Minja Silvennoinen

Displaying Augmented Reality content on HoloLens environment

Author Title Number of Pages Date	Minja Silvennoinen Displaying augmented reality content on HoloLens environment 40 pages 17 September 2017
Degree	Bachelor of Engineering
Degree Programme	Information and Communication Technology
Specialisation option	Game Applications
Instructors	Otto Laurila (Arilyn) Antti Laiho (Senior Lecturer)

Thesis was done for digital communication company Arilyn, which uses augmented reality for creating interactive media. The goal of the thesis was to convert Arilyn mobile application for Microsoft's HoloLens. The application should support basic data types and have a visual appearance similar to Arilyn mobile application.

The first part of thesis concentrates on general research about augmented reality and HoloLens technologies. Next the content creation process for HoloLens is described and best practices for augmented reality applications are considered. Last part concentrates on the actual converting process from Arilyn mobile application to Arilyn for HoloLens.

Arilyn for HoloLens includes almost all the predefined features. It supports image, video and sound files. The only datatype that is missing is 3D models. HoloLens uses different texture compression than smartphones, so the support for this type needs to be added to Arilyn Manager.

During the conversion process, it was noted that target-based augmented reality is not the most suitable for HoloLens device. HoloLens renders dark colors transparent which sometimes leads to a situation where the content seems it is positioned behind the target. Another problem was how the user's eye focuses on the content. The content is rendered close to the eye which leads to seeing the content as a double.

Even though target-based augmented reality has its problems, it is important to keep researching the subject. The problems might be easily solved after the overall quality of head-mounted devices gets better or after the subject is studied more.

| Keywords | augmented reality, HoloLens, target-based, interactive media |

Tekijä Otsikko Sivumäärä Aika	Minja Silvennoinen Lisätyn todellisuuden sisällön esittäminen HoloLens-ympäristössä 40 sivua 17.9.2017
Tutkinto	Insinööri (AMK)
Tutkinto-ohjelma	Tieto- ja viestintätekniikka
Ammatillinen pääaine	Pelisovellukset
Ohjaajat	Teknologiajohtaja Otto Laurila Lehtori Antti Laiho

Insinöörityön tavoitteena oli kehittää lisättyä todellisuutta hyödyntävä sovellus älylaseilla käytettäväksi. Sovelluksen tuli tukea yleisimpiä tiedostotyyppejä: kuvaa, videota, ääntä ja 3D-malleja. Visuaalisen ulkoasun tuli myös olla samankaltainen insinöörityön tilaajayrityksen mobiilisovelluksen kanssa.

Insinöörityössä tutkittiin älylasien teknologiaa sekä niille tehtyjä yleisiä sisällöntuotantoprosesseja ja käyttösuosituksia. Sen jälkeen keskityttiin varsinaiseen käännöstyöhön mobiilisovelluksesta älylaseilla käytettävään sovellukseen.

Sovellus sisältää lähes kaikki ennalta määritetyt ominaisuudet. Sen avulla pystyy katsomaan kuva- ja videotiedostoja sekä toistamaan ääntä. Ainoa puuttuva tiedostotyyppi on 3D-mallit. Valitut älylasit käyttävät erilaista pakkausmuotoa kuin älypuhelimet, joten 3D-malleja ei pystytä näyttämään ennen kuin insinöörityön tilaajayritys lisää tuen puuttuvalle pakkausmuodolle.

Käännöstyön aikana huomattiin, ettei kuvapohjainen lisätyn todellisuuden sovellus ole kaikkein käyttökelpoisin älylaseilla. Valitut älylasit kuvantavat tummat sävyt läpinäkyvinä, minkä takia sisältö näyttää välillä tulevan kuvan takaa. Toinen ongelma johtuu siitä, kuinka käyttäjän silmä tarkentaa kohteeseen. Sisältö kuvannetaan lähelle käyttäjän silmää, mikä voi johtaa sisällön näkemiseen kahtena.

Vaikka kuvapohjaisella lisätyn todellisuuden sovelluksella on omat ongelmansa, on tärkeää, että aihetta tutkitaan lisää. Ongelma saattaa olla helposti ratkaistavissa päähän puettavien laitteiden laadun parantuessa tai ylipäänsä tiedon lisääntyessä aiheesta.

Avainsanat	Lisätty todellisuus, HoloLens, kuvapohjainen, interaktiivinen media

Metropolia

Contents

Glossary

AR   Augmented Reality. Technology to augment virtual objects into real world.

VR   Virtual Reality. Technology that shows only virtually generated objects around the user.

MR   Mixed Reality. Technology that is somewhere between Augmented and Virtual realities.

HMD   Head-mounted Display. A device that can be worn like a helmet or glasses and is used for augmenting virtual objects into the user's sight.

UI   User Interface.

JSON   JavaScript Object Notation. Data structure that allows storing data in a text format.

1 Introduction

Thesis is done for digital communication company Arilyn, which uses augmented reality for creating interactive media. The goal of the project is to convert Arilyn mobile application to be used with Microsoft's HoloLens head-mounted display. The application should support the basic data types: image, video, 3D and sound. It should also have a visual appearance similar to Arilyn mobile application and a basic UI.

Thesis is divided into three main sections: first is general research of augmented reality and HoloLens technologies, second is content creation process for HoloLens and the last one focuses on the actual conversion process of Arilyn-App for HoloLens.

The first part gives a brief history of the augmented reality technology and goes through the evolution from first bulky devices to currently available head-mounted displays. The chapter also considers the possibilities augmented reality grants as well as gives examples of the different ways it can be exploited today. Lastly there are examples of companies that are currently utilizing augmented reality.

The second part focuses on examples of how the applications should be created for HoloLens and what are the best practices to do so. It goes through the glossary which Microsoft has chosen for new features of HoloLens and it will also have a deeper analysis about the technical restrictions needed to remark when developing applications for HoloLens. The chapter also introduces Arilyn and tells how their mobile application and manager software are used.

The last part concentrates on the converting process from Arilyn mobile application to Arilyn for HoloLens. It starts from designing the application and going through the way how Arilyn-App is currently working alongside Arilyn Manager. The rest of the chapter is about the implementation of required features.

The topic was chosen because augmented reality for consumers is predicted to move towards using smart glasses instead of mobile phones and because augmented reality is anticipated to become mainstream in the next few years. The research about the possible future cases of augmented reality is mentioned on the first section of the thesis.

2   Augmented reality and HoloLens technology

This chapter will look into the definition of augmented reality and Microsoft's HoloLens headset and proceed into the possibilities and practical use of the technology. Lastly there is an overview of the companies currently using augmented reality along with an overall future estimation of the industry.

2.1   Definition and history of technology

Augmented reality (AR) can be represented as an improved view of our world. It means virtual objects are mixed with our environment by augmenting them into our sight [1, p. 3]. One definition of augmented reality is "a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world". One commonly used representation of the similarities of augmented and virtual reality is called the Reality-Virtuality Continuum by Paul Milgram. As seen in figure 1 Milgram described augmented and virtual reality as different ends of a line between entirely virtual environment and real world. [2.]

Kuva 1.   Reality-Virtuality Continuum [2].

Virtual reality (VR) is on the side where everything seen is created with virtual objects and augmented reality lies on the opposite side near real world environment. In between these two realities is augmented virtuality which differs from augmented reality only moderately. While augmented reality is augmenting the real world and adding virtuality to it, augmented virtuality is adding the mostly virtual world with parts of real world. [2.] An ordinary example of augmented virtuality is a weather forecast. The weather man is standing in a virtually generated world as shown in figure 2. Everything that is between fully real and fully virtual are defined as mixed reality (MR) [2].

Kuva 2.   Weather forecasts are using augmented virtuality [3].

Augmented reality has been known as a concept as early as 1960s [4] but only now it is becoming more practical for using in applications. Affordable internet connections, the increase of the capabilities of mobile devices and overall advancing in making devices more powerful made it possible to start using these technologies. [5.] It is speculated that Frank Baum was the first person to talk about augmented reality even before it was mentioned as a concept [11]. He wrote a novel called The Master Key in 1901. The novel is about a boy who summons a Demon of Electricity that gives him different electronical devices. One of these devices is called "Character Marker". [6.]

> It consists of this pair of spectacles. While you wear them every one you meet will be marked upon the forehead with a letter indicating his or her character. The good will bear the letter 'G,' the evil the letter 'E.' The wise will be marked with a 'W' and the foolish with an 'F.' The kind will show a 'K' upon their foreheads and the cruel a letter 'C. Thus you may determine by a single look the true natures of all those you encounter. [6.]

This marker can be understood as an early description of the features of augmented reality, which can be used for giving more in depth information about a person, like in the novel, or product, for example artifacts in museums [7].

Kuva 3.   A screenshot of a video describing the use of The Sword of Damocles [9].

One of the first actual augmented reality systems was created by Ivan Sutherland in 1968 [4]. Sutherland wrote a paper about The Ultimate Display and the possibilities it would grant [8]. After that he created The Sword of Damocles, which is a head-mounted display (HMD) that allowed the user to look around the room and see virtually augmented objects through the display [4]. As seen in figure 3, the device was attached on the ceiling and was needed to be held with both hands, which made it clumsy to use.

Kuva 4.   Myron Krueger's Videoplace [10].

The first system which allowed the user to interact with virtual objects was called Videoplace. It was created by Myron Krueger in 1975. [4.] His invention enabled two people standing in different rooms to communicate with each other. A processor analyzed the user's image and made it into a silhouette. It could analyze the posture, rate of movement and the user's position relative to other graphical objects in the system, as shown in figure 4. [10.]

It took a long time before augmented reality started to take the shape it is today. One of the first "real" augmented reality applications similar to what can be achieved today was a HMD device created by researchers Tom Claudell and David Mizell. Their device displayed a wiring instruction for making a Boeing aircraft development easier. The figure 5 shows that the HMD device instructed the place to drill to get the hole in correct position. Claudell and Mizell also invented the term augmented reality. [11.]
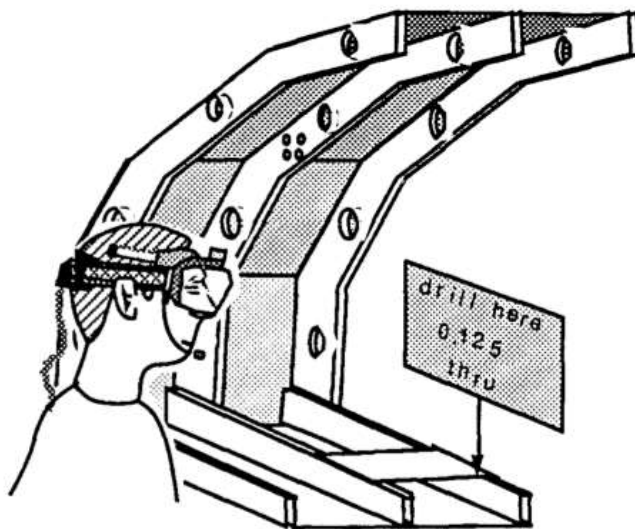
An application where the HUDset is used to dynamically mark the position of a drill/rivet hole inside an aircraft fuselage.

Kuva 5.   Picture of a HMD device used for making aircrafts [11].

Finally in 1999 augmented reality technology moved to consumer markets, from previously being only for scientist, as a result of releasing ARToolKit by Hirokazo Kato [12]. ARToolKit let programmers to build software's that could calculate the user's viewpoint in real time and use that information to add virtual images that aligned relative to marked

cards [13]. ARToolKit was an important invention towards consumer AR applications even though it took another 10 years before camera phones, which are mostly used for AR today, became ubiquitous [14]. Still almost all the Flash-based augmented reality used in web had been made with ARToolKit [4]. Wikitude was the first augmented reality software development kit (SDK) to allow GPS tracking in 2008. It used compass data with Wikipedia articles of points of interests and displayed that data on a real-time camera view of a smartphone. [4.] Today the leading augmented reality platform is Vuforia. It has over 325000 registered developers and powers more than 35000 applications. [15.] Vuforia can get even more ground within augmented reality development because of the recent announcement of Vuforia partnering up with the leading game engine Unity [16].

The latest trend seems to be going towards augmented reality smart glasses. Recent marketing predictions have revealed that smart glasses are going to be the next "big thing" in the evolution of media. These wearable devices work similarly as a smart phone augmented reality but are worn like regular glasses. The virtual information is then rendered directly in the user's field of view. [17.] One of these smart glasses is HoloLens created by Microsoft. It is a HMD device that exploits augmented reality features, though Microsoft prefers the term mixed reality [18]. It has been about two years since Microsoft exposed the HoloLens headset and about one year since they started to send the development kits to developers [19]. HoloLens uses sensors for capturing information about the user's environment. It can recognize physical spaces and for example furniture around the user. HoloLens uses see-through lenses that generate the virtual objects, called holograms, around the user. [20.] More about HoloLens technology can be read in later chapters.

2.2   Possibilities and practical use of augmented reality

One of the early adopters of augmented reality were toy and game industries. Pokémon GO is a geo-location based mobile game, created by Niantic and Nintendo. It encourages the players to walk outside in the real world and catch small creatures called Pokémon. It is one of the most well-known examples of an AR game [21]. It was the fastest mobile game at all times to reach 10 million downloads [22] and only two months after its launch the game had been downloaded over 500 million times [23]. Niantic had made another

augmented reality game, called Ingress, before Pokémon GO. It uses the similar technology as it's descendant. Participants use Google Maps-based interface and walk to nearby portals trying to conquer them. The similarities between Ingress portal and Pokémon GO PokeStops can be seen in figure 6. Even Nintendo has tried augmented reality earlier. Their pet-simulation game Nintendogs + Cats for Nintendo's handheld console 3DS uses AR Cards that allow the player to see their pets in real world via augmented reality camera [24].

Kuva 6.   Ingress and Pokémon GO both have the same important in-game locations on same streets.

Toy companies have also noticed the opportunities augmented reality provides. As shown in figure 7A, it is common for children over 10 years to already own a mobile phone and as seen in figure 7B, it is known that over 70% of the children who have access to Internet use mobile applications. There are various ways to use augmented reality with toys. For example, the modeling compound company Play-Doh has released an application that scans the creation the child has made and turns it to life on phone's screen [26], Sony has made a game called Wonderbook which makes the spells of Harry

Potter world seem real [27] and even the characters in coloring books can be used as a mobile game characters [28].
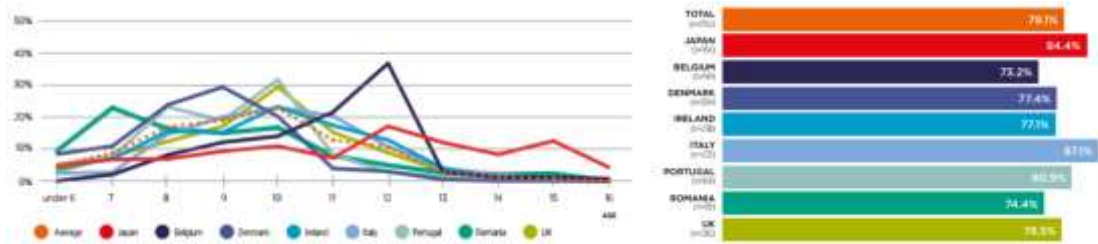

Kuva 7.   A) Age of the first mobile phone ownership by country (% of children who use mobiles). B) Child smartphone users who download/use apps by country (% of children who access the internet via smartphone). [25.]

Toys are not the only option for using augmented reality with children. Another important usage is in education. Augmented reality can be used with various subjects in elementary and even higher educations and the learning effects have been positive with it. There has been increased motivation among students to learn something new and augmented reality is also helpful on understanding otherwise difficult structures: in biology, augmented reality can show how human organs look like, in math it can display complex geometrical shapes and in chemistry it can show structures of chemical compounds. [29.] Augmented reality can also be adopted in higher education. An electrical engineering and computer science student from The University of Western Australia is a lead developer of an AR software which will help dental school students to train more efficiently. It gives fast and accurate feedback while students are learning about dental tasks, such as tooth preparation. [30.] Similar solutions can be benefitted by different industries. Construction workers could have an augmented reality headset that shows the full-scale 3D model of the building at the exact location where it should be build [31] or surgeons could see the CT scans layered on top of their patient [32].

Besides toys and education, augmented reality can be used to make people's lives easier. Over half of the applications for Android and iOS phones belong to Travel and Tourism category. Augmented reality can be used as a virtual tour guide which detects the nearest points of interests, such as landmarks and hotels or restaurants, from the user's location. Some applications show extra information about items displayed on museums or show an older view of what landmark has looked like in the past. [33.] Similar techniques can be used in retail. Some applications, like one made by IBM, show additional information about sold products to help the shopper to choose a brand which has for

example lowest amounts of sugar [34] and others, like the one made by Ikea, help the consumer to measure if the furniture they wish to buy will fit into their apartment, as seen in the figure 8.
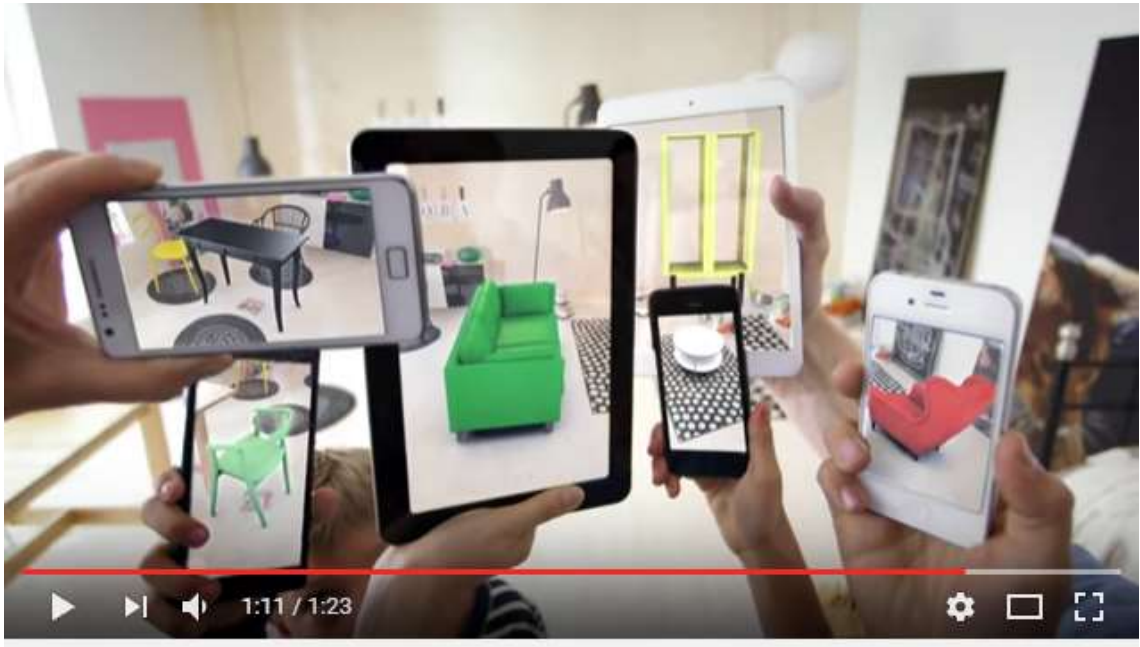
Kuva 8.   Screenshot of IKEA's video introducing their augmented reality software. [35.]

There are valuable benefits when using augmented reality, but challenges in ethical and security uses of it can't be left out of notice. These subjects haven't been studied enough and augmented reality researchers should explore the possible consequences now, when there is still time to modify the way augmented reality applications are build. An experiment proved augmented reality can be used for intentionally misleading the users to be affected into decision-making. The users were asked to sort cards on a criterion and it was acknowledged that after using an augmented reality system the users started to trust it so deeply they didn't notice if the system gave them wrong answers in simple tasks. [36.]

Another important point to beware of is the privacy of location-based services. Location data is commonly used in augmented reality since the application can provide useful information about user's environment by knowing their location. Even though using augmented reality applications is a fairly new trend, Pokémon GO already proved one major

problem with location-based services: some Pokémon GO players were robbed because the robbers were able to lure the players into secluded PokeStops. PokeStops are GPS-located spots where players receive items that help the progression of the game. [37.]

Kuva 9.   Robot Genius' film Sight displays a world where even the simplest tasks have been made into a game [38].

Even though the previously listed risks are real problems in which the solution should be found, there are also various threats that might be exaggerated. There are plenty of short films and TV series that are focused on giving examples of what could go wrong in the field of mixed media. Robot Genius is a small film studio which has been concentrating on making films of the possible future. One of the short films they are most known for is Sight, a futuristic story where computers and smartphones have been replaced by contact lenses that are using augmented reality. As seen in figure 9, even the simplest tasks, like slicing a cucumber, have been made into a game. [38.] This has recently started to feel like a plausible direction of the technology because Samsung has already applied for a patent for contact lens that augments images directly onto the user's eye [39].

One of the popular series in Netflix is a sci-fi anthology called Black Mirror, where each episode shows a different visualization of the future [40]. Some of the episodes have technologies that are already existing. The first episode of third season shows that people are wearing a pair of contact lenses that show person's rating in life above their head. This idea is not that far-fetched either because the face recognition features are starting

to be advanced enough for creating applications like that. Chinese government has already planned a scoring system to rate their citizens [41]. Similar technology as in the TV show is hard and costly invention to achieve but can already be recreated in some form [42].

2.3   Industry and companies

Both virtual and augmented reality markets are predicted to be huge in few years. Augmented reality can be used in consumer's everyday life and that makes it more suitable for mainstream use than virtual reality. [43.] Virtual reality market share is going to be bigger for the next few years but after augmented reality smart glasses and overall mobile phone technology gets better, augmented reality is anticipated to get three times more revenue by 2020 as shown in figure 10.
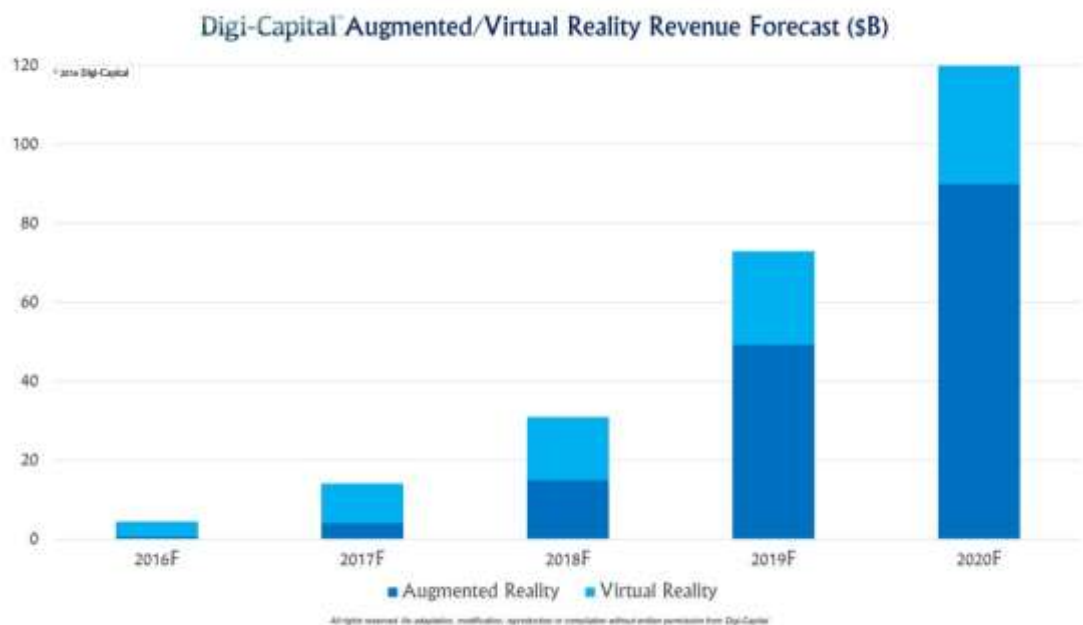
Kuva 10. Augmented reality is predicted to get more revenue that virtual reality by 2020 [43].

One of the biggest technology companies that have started to use augmented reality are Google and Apple. Google has released a Tango platform that uses depth sensors to allow the device to understand its position at the surrounding environment. Tango Android device enables developers to use motion tracking, area learning and depth sensing in their applications. [44.] There are currently only two phones on consumer market that can use Tango features [45] which is why Apple might be the first smartphone company

to bring augmented reality for mainstream usage. Apple has recently released a frame-work called ARKit. It works with the newest iPhones and doesn't require depth sensor like Tango systems. It can analyze the surroundings by the camera view to find horizontal planes, like tables and floors, and place objects on them. ARKit also uses camera sensor for estimating the total amount of light available in a scene and applying the correct amount to virtual objects. Phones compatible with ARKit need to have an iOS device minimum with A9 processor. [46.] This means there are five different smart phones which support it: iPhone 7 & 7 Plus, iPhone 6s & 6s Plus and iPhone SE [47]. After publishing iPhone 6s and iPhone 6s Plus Apple announced they had sold over 13 million devices in three days, meaning there is a decent selection of devices supporting the new ARKit [48].

Kuva 11. Snapchat announced a face recognition feature in 2015 [49].

A social media platform Snapchat has been using augmented reality features since 2015 [49]. At that time they announced Lenses, a face recognition camera that adds filters on user's face. Lenses are demonstrated in figure 11. Today Snapchat is the most popular

application among teenagers in United States [50] but with the recent announce of augmented reality filters in Instagram [51], which is a photo-sharing application owned by Facebook, Snapchat has found a challenger. In addition of social media platforms, also other widely known brands like a cosmetics company L'Oréal [52], entertainment company Disney [53] and a printer manufacturer Epson [54] are testing the possibilities of augmented reality.

There are also companies that are trying to create a platform which makes creating augmented reality software's easier. One of such companies is called Magic Leap. They got almost 800 million in funding from big companies like Google, Warner Bros and Qualcomm [55]. Magic Leap has been seen as one of the most direct rivals of Microsoft's HoloLens [56].

3 Content creation process for HoloLens

The next section will go through requirements for creating mixed reality applications and information about augmented reality application Arilyn. It will also have a deeper analysis about the technical restrictions needed to remark when developing applications for HoloLens.

3.1 Requirements and software

Unity3D game engine is one of the best choices for creating mixed reality applications because it supports all the major AR/VR platforms [57] and the engine simplifies the process for deploying applications for different platforms [58]. Microsoft has published a HoloToolkit repository which contains a collection of useful scripts and components for HoloLens development for Unity3D. Microsoft has granted a license for anyone to use HoloToolkit in their development process. [59.]
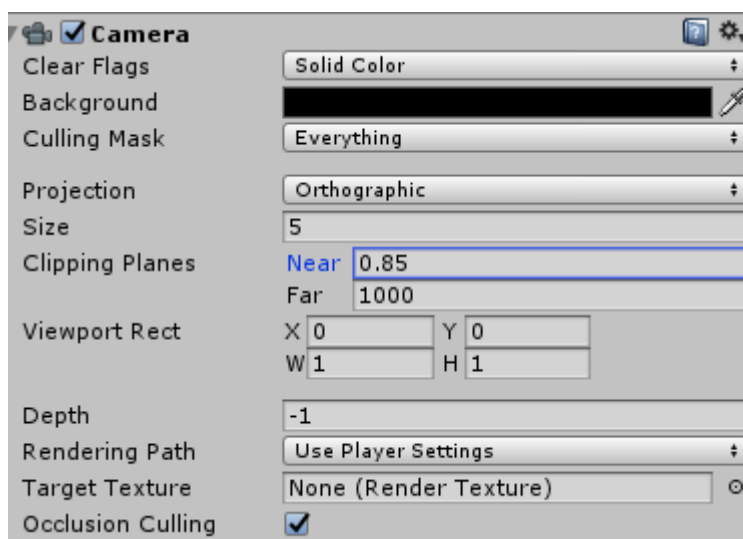
Kuva 12. Main Camera setting for HoloLens

Content creation process for HoloLens is a little different than creating content for mobile augmented reality devices. One of the most notable differences between mobile AR and holographic headset AR is that HoloLens renders black as transparent. This means anything rendered as black does not appear any different from the real world and dark colors can be difficult to notice when wearing a holographic headset because of their

transparency. This is also the reason why Main Camera in Unity is set to use solid black color as background instead of a skybox, as seen in figure 12. [60.]

Another important difference is the interaction. HoloLens does not use the regular ways to interact with objects. Instead it uses technique called gestures. Gestures are particular hand positions that can be used for selecting objects or pushing buttons. HoloLens can identify the position of the user's hands if they are visible for the headset. There are currently only few gestures that HoloLens recognizes and the most important ones are ready- and pressed states, which are used for interacting with holograms. Ready-state can be seen in figure 13A and pressed-state in the figure 13B. [61.]


Kuva 13. HoloLens gestures A) Ready-state. B) Pressed-state. [61.]

Gaze is a fundamental way of targeting with HoloLens along with gestures. HoloLens perceives where the user is looking at making it easy to target the object the user wants to interact with. Gaze should be used alongside of gestures for targeting objects instead of using the position of hands. The combination of gaze and gestures is called gaze-and-commit interaction. [62.] Third key form of interacting with HoloLens is voice input. It is also used in combination with gaze to know which object the user wants to interact with. It is mostly beneficial when used for going through complex interfaces which require multiple gaze-and-commit interactions. [63.]

HoloLens uses spatial mapping for making the holograms seem more real. It produces a mesh generated from real-world surfaces and it can recognize walls, floors, tables and other objects visible for HoloLens headset. It enables virtual objects to interact with real world. User could for example throw a virtual ball towards a real wall and the ball would bounce back from it. The scanned real-world objects can also occlude the holograms allowing them to go for example behind a chair. [64.]

3.2   Arilyn and Manager software

Arilyn is an application for digital communication. It combines augmented reality, location intelligence and interactive media. [65.] Arilyn consists of two platforms: Arilyn-App and Arilyn Manager. Arilyn-App is a mobile application available for download from Google Play and AppStore and Arilyn Manager is an online service where augmented reality campaigns can be created. It is designed for companies interested in innovative ways of creating virtual advertising or features. Arilyn aims to being a pioneer in the field of augmented reality and wish to offer a versatile augmented reality platform for creating visual campaigns. [66.]
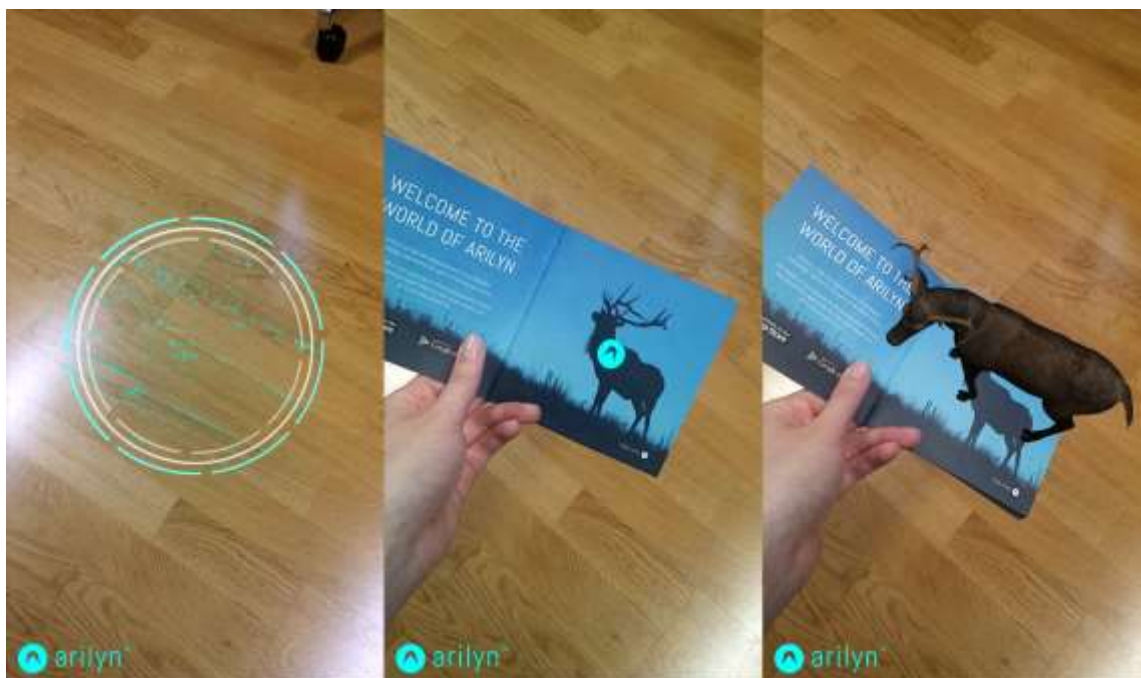

Kuva 14. Three phases of using Arilyn-App. Scanning, downloading the content and displaying it. [65]

As seen in figure 14, Arilyn-App works in three phases. When user opens the software, a circle starts to animate in the middle of the screen. It indicates the application is trying to find something to scan. Once a target with content is found, the application shows the content as it is set up in Manager. Arilyn supports various content files: there is a basic image and video files, including viewing the content in 360 degrees and panoramas, and also 3D models, buttons and text.

3.3   Quality and performance of HoloLens application

Visual quality is an important aspect of creating video games or applications. Entertain-ment Software Association made a survey and asked gamers what is the most important factor of purchasing a new video game. As seen in figure 15, quality of the graphics was chosen by 67% of the people who answered the survey. [67.] People have also become interested in sharing their experiences via smartphone. The quality of the visuals needs to be high enough to get the user to share for example an image of their experience in social media. [68.]
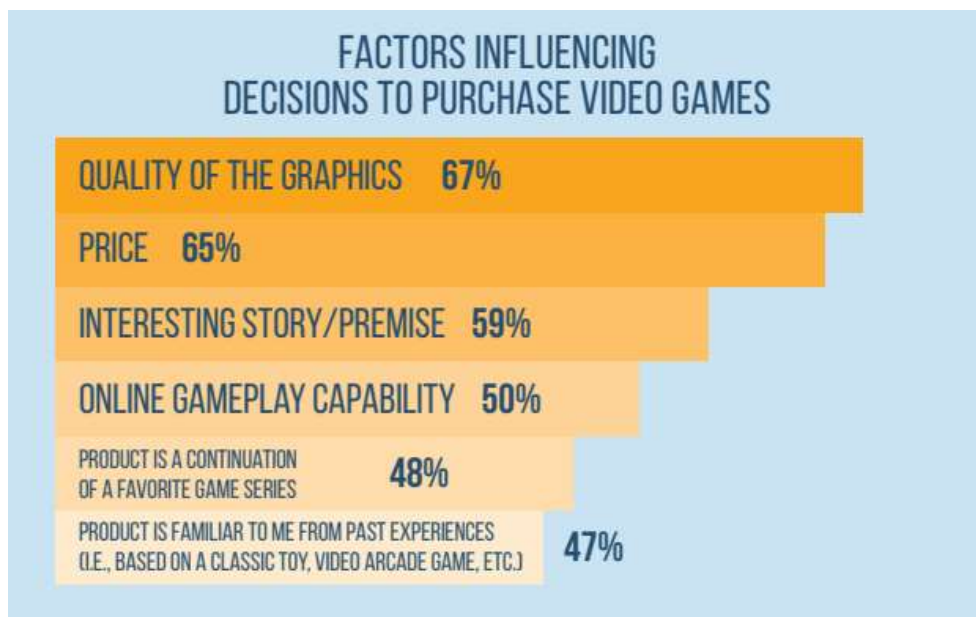
Kuva 15. Survey about the most factors of purchasing video games [67].

High visual cost leads directly to higher cost on performance which is an important aspect to be considered when developing for HoloLens. If HoloLens can't play the application with frame rate of 60 it can cause nausea to the users [69]. The "simulator sickness" happens when the user's brain notices a difference between what the user is seeing and feeling. Multiple researches have been made about removing the nausea. For example, researchers noticed that by adding a virtual nose in VR environment reduces the simu-lator sickness effect. [70.]

To maintain the frame rate of 60 and to keep the power utilization down, developers should write the code of the project efficiently. If there are too many objects being ren-dered simultaneously it will affect the CPU performance of HoloLens. Also, expensive

graphic settings, hitches due to garbage collection and too expensive updates or too many object updates are costing a lot of performance. [71.]

It's important to use the fastest quality settings in Unity when developing for HoloLens [71]. The fastest settings optimize for example overall texture qualities, shadows and anti-aliasing used in application [72]. The fast quality settings can be made to look better by using shaders. Shaders are settings that are set for each pixel on the screen. Figure 16 shows an over exaggerated example of how shaders can make enhancements for content. [73.]

Kuva 16. Shaders can be used for making effects [73].

There are some basic guidelines to be aware of when creating applications for HoloLens. Unity's update functions should be avoided if there are many objects on the scene that use heavy processing. There also shouldn't be plenty of code loading synchronized. This can make HoloLens to drop the frame rate under 60 and cause discomfort. This is the reason any long running code should be asynchronous. Another important aspect to re-member is to avoid deep object hierarchies when moving objects. The calculation cost will add up if content has many child objects underneath it. [71.]

4   Converting Augmented Reality software for HoloLens applications

The goal of the thesis was to convert the mobile augmented reality application Arilyn for HoloLens. The application should recognize targets that are currently used with Arilyn Manager and display image, video, 3D and sound content on them. The application should also have an User Interface (UI) and a scanning animation that is suitable for HoloLens environment.

4.1   Designing an application for HoloLens

Converting Arilyn for being compatible with HoloLens requires the understanding of how the application works and what are the important phases for fetching information about the targets located in Arilyn Manager.

Understanding Cloud Recognition service

Augmented reality platform Vuforia has a huge role in Arilyn. It uses Vuforia's Cloud Recognition System which is a service that is ideal for applications with multiple targets. Cloud recognition saves the information about targets into a Cloud database instead of saving them all into the device. [74] Arilyn has hundreds of targets and saving them all into the device would make the application too sizeable.

Arilyn's own logging information is needed for the actual project but for testing purposes a new account can be created. Vuforia offers three options for License Keys: development, consumer and enterprise. The first option is free and can be used for applications currently under development, consumer is for applications that are ready for publishing and enterprise is distributed for the use by employees of a company using Vuforia. The generated License Key is added into the Vuforia configuration in Unity project.

Kuva 17. Adding targets into Vuforia database. A) Device target. B) Cloud target.

A new database can be set after creating the License Key. There are three different database types for creating application with Vuforia. First one uses the device for storing the targets, second one uses the Cloud Service and the third one is for use of VuMarks, specific barcodes that can be used with augmented reality targets. Vuforia Cloud database generates a set of Access Keys that are specific to each Cloud. Client Access Keys are passed to the Vuforia library within the application. This authenticates the application for using the Cloud server.

First targets can be uploaded after the setup process. The target creation is moderately different with Cloud targets when compared to Device targets. As shown in figure 17A, Vuforia needs to know the type of the target, its width compared to Unity units and a unique name when creating Device targets. However as seen in figure 17B, when creating Cloud targets the type of the target is stored into a specific Metadata Package. It is a user-defined data which can store customized information about the target and the content combined with it. Arilyn uses a JSON (JavaScript Object Notation) format to store for example the type, position and name of the target. JSON is a universal data structure that is supported by virtually all modern programming languages. It stores a set of data in text format which can be used for exchanging data between a browser and a server. [75] Vuforia uses a star rating for defining the quality of the uploaded target. The star rating determines if the target is well suitable for detection and stable tracking. Vuforia

will not attempt to recognize the target if the rating is not at least 1 star. Figure 18 shows and example of the star rating.
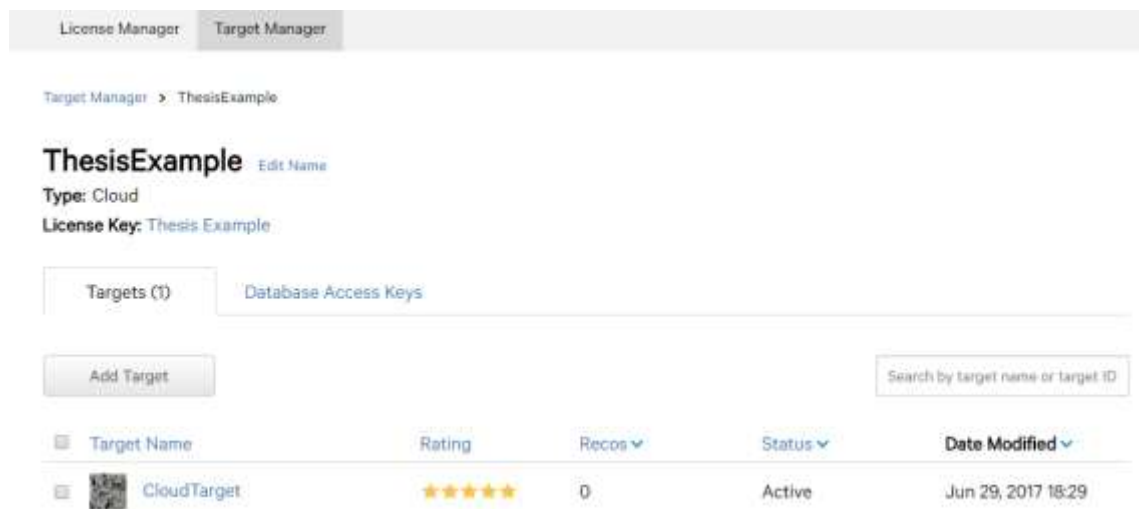
Kuva 18. Vuforia uses a star rating for determine the quality of uploaded target.

Next the Vuforia extension can be downloaded into Unity project from the Asset Store. Asset Store is created by Unity Technologies and the members of the community. It is a library of assets including anything from textures or models to a project examples and plugins. [76.] The most important components of the extension are ARCamera and CloudRecognition prefabs. Prefabs are assets that can save information about objects. The information can be for example script files or components with specific properties set inside of Unity. [77.] Both ARCamera and CloudRecognition prefabs can be found from Prefabs folder that came with Vuforia extension. These prefabs should be added into the scene hierarchy. ARCamera acts as a camera view of the device for which the application is built for and CloudRecognition takes care of the connection between Vuforia and Unity project. It needs the Access and Secret Keys that were generated earlier alongside with the database.

Cloud recognition can be used in couple different ways: having only the targets being stored on the Cloud and leaving the content stored in the device or storing also the content on the Cloud. It is more practical to store the content on the Cloud because Arilyn has hundreds of content files in Arilyn Manager. For the sake of getting to know the Cloud Recognition System the first option is used now for practice and the second option is implemented for the final project later. The basic principle is the same with both ways. ImageTarget prefab is added from the Prefabs folder into the scene. It should be setup

to use the CloudReco instead of Predefined User Targets. A simple cube can be placed as a child of the ImageTarget. Figure 19 describes the scene view of the project.

Kuva 19. The scene view of cloud recognition project.

A script called CloudHandler should be added to CloudRecognition prefab. It manages finding the Cloud based targets from Vuforia Cloud Service. CloudHandler implements ICloudRecoEventHandler and has a few overridden functions which are used for sending events from different states of initialization of cloud recognition. This is all the implementation needed for an application using cloud recognition. After scanning a target uploaded into the Vuforia cloud database the application shows the Cube object that was positioned as a child of the ImageTarget.

Designing the structure for HoloLens Arilyn

The most important functions of Arilyn are the ones Vuforia requires and the ones used for fetching data from Arilyn Manager. A plan for needed classes can be seen in figure 20.
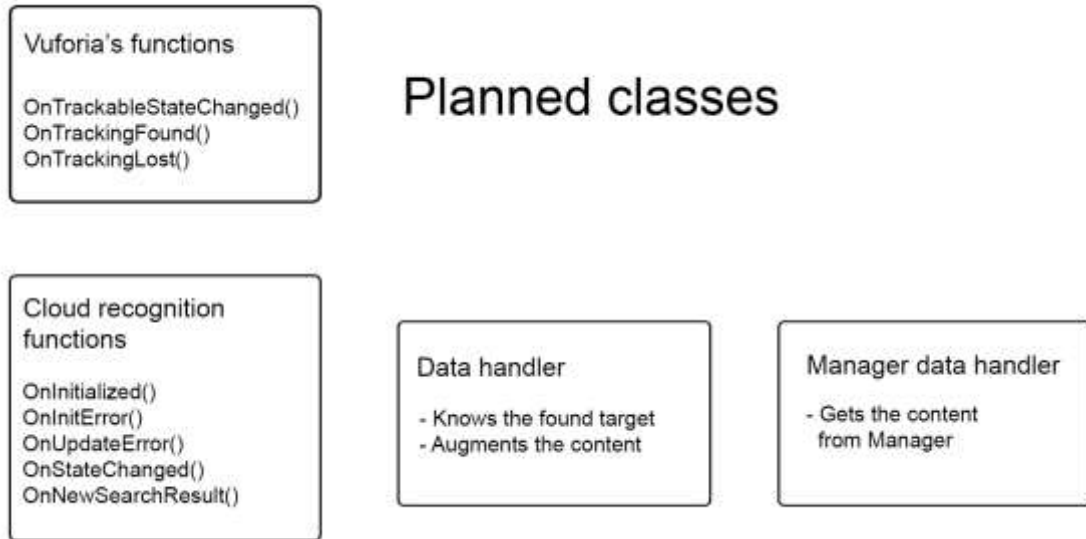
Kuva 20. Planned classes for Arilyn for HoloLens.

Functions needed by Vuforia are used for knowing the current status of the target. On-TrackableStateChanged() function is observing the found and lost targets. It calls On-TrackingFound() function if a target is identified and OnTargetLost() function if the identified target is not tracked anymore. OnTrackingFound() can be used for starting the data fetching from Arilyn Manager and OnTrackingLost() can be used for example for restaring the scanning animation. Cloud recognition functions are also part of the Vuforia namespace but the functions are used for setting up a Cloud Recognition Service. The functions are for initializing new target finders.

Data handler and Manager data handler are scripts that manage the content data. The data handler should be split into two separate classes to avoid creating too complex and long scripts. Data handler saves the information about currently tracked targets and augments the content. Manager data handler is for getting the JSON data saved to targets.

4.2   Implementing Cloud Recognition for Arilyn Hololens

The next chapter has more in depth look of the different data types used in Arilyn. Basic data fetching from Arilyn Manager and the functions for leading the JSON information to correct data type functions are implemented.

Basic data fetching and image prefab

The earlier project made for testing Cloud recognition can be used as a base for implementation of Arilyn for HoloLens. The project should be first set up for easier debugging. At first the project can be tested with the Game View which allows the developer to preview the work in progress. Another testing platform that can be used is Android, because all the features might not work correctly on Unity's own player and Android app works in a similar way as HoloLens application would. HoloLens is used later on the project after programming the basic functions. An OnGUI() function can be added to CloudHandler script for displaying the different states of the program as text on devices screen. As figure 21 shows, scanning and target found states can be displayed on the screen. This is helpful for knowing if the problem is with Cloud recognition or fetching the data from Manager.

Kuva 21. OnGUI() function can be used for debugging different states of the program.

ImageTarget prefab that was implemented earlier can be used as a base for all Cloud recognition components. Its name should be changed to CloudTarget so it is more describing. Image content is the most easier to start implementation with. After getting the data from Arilyn Manager the image only need to be set as a texture of a plane object. A new GameObject called DataHandler should be added to the scene. It has two scripts: DataHandler and ManagerDataHandler, which purpose were described earlier.

A StartPresentation() function should be added for DataHandler script as a starting point for augmenting the content. StartPresentation() gets the name of a found target and passes it to GetManagerData() function in ManagerDataHandler. GetManagerData() saves the name of the target as a variable and then starts a Coroutine called GetJSON-Data(). Coroutine is a call function which runs to completion before it returns [78]. It

should be used when fetching information from web so the application waits the function has downloaded all the data before continuing.

GetJSONData() first needs the URL address of the found target. GetURL() function gets the URL address of Arilyn Manager that is stored in SessionHandler GameObject. It then adds all the needed parts for the URL to start working by using the name of found target. After getting the URL address, GetJSONData() uses a WWW class to access the Arilyn Manager and passes the found JSON information to Augment() function in DataHandler. The Augment() function goes through the JSON information and checks the type of the content. Each data type should have its own prefab.

Augment() function has a switch statement where the cases are different data types pre-sented as enums. Enum, or enumeration, is a distinct type that increases the compile-time checking and likelihood for correctness compared to integer or a string. The switch statement then instantiates the correct prefab and adds that prefab to a list of all currently augmented GameObjects. The list of augmented GameObjects is needed for example if the content is a video that needs to be paused when target is lost for some reason. Otherwise the video and its sound would continue to play even though the content itself wouldn't be visible anymore.

Kuva 22. DataHandler GameObject with all the components added to it.

After instantiating the prefab OnContentFound() function is called in SetContentTransform script. This script works with each of the content types since all of them can be set up similarly. SetContentTransform() sets the prefab as a child of CloudTarget and sets the same rotation and position for it as the parent has. After that SetParameters() function uses the JSON information and sets the position, rotation and scale set for the content on Arilyn Manager. Lastly a Coroutine LoadContent() gets called. It uses the content URL found from the JSON information to load the content from Arilyn Manager and augments the content on top of the content prefab. Figure 22 is describing the components of DataHandler GameObject.

The rest of the data types

After getting the image content type to work it is time to add other data types. The augmentation of video content works similarly as in image content. It uses all the same functions, only enum is set as video and the instantiated prefab is called VideoContent. It has an extra script called StreamVideo, in which function StartVideoPlay() gets called in LoadContent() function instead of the image content's texture setting function.

StartVideoPlay() function gets a video path as a parameter. This is used later for downloading the video. A Coroutine PlayVideo() is called next. It checks the video path is not empty and then instantiates VideoPlayer and AudioSource Unity objects. VideoPlayer is a new feature in Unity 5.6. It replaces the earlier MovieTexture feature. There is not yet a lot of documentation about VideoPlayer, but because the old system is deprecated soon there is no point of implementing it. [79.] VideoPlayer is set to use the URL from JSON and the video is set to use AudioSource. VideoPlayer starts to prepare the video and after preparation PlayVideo() function is called. PlayVideo is aptly named: it is used for playing the video file. It gets a boolean parameter so the function can also be used for pausing the video when the target is lost.

The last data type needed to implement for now is 3D models. They are created as Unity's AssetBundles, which is a system that provides a method for storing multiple files in an archival format that Unity can index. It is a primary way of updating non-code content after installation of the application. [80.] However, it was noticed that the current AssetBundles used in Arilyn Manager does not work with this project because the texture compression is not correctly set for HoloLens. It also needs some modification for Arilyn Manager to get it to support this new texture compression.

The AssetBundles can be tested anyhow. A 3D model can be converted to be using a correct texture compression and Dropbox can be used for storing the AssetBundle. SetContentTransform script is modified for loading data type 'asset'. LoadAssetContent() function has a contentUrl variable where the Dropbox link is stored. After that a WWW class is used for downloading the asset and instantiating it.

4.3   Adding HoloLens support

The project needs to be configured for using HoloLens before the application can start benefitting the HoloLens features. The setup does not require complex phases and even building the application is fairly easy. Next this whole process will be gone through step by step.

Setting the project to use HoloLens

The Unity project should be modified a little for it to support HoloLens. The first thing to set up is ARCamera. Currently under Vuforia Configuration the Digital Eyewear is not set. This needs to be changed to Optical See-Through and See Through Config is set to use HoloLens. After that a MainCamera is added to the scene. It is usually removed when creating augmented reality applications, but HoloLens needs it for tracking the users head and for stereoscopic rendering, which means that instead of rendering only a single image it creates two, one for each eye, and enables to see the image in stereo. MainCamera is positioned in origin, which is the head position. Its flags need to be set to solid black color similarly as in the ARCamera prefab. MainCamera is set to be used as a central anchor point for ARCamera. Another setting to be changed is the quality settings mentioned earlier in the chapter about quality and rendering. The graphical quality is set for Windows Store to be using the fastest performance. The frame rate might drop on higher quality options so it is important to remember to set this correctly.

These rest of the changes are Build and Player settings. Build settings allow the developer to choose the target platform, adjust the settings considering the deployed project and start the build process. The Player settings are for setting the resolution and presentation options, choosing the icon for the application, having some platform specific settings and settings for publishing the project.
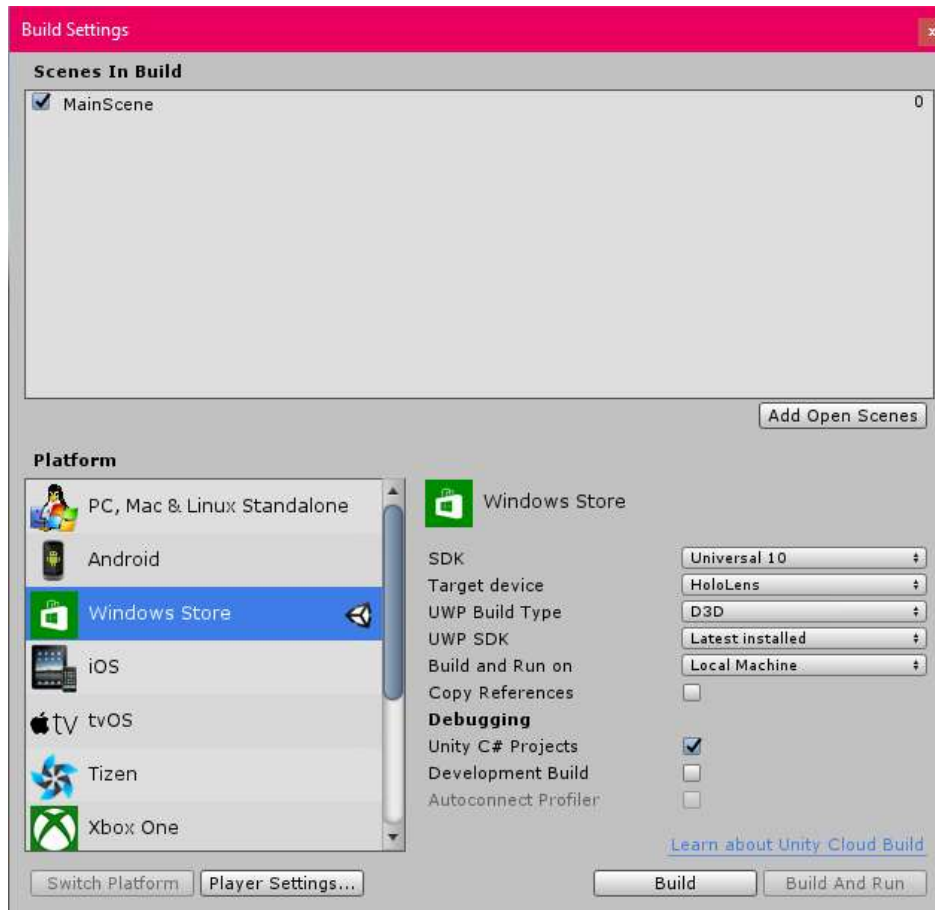
Kuva 23. Build settings set for using HoloLens

As seen in figure 23, the target build for HoloLens is set to Windows Store. The SDK should be set to use Universal 10, which is the Windows 10 compatible SDK. HoloLens has Windows 10 as operating system. There are two options for build type: D3D and XAML. The build type is set to D3D, which allows more complex 3D effects with lower CPU consumption [81]. XAML is more suitable if the project has 2D or UI elements [82].

Unity project needs to be set up to use certain capabilities under publishing settings. The capabilities include SpatialPerception, Microphone and Picture-, Video- and Music libraries. SpatialPerception allows the use of Spatial Mapping, which is the technology behind providing a detailed presentation of real-world surfaces. Microphone is used for voice commands and the libraries are required for capturing image, video and audio functionalities. Arilyn also needs InternetClient, which allows the application to receive data from Internet.

Lastly the application should be set to use holographic view instead of 2D view. This is done by choosing Virtual Reality support and adding Windows Holographic to the list under Rendering tab.

Deploying the project for HoloLens

There are two ways to test the HoloLens application. First way is to use a Holographic Remote Player, which can be downloaded from Windows Store, and second is by deploying the project directly into HoloLens. The latter is slower to test the project with, but the first does not necessarily always display the application correctly.
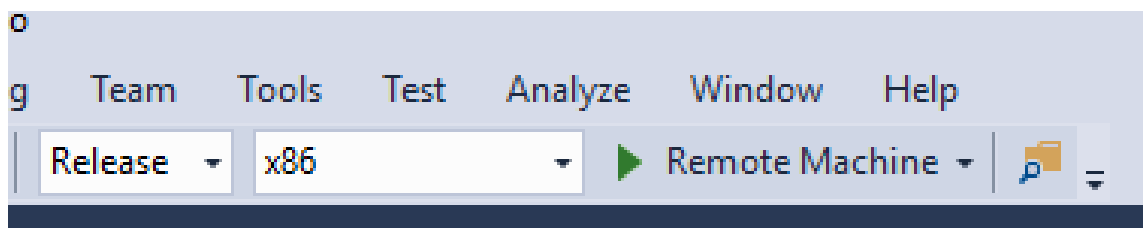
Kuva 24. Settings for deploying the application for HoloLens in Visual Studio

Holographic Remote Player is used for remotely playing the application. It works basically instantly when pressing the play button in Unity, but it requires good internet connection in order to work well. After downloading Holographic Remote Player to HoloLens and opening the application, it displays the IP address of HoloLens. The address is then added to Holographic emulation window in Unity. Both the device running the Unity project and HoloLens need to be in the same network for this to work. This works well for most of the testing, but for some reason Vuforia is not showing any content when emulating the application. The project must be deployed directly into HoloLens for testing that part of the application.

To get the project to HoloLens the application needs to be built for Windows Store from Unity and then the generated .sln file has to be opened in Visual Studio. There the Solution Configuration is set to Release, the Solution Platform to x86 and Build target for Remote Device, as seen in the figure 24. Visual Studio will ask for a IP address of the HoloLens. This is the same IP as used with Holographic Remote Player. After that the project can be deployed from Build tab. When deploying the project for the first time it will ask HoloLens PIN. This can be generated by setting the HoloLens to developer mode

and pairing it with the PC from the developer settings. When clicking Pair-button Ho-loLens will give the PIN number that is inserted into Visual Studio. Then the project can be built to HoloLens so that it allows debugging from Visual Studio. This can be done by choosing Start Debugging from Debug tab. This will run the application on HoloLens and scan the targets correctly.

4.4   Setting up the user interface and scanning animation

Next the user interface and scanning animation should be added. Both are making the project more visually appealing and make the overall experience of using the application easier.

Setting up the UI

There is not a lot use for user interface in this project. There will only be Arilyn logo displayed with an info button. The info button is useful for the users who have not used HoloLens or Arilyn before. The info will be similar as in Arilyn mobile application, which can be seen in figure 25. The details will be slighty modified, for example instead of asking the user to point their camera, they will be asked to point a cursor to a target and unnecessary explanations will be removed. Information about interacting with HoloLens application will be added as well.
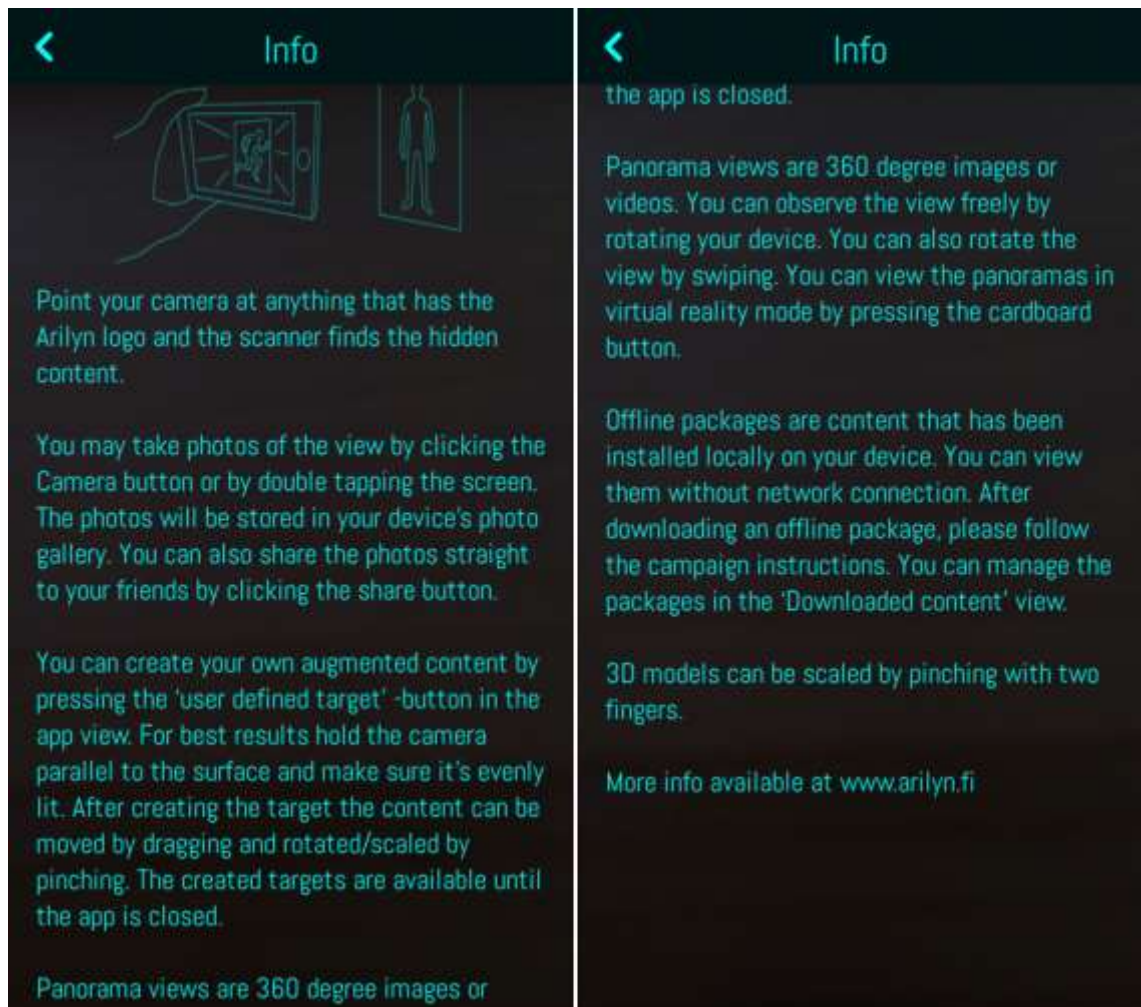
Kuva 25. Info found from Arilyn-App.

A way to interact should be implemented before starting to build the UI. A good starting point is to add a cursor that helps the user to know where they are looking at. A white Sphere can be used for that. Microsoft's HoloToolKit repository has a basic example of cursor. It gets the head position and gaze direction from the MainCamera, which acts as the user's head. A raycast is then send to the gaze direction from head position. Anyway, this is an unnecessarily heavy way to implement a cursor for this application. This time the cursor can be implemented by adding the Sphere as a child of the MainCamera since it doesn't currently need any interactivity.

It is time to add gestures to the project now that the user knows the direction they are looking at. Gestures are, as mentioned earlier, the way for interacting with HoloLens. Gestures are combined with gaze, the direction where user is looking at, to allow the user for example to push the buttons. The HoloToolkit repository also has examples of

using gestures. GazeGestureManager script should be added to ARCamera. It uses head position and gaze direction to calculate where the user is looking at. It then uses a raycast to determine if the direction has anything that can be used for interaction, like a UI button.

The same principles as when designing a user interface for virtual reality can be used with augmented reality, especially with augmented reality applications that use a head-mounted display. The UI should be positioned within the surrounding environment itself by using World Space Canvas, which is sometimes referred as Spatial UI. It is important to test what is the perfect distance for the UI from the user. If it is too close it can cause eye strain, and if it is too far away it will feel like focusing far on the horizon. Since the UI of this project is simple, only a one button and an image is created under the canvas.

Kuva 26. Finished UI and cursor are seen in picture.

The image has an Arilyn logo as a texture. A button is positioned under that. This will be the info button. After pressing that a text box is created, which has the information about using the application.

Lastly a particle effect is added when pressing the button. This helps the user to know if they have pressed the button. The button should have some indicator when the user is

gazing directly at it. This can be done by moving the button slightly closer to the user when it is gazed at. The finished UI and the cursor can be seen in figure 26.

Scanning animation

Finally a scanning animation should to be implemented. This will work as an indicator about when the application has found a target by disabling the animation. This is making it easier for the user to know they are looking at the correct direction. HoloLens has the spatial mapping feature, which tells information about the environment the user is currently at. Spatial mapping can be used for setting up colliders where the virtual objects can not go through. However for this project spatial mapping is only used as a visual feature so all the colliders and collider calculations should be disabled.
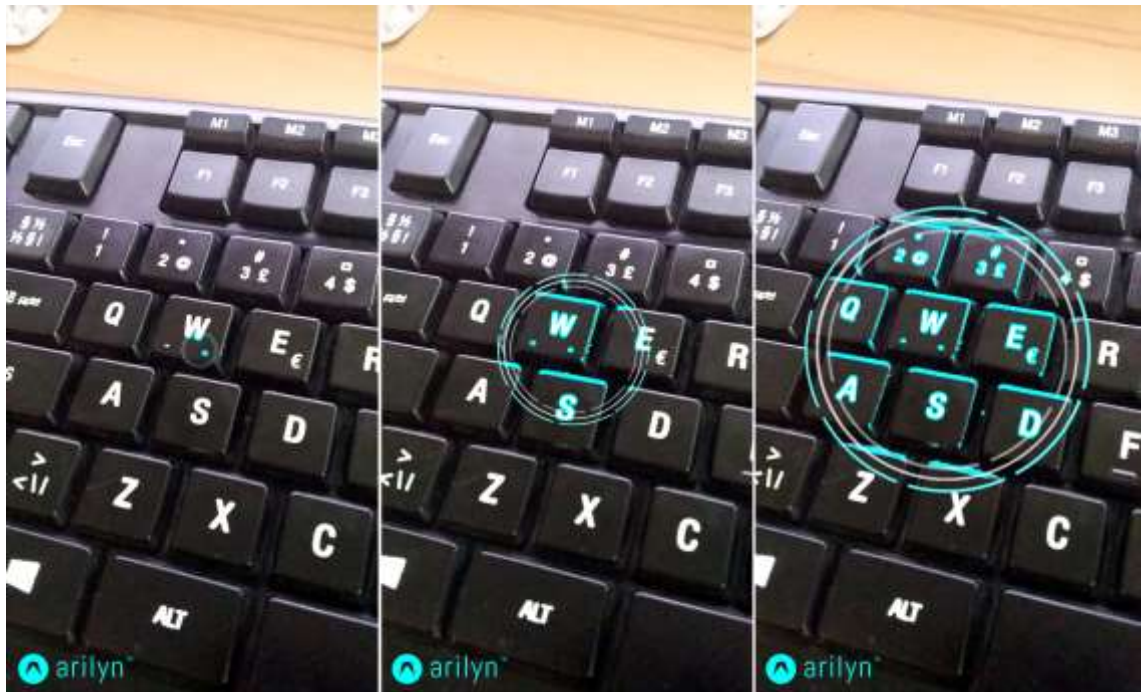
Kuva 27. Arilyn-App has a pulse animation that indicates the application is trying to find a target.

SpatialMapping gameobject should be added to the scene with SpatialMapping script attached to it. The script can be found under HoloToolkit. It examines the room around HoloLens and draws a mesh on top of surrounding furniture, walls and floor. A shader is used for visual representation of the mesh. HoloToolkit has a basic wireframe shader which was modified to be more suitable for Arilyn HoloLens. First the color of the wireframe was changed to Arilyn blue. Arilyn mobile application has a pulse animation

which is shown in figure 27. It is suitable for the HoloLens version of Arilyn to have sim-
ilarities in the scanning animation, so a pulse effect was made for the wireframe.

Kuva 28. Illustration of the wireframe used to indicate the application is scanning the room.

A smoothstep was used to make the wireframe shader to have a pulse effect. Smooth-
step calculates an interpolation between two values. This enables the smooth transition
between transparent wireframe and blue colored wireframe. An illustration of the
wireframe can be seen in figure 28.

5   Results and value of the product

5.1   Analysis of the new software

The software delivers almost all the features it was supposed to. All the targets contain-
ing image or video content are working and get augmented correctly. The application
can display multiple content if set on one target and it also succeeds on displaying both
image and video files simultaneously.

3D content had to be left out for now, because HoloLens uses different texture compres-
sion than other devices where Arilyn works. Arilyn Manager should be modified to un-
derstand the new AssetBundle type and after that HoloLens texture compression support
has to be added for all the 3D content.

Kuva 29. Example of how the target is in some occasions seen through the content.

User interface works and gives instructions about how to use the application. The scan-
ning animation is handy for knowing when the application is trying to find something to
scan.

There were also a few problems that were noticed during the development of the application. Most notable problem is the way HoloLens display renders the content. Because all the dark colors appear transparent, there sometimes is a situation when HoloLens does not display the content correctly when looking at a target. As a result, the target can be seen under the content and this lead to a feeling the content is positioned behind the target. One of these situations is described in figure 29.

Kuva 30. First picture illustrates how the content is seen when focusing on target, and the second picture shows how the target is seen when focusing on content.

Another notable problem is focusing on the content. Because the content is rendered close to the user's eye it leads to the user trying to focus differently when looking at content than when focusing on the target. Due to this if user focuses on target, they will see the content as a double and vice versa. There are at least two problems with this. First is that it can be distracting to watch the content when it focuses weirdly as described in figure 30. Secondly because the user has to be cross-eyeing it can cause headache if doing constantly. Other than that, the application seems to be doing what it was supposed to do.

5.2 Future use and required features

Even though augmented reality application that uses targets is not currently the most suitable for HoloLens because of the issues mentioned earlier, it is still important to keep trying different ways of developing the HoloLens applications. The issues might as well be easily fixed after doing more research about the subject or after the overall quality of HMD devices is improved.

Arilyn for mobile has multiple different features which could be implemented to work with HoloLens too. 360-degree videos were intentionally left out for now because of the narrow field of view HoloLens currently has. It could be interesting feature to add later when the quality of head-mounted devices gets better. There are also targets that are curved, for example a video or image could be curved around a soda can, and targets that have more functionalities, for example buttons that can lead to websites. One of the newest features that Arilyn-App supports are live stream videos and colorable targets.

Another good point to research is the different ways the user interface could be benefitted. Virtual and augmented reality are fairly new technologies so the best ways are not necessarily even discovered yet.

6   Conclusion

The objective of the thesis was to convert the augmented reality mobile application Arilyn for Microsoft's HoloLens device. The basic datatypes, like image and video, should be supported and fetched from Arilyn Manager. The datatypes should be displayed simultaneously if multiple content has been set on Manager. There also should be a user interface that is similar to what Arilyn mobile application is currently using.

The first part of the thesis concentrates on the definition of augmented reality and how it can currently be benefitted. It also goes through the best practices to be considered when creating augmented reality applications and had research about the new HoloLens technology. The actual converting process was completed using Unity game-engine and augmented reality SDK Vuforia alongside with the HoloLens SDK.

Arilyn for HoloLens succeeded on featuring almost all the set goals. It can display simultaneously video, sound and image content and it correctly gets the data from Arilyn Manager. The content gets positioned in respect of the scanned target and the content correctly follows it. The application has a user interface where Arilyn logo is shown along with instruction button. There is also a scanning animation which indicates when the application is trying to find a target. The animation utilizes the spatial mapping function which is used in HoloLens.

Only feature missing is 3D datatype. HoloLens uses different texture compression than other devices where Arilyn-App can be used. Arilyn Manager needs to be modified to understand the new compression and that compression format needs to be added to all the 3D content that are currently in use in Arilyn-App. Arilyn for HoloLens could be continued to support even more of the features of Arilyn-App. Interesting features to add could be for example curved and colorable content, live stream, buttons and 360-degree panorama and video files in addition to basic datatypes.

It was noticed during the process that target-based augmented reality is not the most suitable for HoloLens device. HoloLens renders dark colors transparent which sometimes leads to a situation where the content seems like it is positioned behind the target. This can be distracting for the user and break the immersion. Another problem was how the user's eye focuses on the content. The content is rendered close to the eye which

leads to seeing the content as double. It can cause headache for the user if they are looking at the content for longer periods of time.

Even though target-based augmented reality might not be the most suitable for HoloLens, it is important to keep researching the subject. The problems might be easily solved after the subject is studied more or after the overall quality of head-mounted devices gets better.

References

1   Furht, Borko. 2011. Handbook of Augmented Reality. Springer, p. 3

2   Milgram Paul and Takemura Haruo. 1994. Augmented Reality: A class of dis-plays on the reality-virtuality continuum. Online document. <http://etclab.mie.utoronto.ca/publication/1994/Milgram_Take-mura_SPIE1994.pdf>. Accessed 9 Jun. 2017.

3   BBC weather forecast. 2013. Online article. < http://www.bbc.com/news/av/uk-25502655/uk-weather-forecast-more-wild-weather-to-come>. Accessed 13 Jun. 2017.

4   Kipper, Gregory & Rampolla, Joseph. 2012. Augmented Reality An Emerging Technologies Guide to AR. Syngress, p. 7-14

5   Chatzopoulos, D., Bermejo, C., Huang, Z. & Hui, P. 2017. Mobile Augmented Re-ality Survey: From Where We Are to Where We Go. Online article. < http://ieeex-plore.ieee.org.ezproxy.metropolia.fi/stamp/stamp.jsp?tp=&ar-number=7912316&tag=1>. Accessed 9 Jun. 2017.

6   Baum, Frank. 2006. The Master Key. Ebook. < http://www.guten-berg.org/files/436/436-h/436-h.htm>. Accessed 17 May. 2017.

7   Vincent, James. 2017. Google's AR platform Tango is going to let museum visi-tors explore exhibits. News article. < https://www.thev-erge.com/2017/1/9/14210956/google-tango-museum-ar-detroit>. Accessed 28 Jun. 2017.

8   Sutherland, Ivan. 1965. The Ultimate Display. < http://www8.in-formatik.umu.se/~jwworth/The%20Ultimate%20Display.pdf>. Accessed 9 Jun. 2017.

9   First Head-mounted display. 2014. Video. < https://www.youtube.com/watch?v=ISJWZpFIAIQ>. Accessed 13 Jun. 2017.

10   Myron, Krueger. Videoplace, Responsive Environment. 2008. Video. < https://www.youtube.com/watch?v=dmmxVA5xhuo>. Accessed 13 Jun. 2017.

11   Grover, David. 2014. Augmented reality history, background and philosophy. Online article. < https://wiki.mq.edu.au/display/ar/Augmented+reality+his-tory%2C+background+and+philosophy>. Accessed 13 Jun. 2017.

12   ARToolKit. History. Online documentation. < http://www.hitl.washington.edu/ar-toolkit/documentation/history.htm>. Accessed 13 Jun. 2017.

13   Introduction to ARToolKit. Online documentation. < http://www.hitl.washing-
        ton.edu/artoolkit/documentation/userintro.htm>. Accessed 13 Jun. 2017.

14   Jeffries, Struart. 2010. News article. < https://www.theguardian.com/technol-
        ogy/2010/jan/08/stuart-jeffries-camera-phones>. Accessed 13 Jun. 2017.

15   Vuforia. 2017. Online documentation. < https://vuforia.com/>. Accessed 13 Jun.
        2017.

16   PTC and Unity Announce Strategic Partnership. 2016. Online article. < https://de-
        veloper.vuforia.com/>. Accessed 13 Jun. 2017.

17   Rauschnabel, Philipp. 2016. Augmented reality smart glasses: an investigation of
        technology acceptance drivers. Online article. < https://www.re-
        searchgate.net/profile/Philipp_Rauschnabel/publica-
        tion/301565182_IJTMKT110201_RAUSCHNA-
        BEL/links/571a45d808ae408367bc87ac.pdf>. Accessed 13 Jun. 2017.

18   Mixed Reality. Online documentation. < https://developer.microsoft.com/en-
        us/windows/mixed-reality/mixed_reality>. Accessed 13 Jun. 2017.

19   Bonasio, Alice. 2017. Our new (mixed) reality: Early adopters have become Ho-
        loLens believers at work. Online article. < https://arstechnica.com/information-
        technology/2017/03/our-new-mixed-reality-early-adopters-have-become-ho-
        lolens-believers-at-work/>. Accessed 13 Jun. 2017.

20   Microsoft HoloLens. Online documentation. < https://www.microsoft.com/en-
        us/hololens/hardware>. Accessed 13 Jun. 2017.

21   Pokemon GO. Official website. < http://www.pokemongo.com/en-uk/>. Accessed
        27 Jun. 2017.

22   Molina, Brett. 2016. 'Pokemon GO' fastest mobile game to 10M downloads.
        News article. < https://www.usatoday.com/story/tech/gam-
        ing/2016/07/20/pokemon-go-fastest-mobile-game-10m-downloads/87338366/>.
        Accessed 27 Jun. 2017.

23   Grant, Christopher. 2016. Pokemon GO has been downloaded 500 million times.
        News article. < https://www.polygon.com/pokemon-
        go/2016/9/7/12836898/pokemon-go-downloads-500-million>. Accessed 27 Jun.
        2017.

24   Pose with Your Pet!. Online documentation. < http://nintendogspluscats.nin-
        tendo.com/pose/>. Accessed 13 Jun. 2017.

25   Children's use of mobile phones. 2015. Online report. < https://www.gsma.com/publicpolicy/wp-content/uploads/2012/03/GSMA_Children_use_of_mobile_phones_2014.pdf>. Accessed 27 Jun. 2017.

26   Play-Doh. Online documentation. < https://playdoh.hasbro.com/en-us/product/play-doh-touch-shape-to-life-studio:2FC58215-5056-9047-F5FA-060659E8A3B7>. Accessed 27 Jun. 2017.

27   Wonderbook: Book of Spells. Online documentation. < https://playdoh.hasbro.com/en-us/product/play-doh-touch-shape-to-life-studio:2FC58215-5056-9047-F5FA-060659E8A3B7>. Accessed 27 Jun. 2017.

28   Mardles discovAR. Online documentation. < https://mardleslife.com/universe/discovar-4d-colouring/>. Accessed 27 Jun. 2017.

29   Radu, Iulian. 2012. Why Should My Students Use AR? A Comparative Review of the Educational Impacts of Augmented-Reality. Online publication. < http://ieeexplore.ieee.org.ezproxy.metropolia.fi/stamp/stamp.jsp?arnumber=6402590&tag=1>. Accessed 27 Jun. 2017.

30   Reid, Jess. 2016. Invention will mean less time in the chair for dental patients. Online article. < http://www.news.uwa.edu.au/201612139295/awards-and-prizes/invention-will-mean-less-time-chair-dental-patients>. Accessed 27 Jun. 2017.

31   Cote, Stephane. 2015. Using Augmented Reality to Facilitate the Interpretation of 2D Construction Drawings. Online article. < https://communities.bentley.com/other/old_site_member_blogs/bentley_employees/b/stephanecotes_blog/archive/2015/12/09/using-augmented-reality-tool-for-facilitating-the-interpretation-of-2d-construction-drawings#pi21443=1>. Accessed 27 Jun. 2017.

32   Balch, Oliver. 2016. The future of healthcare: AI, augmented reality and drug-delivering drones. News article. < https://www.theguardian.com/sustainable-business/2016/nov/01/the-future-of-healthcare-ai-augmented-reality-and-drug-delivering-drones>. Accessed 5 Jul. 2017.

33   Bazzaza, Wael. Delail, Buti. Zemerly, Jamal. 2014. An Immersive Augmented Reality system for education. Online publication. < http://ieeexplore.ieee.org.ezproxy.metropolia.fi/xpls/icp.jsp?arnumber=7062576&tag=1#article>. Accessed 27 Jun. 2017.

34   Augmented reality makes shopping more personal. Online article. < https://www.research.ibm.com/articles/augmented-reality.shtml>. Accessed 27 Jun. 2017.

35   Place IKEA furniture in your home with augmented reality. 2013. Online video. < https://www.youtube.com/watch?v=vDNzTasuYEw>. Accessed 27 Jun. 2017.

36   Brinkman, Bo. 2012. Willing to be fooled: Security and autoamputation in augmented reality. Online publication. < http://ieeexplore.ieee.org.ezproxy.metropolia.fi/document/6483995/>. Accessed 27 Jun. 2017.

37   Yuhas, Alan. 2016. Pokemon Go: armed robbers use mobile game to lure players into trap. News article. <https://www.theguardian.com/technology/2016/jul/10/pokemon-go-armed-robbers-dead-body>. Accessed 28 Jun. 2017.

38   Robot Genius. Official webpage. <https://www.robotgeniusfilms.com/>. Accessed 28 Jun. 2017.

39   Yadron, Danny. 2016. Samsung patent reveals 'smart' contact lens with built-in camera. News article. <https://www.theguardian.com/technology/2016/apr/06/samsung-smart-contact-lens-camera-patent>. Accessed 28 Jun. 2017.

40   Black Mirror. 2016. Official webpage. <https://www.netflix.com/fi-en/title/70264888>. Accessed 28 Jun. 2017.

41   Nguyen, Clinton. 2016. Chine might use data to create a score for each citizen based on how trustworthy they are. News article. <http://www.businessinsider.com/china-social-credit-score-like-black-mirror-2016-10?r=US&IR=T&IR=T>. Accessed 28 Jun. 2017.

42   Starner, Thad. Mann, Steve. Rhodes, Bradley. & co. Augmented Reality Through Wearable Computing. Online publication. <http://www.businessinsider.com/china-social-credit-score-like-black-mirror-2016-10?r=US&IR=T&IR=T>. Accessed 28 Jun. 2017.

43   After mixed year, mobile AR to drive $108 billion VR/AR market by 2021. 2017. Online publication. < http://www.digi-capital.com/news/2017/01/after-mixed-year-mobile-ar-to-drive-108-billion-vrar-market-by-2021/#.WV0FBYiGOUl>. Accessed 23 May 2017.

44   Tango Developer Overview. Official webpage. < https://developers.google.com/tango/developer-overview>. Accessed 6 Jun. 2017.

45   Google Tango. Official webpage. < https://get.google.com/tango/>. Accessed 5 Jul. 2017.

46   Introducing ARKit. Official webpage. < https://developer.apple.com/arkit/>. Accessed 6 Jun. 2017.

47   iPhone. Official webpage. < https://www.apple.com/iphone/>. Accessed 5 Jul. 2017.

48   Muller, Trudy. Kirschner, Alex. 2015. Apple Announces Record iPhone 6s & iPh-one 6s Plus Sales. Press release. < https://www.apple.com/news-room/2015/09/28Apple-Announces-Record-iPhone-6s-iPhone-6s-Plus-Sales/>. Accessed 5 Jul. 2017.

49   A Whole New Way to See Yourself(ie). Press release. < https://www.snap.com/en-US/news/page/3/>. Accessed 5 Jul. 2017.

50   Dunn, Jeff. 2017. Snapchat has teens right under its thumb. News article. < http://nordic.businessinsider.com/snapchat-instagram-facebook-twitter-popularity-teens-chart-2017-4>. Accessed 5 Jul. 2017.

51   Introducing Face Filters and More on Instagram. 2017. Press release. < https://in-stagram-press.com/blog/2017/05/16/introducing-face-filters-and-more-on-insta-gram/>. Accessed 5 Jul. 2017.

52   Huard, Polina. Prouty, Birgitte. 2016. L'Oreal signs new exclusive license agree-ment with image metrics for new makeup services. Press release. < http://www.loreal.com/media/press-releases/2016/mar/image-metrics>. Accessed 5 Jul. 2017.

53   Magnenat, Stephane. Zund, Fabio. & co. 2015. Live Texturing of Augmented Re-ality characters from Colored Drawings. Online publication. < https://www.dis-neyresearch.com/publication/live-texturing-of-augmented-reality-characters/>. Accessed 5 Jul. 2017.

54   Moverio Smart Eyewear. Epson. Official webpage. < https://epson.com/moverio-augmented-reality>. Accessed 5 Jul. 2017.

55   Gaynor, Julia. 2016. Magic Leap Announces $793.5 million in New Funding. Press release. < https://www.magicleap.com/#/press/magic-leap-series-c-fund-ing>. Accessed 5 Jul. 2017.

56   Dredge, Stuart. 2015. Mysterious startup Magic Leap shows off augmented real-ity action game. News article. < https://www.theguardian.com/technol-ogy/2015/mar/20/magic-leap-augmented-reality-action-game>. Accessed 5 Jul. 2017.

57   The Foundation for VR/AR. Official webpage. < https://unity3d.com/vr-ar>. Ac-cessed 22 May 2017.

58   Unity 2017: The world-leading creation engine for gaming. Official webpage. < https://unity3d.com/unity>. Accessed 22 May 2017.

59   Microsoft HoloToolkit. Webpage. < https://github.com/Microsoft/HoloToolkit-Unity>. Accessed 22 May 2017.

60   Color design. Microsoft Dev Center. < https://developer.microsoft.com/en-us/win-dows/mixed-reality/color_design>. Accessed 22 May 2017.

61   Gestures. Microsoft Dev Center. < https://developer.microsoft.com/en-us/win-dows/mixed-reality/gestures>. Accessed 5 Jun. 2017.

62   Gaze. Microsoft Dev Center. < https://developer.microsoft.com/en-us/win-dows/mixed-reality/gaze>. Accessed 5 Jun. 2017.

63   Voice Input. Microsoft Dev Center. < https://developer.microsoft.com/en-us/win-dows/mixed-reality/voice_input>. Accessed 5 Jun. 2017.

64   Spatial mapping. Microsoft Dev Center. < https://developer.microsoft.com/en-us/windows/mixed-reality/spatial_mapping>. Accessed 5 Jun. 2017.

65   Arilyn. Official webpage. < http://www.arilyn.fi/>. Accessed 22 May 2017.

66   Lehtimäki, Niina. 2016. Arilyn – One of Coolest Nordic Augmented Reality Com-panies Leaps Into U.S. Market. Interview. <http://www.finland.org/public/de-fault.aspx?contentid=352706>. Accessed 22 May 2017.

67   Entertainment Software Association. 2017. Essential Facts About the Computer And Video Game Industry. Online publication. < http://www.theesa.com/wp-con-tent/themes/esa/assets/EF2017_Design_FinalDigital.pdf >. Accessed 12 Sep. 2017.

68   Pollard, Catriona. 2015. Why Visual Content Is a Social Media Secret Weapon. Online publication. <http://www.huffingtonpost.com/catriona-pollard/why-visual-content-is-a-s_b_7261876.html>. Accessed 5 Jul. 2017.

69   Performance recommendations for HoloLens apps. Windows Dev Center. <https://developer.microsoft.com/en-us/windows/mixed-reality/performance_rec-ommendations_for_hololens_apps>. Accessed 5 Jul. 2017.

70   Lincoln, Steven. 2015. Virtual nose may reduce simulator sickness in video games. Online publication. <https://polytechnic.purdue.edu/newsroom/virtual-nose-may-reduce-simulator-sickness-video-games>. Accessed 5 Jul. 2017.

71   Performance recommendations for Unity. Windows Dev Center. <https://devel-oper.microsoft.com/en-us/windows/mixed-reality/performance_recommenda-tions_for_unity>. Accessed 5 Jul. 2017.

72   Quality settings. Unity documentation. < https://docs.unity3d.com/Manual/class-QualitySettings.html>. Accessed 5 Jul. 2017.

73   Surface Shader examples. Unity user manual. < https://docs.unity3d.com/Manual/SL-SurfaceShaderExamples.html>. Accessed 5 Jul. 2017.

74   Cloud Recognition. Vuforia Developer Library. <https://library.vuforia.com/articles/Training/Cloud-Recognition-Guide>. Accessed 30 Jun. 2017.

75   Introducing JSON. Official webpage. <http://www.json.org/>. Accessed 29 Jun. 2017.

76   Importing from the Asset Store. Unity Documentation. < https://docs.unity3d.com/Manual/AssetStore.html?_ga=2.28789951.2024258433.1498657819-1840352267.1498657819>. Accessed 29 Jun. 2017.

77   Prefabs. Unity Documentation. < https://docs.unity3d.com/Manual/Prefabs.html>. Accessed 29 Jun. 2017.

78   Coroutines. Unity Documentation. <https://docs.unity3d.com/Manual/Coroutines.html>. Accessed 26 Jun. 2017.

79   Video Player. Unity Documentation. <https://docs.unity3d.com/Manual/VideoPlayer.html>. Accessed 8. Jul. 2017.

80   AssetBundles. Unity Documentation. <https://docs.unity3d.com/Manual/AssetBundlesIntro.html>. Accessed 6 Jul. 2017.

81   What is Direct3D 12. Windows Dev Center. <https://msdn.microsoft.com/en-us/library/windows/desktop/dn899228(v=vs.85).aspx>. Accessed 14 Jun. 2017.

82   XAML overview. Windows Dev Center. <https://docs.microsoft.com/en-us/windows/uwp/xaml-platform/xaml-overview>. Accessed 14 Jun. 2017