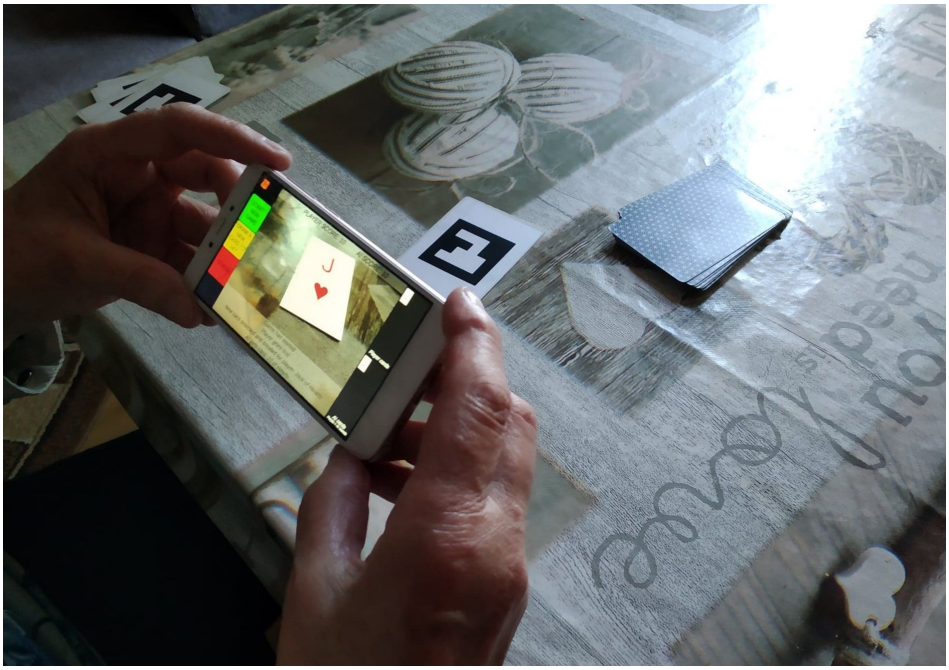

Figure 5.1: User testing 1

Testing was not time limited and the amount spent varied a lot between different testers. Lowest amount of time spent in the application was by playing 3-5 rounds and

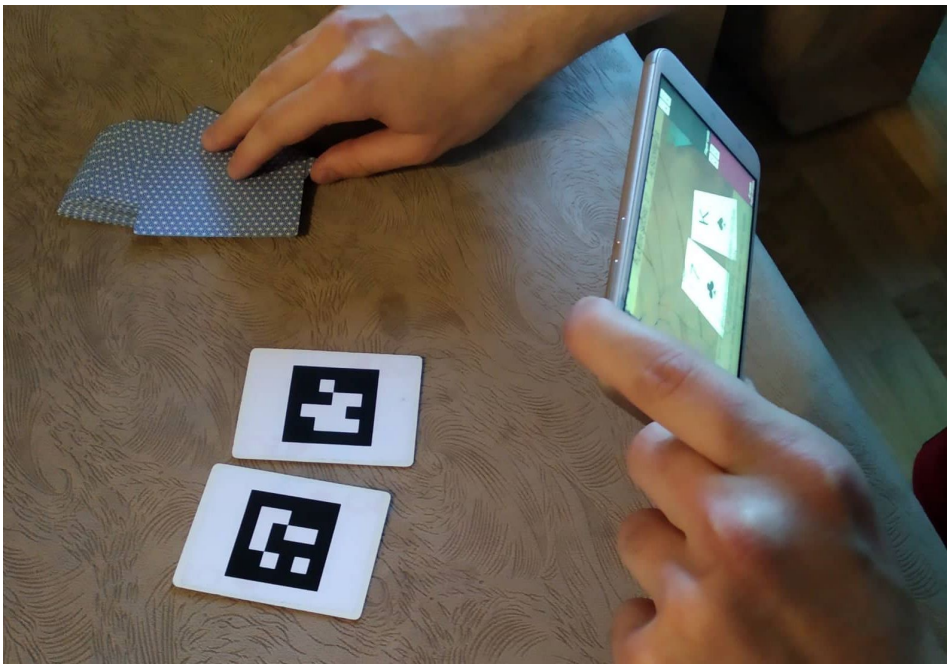

Figure 5.2: User testing 2

longest lasted over 10-15 minutes. Once the user had finished the testing, they were given the chance to take a survey regarding the AR mobile application.

5.2 The survey

The survey consisted of a total of 10 questions, of which 3 were about the player, 6 were statements, where the questionee had to rate their agreeance with each one and last was optional additions. The survey was filled in one of the following forms: the tester filling in the survey paper, the tester filling in electronic survey on tablet, the tester being asked the questions and answers being filled in by the questioner on tablet or phone. The entire questionnaire is brought out in Appendix 1.

Personal questions were about tester's age, sex and previous player experience. In the 6 statements, the questionee had to respond with a number from 0 to 5, where 0 stood for strong disagreement and 5 for strong agreement with the statement. The statements inquired about user's first impression, how they see it as an alternative, do they find it entertaining/innovative, ease of use, impact on the industry and likeliness of downloading the app if they had the opportunity.

5.3 The results

A total of 57 people participated in the testing and took the survey during the two weeks between 17.04.2019 - 30.04.2019. There were some people, who tested the application but

did not agree to take the survey. Those people are not counted or included in this overview and their testing observations were not saved or documented. Among participants were 32 men and 25 women from ages 16-59 of different nationalities, ethnicities and with varying backgrounds. Testers' previous player's experience ranged from people who had never owned or used intensively a smartphone and had not heard of blackjack game or AR technology before to amateur poker players.

The results to the 6 statements are brought out below on graphs, where for each statement, experienced and non-experienced players are separated. The testers had to judge if they see themselves as experienced players or non-experienced players. A total of 24 people considered themselves as experienced players and 33 as non-experienced players. The reason for such distinction was to see the difference between people, who may have played similar games before and might already have some certain expectation and those, to who it is a new experience.

Statement 1. *"I think that I would like to use this AR game frequently"*. This statement was to find out about the tester's first impression about the game. The response distribution is brought out in Figure 5.3. The entire average response value was 2.68. For experienced players it was 1.92 and non-experienced players 3.24. From this we can see, that while the average first impression of the game is rather neutral, then experienced players lean towards not wanting to play the game frequently and non-experienced players lean towards wanting to.

Statement 2. *"I found the AR element in the game unnecessarily complex"*. The statement was to see, how the testers see the AR element as an addition and do they agree, that it was an unnecessary addition. The overall result was 1.04 and roughly the same for experienced (1.04) and non-experienced (1.03) players. Total response distribution seen at Figure 5.4. It is clear here, that the testers did not find the AR element in the card game unnecessarily complex addition.

Statement 3. *"I found the AR element an entertaining addition to a conventional card game"*. Regarding this statement, the testers answered, how entertaining they found the AR element in the game. The total response average value was 4.07. For experienced players 3.83 and non-experienced players 4.24. While the average was slightly higher for non-experienced players, it was still high for both sides and it is safe to say, that on average, users found the AR element an entertaining addition to a conventional card game. All results seen in Figure 5.5.

Statement 4. *"I needed to learn a lot of things before I could get going with this game"*. Statement 4 was about the ease of use of the application. Testers answered, if they had to

learn a lot of things before they could get going with the game. The results are brought out in Figure 5.6. The average response value was 1.12. For experienced users 0.92 and non-experienced 1.27. Players with experience found the game slightly easier to use, but in general, most of the testers did not find any difficulties.

Statement 5. *"I would imagine that most people would learn to use this AR game very quickly"*. In statement 5, I looked for testers' response, how likely they think other people in general would learn to use that game and thus evaluate the possible impact on the industry. Full results are seen in Figure 5.7. Total average response value was 4.32. For experienced players 4.42 and non-experienced 4.24. From this it can be said rather conclusively, that among surveyed people, the consensus is that most people would very likely learn to use this game very quickly.

Statement 6. *"I would install it on my own phone"*. In last statement, testers had to respond with the likeliness of them installing the application on their won phone, if it was available for download. The total response average was rather neutral 2.30. Only 1.38 for experienced players and 2.97 for non-experienced players. 28% of the surveyed people answered 4 or 5 to the statement and are very likely to install such application on their own phone. Full responses are seen in Figure 5.8.

5.4 Proposed changes and improvements

In the last question, the questionees were given an option to add some additional key points or thoughts that they would add or change in the application to make it more appealing. The mentioned points are brought out in table 5.1.

Table 5.1: Survey improvement points

Improvement point	No. of occurrences
Overall score, keeping track of total wins/losses/draws	6
Overall UI look/design improvements	6
Holding the phone is annoying	5
Sound effects/notifications	4
More (interesting) games	4
Points, play or real currencies to play with	4
Player vs player option	3
Player cards tab is confusing	3
False detections	2
Better instructions/tutorial	2
Defeats the purpose of card games/is not a replacement	2
Higher response speed	2
Yellow button confusing	1
AI should win less	1
Voiceover for received cards	1
Fewer cards	1
Start new game button should appear only, when the round is over	1
Scalable UI size	1
Clearer AI actions	1
Find a better way to relax	1
Overall colored buttons confusing	1
Actual face card images	1
Possibility for trial runs	1
Rewards and rankings	1
Less touch screen commands	1
Wearable tech/glasses option	1
More rewarding	1
Gets boring quickly	1
The need for special cards is a problem	1
Phone got very hot	1
More casino-like versions	1

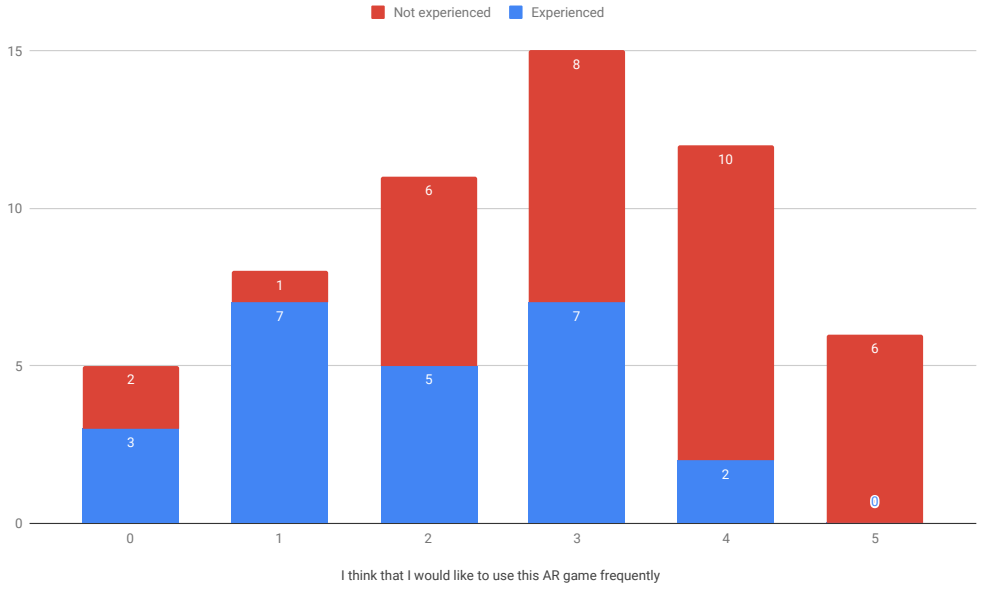

Figure 5.3: Statement 1 results

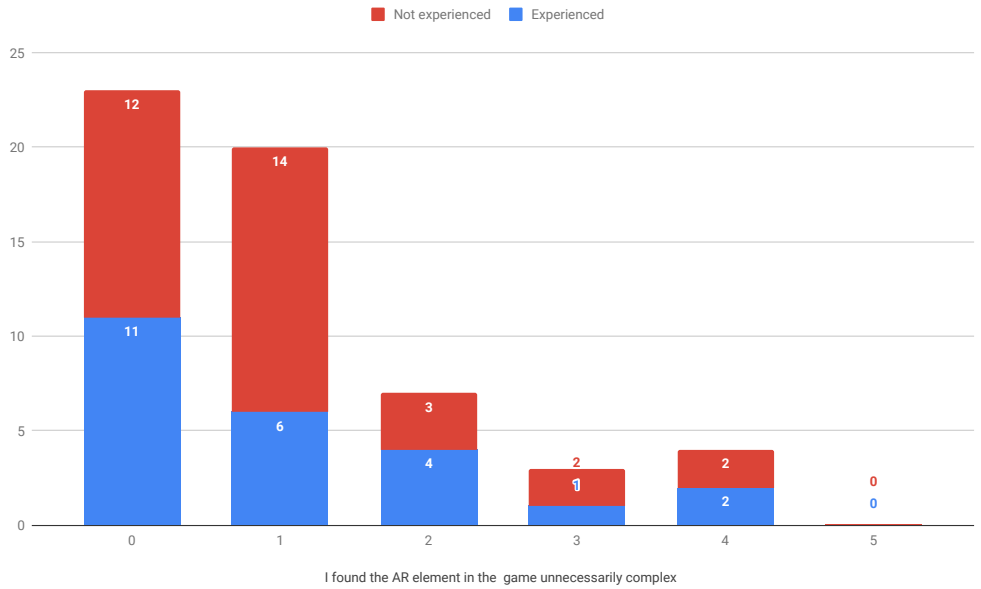

Figure 5.4: Statement 2 results

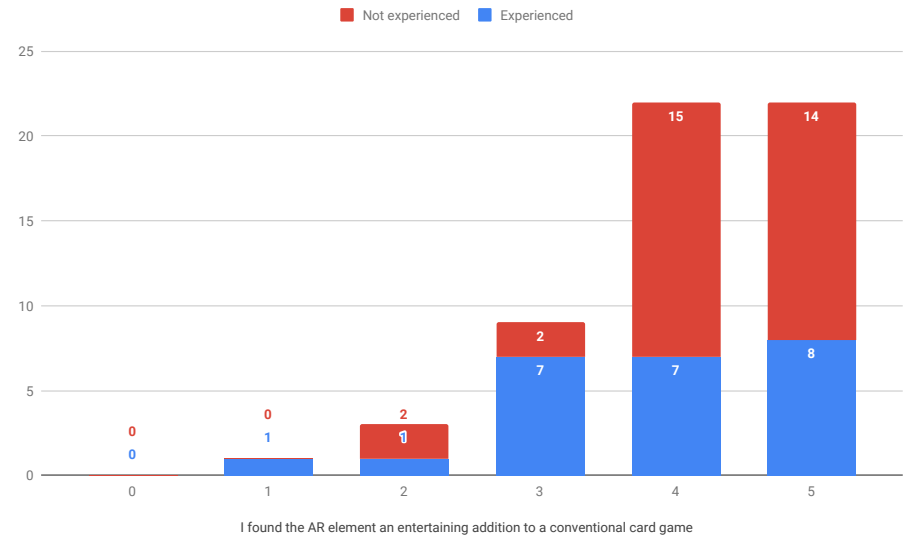

Figure 5.5: Statement 3 results

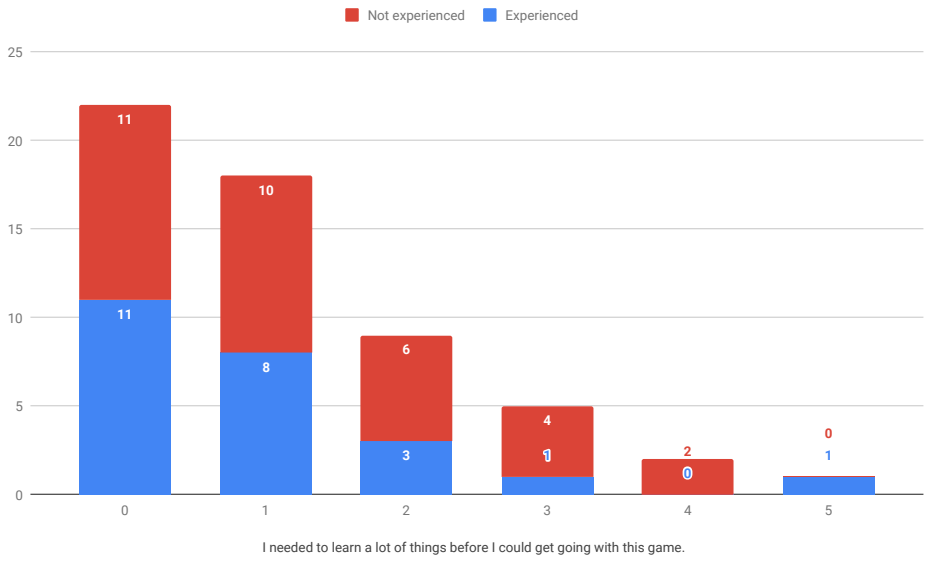

Figure 5.6: Statement 4 results

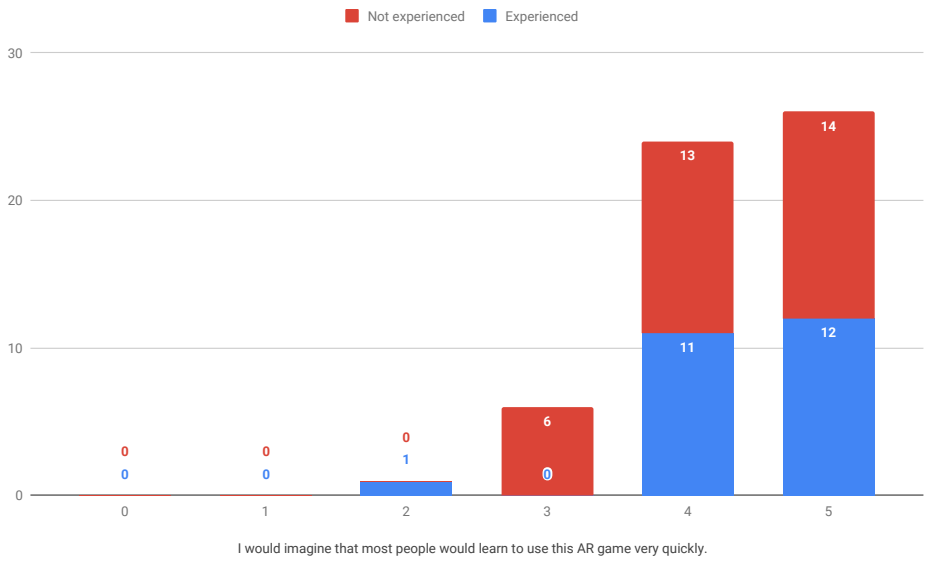

Figure 5.7: Statement 5 results

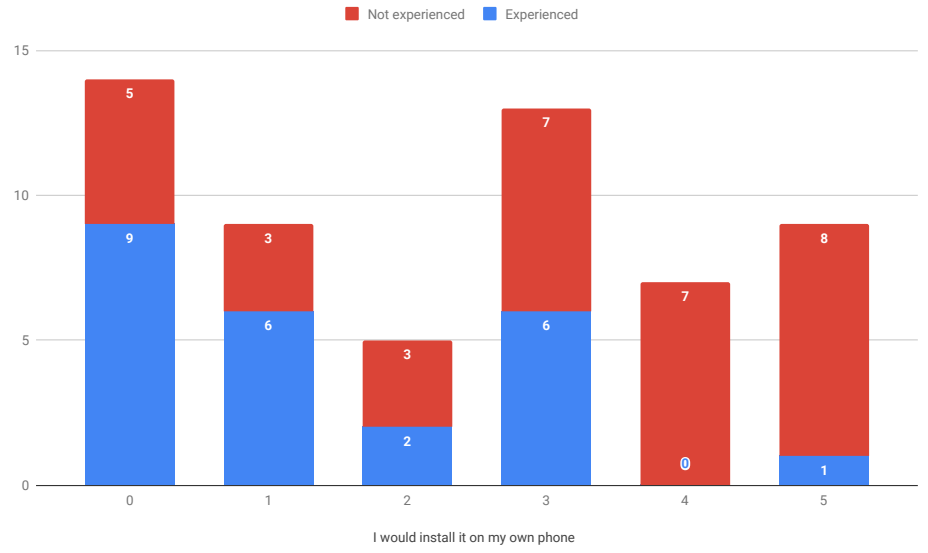

Figure 5.8: Statement 6 results

6 Conclusion and future work

6.1 Conclusion

This thesis has given a brief overview of the development process of an ArUco marker based AR card game and the topics related to it. The developed application has fulfilled the requirements set to it and an additional user experience testing has been carried out. While testers' likeliness to play the game more in the future and download it on their own phone appear promising, the application has some shortcomings. The main lacklustre points are related to overall UI elements and limited engaging game mechanics.

Based on the results that users do pick up the AR game quickly, find it entertaining and do not see it as a complex addition to a conventional card game, it can be said, that future developments in similar card games can find positive support. In addition, as the testers found that in their opinion, most people would not have trouble with picking up this game, it can be assumed, that there would not be major technical difficulties for a wider range of possible users.

6.2 Future work

The fact that the most of the main problems, that the users saw with the applications were related to UI or minor game mechanics shows that future refinement of the application is necessary. More attention should be paid to mechanics, that keep the users interested and the UI should meet the brought out expectations. Some of the more fundamental issues that were brought out would need further research. This includes making playing the game more comfortable while holding the phone, better false detection removal, improving the detection speed, multiplayer options and additional games. Using this platform for developing more and different games would offer a more diverse selection of games and could emphasise the universality of the ArUco playing card deck.

Additionally, it can be researched, how using an infinite deck could completely eliminate the possibility of card counting for example in casino blackjack games.

7 Acknowledgements

I would like to express my sincere gratitude to my extremely helpful supervisors Rain Eric Haamer and Prof. Gholamreza Anbarjafari for supporting and guiding me throughout the entire creation process of this thesis.

Additionally, I want to thank all the people who voluntarily joined in to contribute to the user testing and survey part.

Bibliography

[1] N. Sorge, "Card deck and method of playing card games with same," May 22 2014. US Patent App. 14/232,819.

[2] "Alphabetical index of card games." https://www.pagat.com/alpha/. Accessed: 2019-05-02.

[3] "Mängukaardid." https://www.apollo.ee/mangukaardid.html. Accessed: 2019-05-02.

[4] "Spellslinger starter kit 2018." https://www.lorien.ee/toode/6328/Spellslinger-Starter-Kit-2018/. Accessed: 2019-05-02.

[5] "Most played trading card game." http://www.guinnessworldrecords.com/world-records/most-played-trading-card-game/. Accessed: 2019-05-02.

[6] "Card search." https://gatherer.wizards.com/Pages/Search/Default.aspx?action=advanced&cmc=+>=%5b0%5d. Accessed: 2019-05-02.

[7] "Statista - value of the global video games market from 2012 to 2021 (in billion u.s. dollars)." https://www.statista.com/statistics/246888/value-of-the-global-video-game-market/. Accessed: 2019-04-03.

[8] Y. Nakamura, "Peak video game? top analyst sees industry slumping in 2019." https://www.bloomberg.com/news/articles/2019-01-23/peak-video-game-top-analyst-sees-industry-slumping-in-2019. Accessed: 2019-04-03.

[9] "Virtual reality (vr) video gaming sales revenue worldwide from 2015 to 2020 (in billion u.s. dollars)." https://www.statista.com/statistics/499714/global-virtual-reality-gaming-sales-revenue/. Accessed: 2019-04-03.

[10] "Forecast augmented (ar) and virtual reality (vr) market size worldwide from 2016 to 2022 (in billion u.s. dollars)." https://www.statista.com/statistics/591181/global-augmented-virtual-reality-market-size/. Accessed: 2019-05-02.

[11] W. R. Sherman and A. B. Craig, *Understanding virtual reality: Interface, application, and design.* Morgan Kaufmann, 2018.

[12] M. K. Bekele, R. Pierdicca, E. Frontoni, E. S. Malinverni, and J. Gain, "A survey of augmented, virtual, and mixed reality for cultural heritage," *Journal on Computing and Cultural Heritage (JOCCH)*, vol. 11, no. 2, p. 7, 2018.

[13] S. J. Kim, Y. Jeong, S. Park, K. Ryu, and G. Oh, "A survey of drone use for entertainment and avr (augmented and virtual reality)," in *Augmented Reality and Virtual Reality*, pp. 339–352, Springer, 2018.

[14] "Online etymology dictionary - virutal description." https://www.etymonline.com/word/virtual#etymonline_v_7821. Accessed: 2019-03-18.

[15] "Cambridge Dictionary meaning of virtual reality in english." https://dictionary.cambridge.org/dictionary/english/virtual-reality. Accessed: 2019-03-18.

[16] "Virtual reality - wikipedia." https://en.wikipedia.org/wiki/Virtual_reality. Accessed: 2019-04-03.

[17] "Virtual reality headset - wikipedia." https://en.wikipedia.org/wiki/Virtual_reality_headset. Accessed: 2019-04-03.

[18] "The ultimate vr headset buyers guide." https://www.theverge.com/a/best-vr-headset-oculus-rift-samsung-gear-htc-vive-virtual-reality. Accessed: 2019-04-03.

[19] "Maclean 3d-prillid google cardboard nano rs500." https://www.photopoint.ee/telefonide-tarvikud/578549-maclean-3d-prillid-google-cardboard-nano-rs500. Accessed: 2019-04-03.

[20] "Make your own virtual reality glasses." https://www.instructables.com/id/Make-Your-Own-Virtual-Reality-Glasses/. Accessed: 2019-04-03.

[21] "Gearvr koos puldiga - samsung ee." https://www.samsung.com/ee/wearables/gear-vr-r325/. Accessed: 2019-04-09.

[22] "Specifcations - samsung vr with controller - the official samsung galaxy site." https://www.samsung.com/global/galaxy/gear-vr/specs/. Accessed: 2019-04-09.

[23] "Vive - user guide." https://dl4.htc.com/Web_materials/Manual/Vive/Vive_User_Guide.pdf?_ga=2.3121584.1662424367.1554794904-684342291.1554794904. Accessed: 2019-04-09.

[24] "Vive pro hmd user guide." https://dl4.htc.com/Web_materials/Manual/Vive_HMD/User_Guide/VIVE_Pro_HMD_User_Guide.pdf?_ga=2.101722753.1662424367.1554794904-684342291.1554794904. Accessed: 2019-04-09.

[25] "Vive - buy vive hardware." https://www.vive.com/eu/product/#vive-spec. Accessed: 2019-04-09.

[26] "Vive pro full kit." https://www.vive.com/eu/product/vive-pro-full-kit/. Accessed: 2019-04-09.

[27] I. The Goldman Sachs Group, "Profiles in innovation - virtual and augmented reality," 2016.

[28] "Applications of virtual reality." https://www.vrs.org.uk/virtual-reality-applications/. Accessed: 2019-04-09.

[29] M. Billinghurst, A. Clark, and G. Lee, "A survey of augmented reality," *Foundations and Trends in HumanComputer Interaction*, vol. 8, no. 2-3, pp. 73–272, 2015.

[30] R. T. Azuma, "A survey of augmented reality," *Presence: Teleoperators & Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.

[31] J. E. Swan and J. L. Gabbard, "Survey of user-based experimentation in augmented reality," in *Proceedings of 1st International Conference on Virtual Reality*, vol. 22, pp. 1–9, 2005.

[32] J. Bacca, S. Baldiris, R. Fabregat, S. Graf, *et al.*, "Augmented reality trends in education: a systematic review of research and applications," 2014.

[33] J. Batchelor, "Gamesindustrybiz presents... the year in numbers 2018." https://www.gamesindustry.biz/articles/2018-12-17-gamesindustry-biz-presents-the-year-in-numbers-2018. Accessed: 2019-04-09.

[34] "Forecast for the number of active virtual reality users worldwide from 2014 to 2018 (in millions)." https://www.statista.com/statistics/426469/active-virtual-reality-users-worldwide/. Accessed: 2019-05-04.

[35] "Mobile gaming app revenue worldwide in 2015, 2016 and 2020 (in billion u.s. dollars)." https://www.statista.com/statistics/511639/global-mobile-game-app-revenue/. Accessed: 2019-04-09.

[36] "World population prospects: The 2017 revision - un)." https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html. Accessed: 2019-04-09.

[37] P. Curwen, "Has the smartphone market hit the rocks? a regular column on the information industries," *Digital Policy, Regulation and Governance*, vol. 21, no. 2, pp. 193–195, 2019.

[38] S. SRIVASTAVA, "Global smartphone market declines for the first time in cy 2018)." https://www.counterpointresearch.com/global-smartphone-market-declines-first-time-cy-2018/. Accessed: 2019-04-09.

[39] "The mobile gaming industry: Statistics, revenue, demographics, more [infographic]." http://mediakix.com/2018/03/mobile-gaming-industry-statistics-market-revenue/#gs.93m9yl. Accessed: 2019-05-04.

[40] "Card game - wiki)." https://en.wikipedia.org/wiki/Card_game. Accessed: 2019-04-09.

[41] R. M. French, "Card game," Aug. 10 2004. US Patent 6,773,012.

[42] "Collectible card game." https://en.wikipedia.org/wiki/Collectible_card_game. Accessed: 2019-05-04.

[43] "Magic: The gathering price list." https://www.mtggoldfish.com/prices/paper/standard. Accessed: 2019-05-04.

[44] "New to magic - magic: The gathering)." https://magic.wizards.com/en/new-to-magic?B=. Accessed: 2019-04-09.

[45] "Pokemon trading card game)." https://www.pokemon.com/us/pokemon-tcg/. Accessed: 2019-04-09.

[46] "Yu-gi-oh! - trading card game)." https://www.yugioh-card.com/en/about/newto.html. Accessed: 2019-04-09.

[47] J. Albrecht, "Card dispensing shoe having a counting device and method of using the same," Dec. 20 1994. US Patent 5,374,061.

[48] O. Toole and D. Dolben, "Marker detection and tracking for augmented reality applications,"

[49] J. Köhler, A. Pagani, and D. Stricker, "Detection and identification techniques for markers used in computer vision," in *Visualization of Large and Unstructured Data Sets-Applications in Geospatial Planning, Modeling and Engineering (IRTG 1131 Workshop)*, Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, 2011.

[50] S. Garrido-Jurado, R. Muñoz-Salinas, F. J. Madrid-Cuevas, and M. J. Marín-Jiménez, "Automatic generation and detection of highly reliable fiducial markers under occlusion," *Pattern Recognition*, vol. 47, no. 6, pp. 2280–2292, 2014.

[51] "Narrow (bridge) size verses wide (poker) size)." https://www.kemcards.net/kem-narrow-vs-wide-size. Accessed: 2019-04-09.

[52] "Artoolkit homepage from november 2017 - wayback machine." https://web.archive.org/web/20171107030524/https://artoolkit.org/. Accessed: 2019-04-11.

[53] "Artoolkit homepage from november 2017 - wayback machine." http://www.arreverie.com/blogs/getting-started-with-artoolkit-unity-plugin/. Accessed: 2019-04-11.

[54] "Partners - vuforia - unity." https://unity3d.com/partners/vuforia. Accessed: 2019-05-12.

[55] "Pricing and licensing options." https://library.vuforia.com/articles/FAQ/Pricing-and-Deployment-Plans. Accessed: 2019-05-12.

[56] "Arcore - fundamental concepts." https://developers.google.com/ar/discover/concepts#motion_tracking. Accessed: 2019-05-14.

[57] "Arcore - supported devices." https://developers.google.com/ar/discover/supported-devices. Accessed: 2019-05-14.

[58] "The worlds leading real-time creation platform." https://unity3d.com/unity?_ga=2.157732793.2020807172.1554997063-1529746647.1550438138. Accessed: 2019-04-11.

[59] "Unity 2018.3.5." https://unity3d.com/unity/whats-new/2018.3.5. Accessed: 2019-04-28.

[60] "Unity 2018.3.6." https://unity3d.com/unity/whats-new/2018.3.6. Accessed: 2019-04-28.

[61] "Unity 2018.3.11." https://unity3d.com/unity/whats-new/2018.3.11. Accessed: 2019-04-28.

[62] "Importing objects from blender." https://docs.unity3d.com/2017.3/Documentation/Manual/HOWTO-ImportObjectBlender.html. Accessed: 2019-04-12.

[63] "Opencv for unity." https://enoxsoftware.com/opencvforunity/. Accessed: 2019-05-14.

Appendices

Appendix 1: Survey questions

NoQ: -----
Age: -----
Gender: F/M
Experienced Player: Y/N

0: Strongly Disagree
5: Strongly Agree

1. I think that I would like to use this AR game frequently. [personal first/second impression]

   0 1 2 3 4 5

2. I found the AR element in the game unnecessarily complex. [alternative]

   0 1 2 3 4 5

3. I found the AR element an entertaining addition to a conventional card game [innovative]

   0 1 2 3 4 5

4. I needed to learn a lot of things before I could get going with this game. [how easy it is to use]

   0 1 2 3 4 5

5. I would imagine that most people would learn to use this AR game very quickly. [impact in the industry]

   0 1 2 3 4 5

6. I would install it on my own phone

   0 1 2 3 4 5

7. 3 things I would add or change to make the application more appealing for me/users:

   A ----------

   B ----------

   C ----------

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