TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

DEVELOPMENT OF AUGMENTED REALITY BASED OPERATION GUIDE FOR FESTO FMS

LIITREAALSUSEL PÕHINEVA KASUTUSJUHENDI VÄLJATÖÖTAMINE FESTO PAINDTOOTMISSÜSTEEMILE

MASTER THESIS

Student: Kerd Kaarus

Student code: 192602MARM

Supervisors: Aigar Hermaste, Lecturer
Simone Luca Pizzagalli, Early Stage Researcher

Tallinn 2024

AUTHOR'S DECLARATION

Hereby I declare that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the authors used in this thesis have been referenced.

“20” May 2024

Author: Kerd Kaarus
/signed digitally/

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Supervisor: …………………………….....
/signature/

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Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Kerd Kaarus, MARM 192602

Study programme, main speciality: MARM06/18, Industrial Engineering and Management

Supervisors: Aigar Hermaste, Lecturer

Simone Luca Pizzagalli, Early Stage Researcher

Thesis topic:

(in English) Development of Augmented Reality based Operation guide for Festo FMS

(in Estonian) Liitreaalsusel põhineva kasutusjuhendi väljatöötamine Festo paindtootmissüsteemil

Thesis main objectives:

1. Develop AR operation guide for starting the system in automatic mode
2. Develop AR operation guide for making new production order
3. Develop AR operation guide for shutting down the automatically running FMS

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Study the FMS system to make the AR programming task	01.12.21
2.	AR operation guide for FMS system	08.04.22
3.	Writing theory part of the thesis, writing conclusion	08.05.24

Language: English **Deadline for submission of thesis:** “20” May 2024 a

Student: Kerd Kaarus “20” May 2024

/signed digitally/

Supervisor: Aigar Hermaste “20” May 2024

/signed digitally/

Supervisor: Simone Luca Pizzagalli “20” May 2024

/signed digitally/

Head of study programme: Kristo Karjust “20” May 2024

/signed digitally/

Terms of thesis closed defence and/or restricted access conditions to be formulated on the reverse side

CONTENTS

PREFACE

I have been working over 20 years in different machine building companies. We have created automated flow solutions for industrial handling, storage, packing and logistics. All machines are connected and operated through central automation system. The studies in Industrial Engineering and Management provide much essential modern knowledge on how to understand and run the projects more efficiently. I have come across the Augmented Reality topic several times. I have tried different AR (Augmented Reality) applications and also during studies made my first AR application. I have seen some examples of how these applications are used in training and in Industry. These experiences gave me an idea for this thesis. I wanted to make an application which would be an example of how to use Augmented Reality and to research if it is useful or better than traditional ways.

The machine test bench for the application in Taltech is the fully automated Flexible Manufacturing System from FESTO.

I would like to thank the supervisors Aigar Hermaste and Simone Luca Pizzagalli for their continuous support. Also I am grateful to department employers who always helped when I asked for it.

Keywords: AR application, Augmented Reality, Industrial AR application, Master thesis

List of abbreviations

API - Application programming Interface

APK - Android Application Package

AR - Augmented Reality

ARAUM - Augmented Reality Authoring for Maintenance

ASRS - Automated Storage Retrieval System

CRT - Cathode-ray tube

EWK - Extent of World Knowledge

FMS - Flexible Manufacturing System

HMD - Head mounted display

MR - Mixed Reality

NASA TLX - NASA Task Load Index

OSH - Occupational Safety and Health

PBP - Payback period

RTLX - Raw Task Load Index

RT3D - real-time 3D

SDK - Software development kit

SUS - System Usability Scale

UE - Unreal Engine

UI - User Interface

VC - Virtual Continuum

VR - Virtual Reality

VS - Visual Studio

XR - Extended Reality

1. INTRODUCTION

Augmented reality (AR) is increasingly integrating into our daily life. AR is transforming educational and professional training environments, delivering immersive and interactive experiences. This enhances learning outcomes and the acquisition of skills.

The goal of this work is to research if AR is the feasible way to use it with the Festo Flexible Manufacturing System (FMS) located in Taltech. There is a lot of information on the internet, how useful and helpful AR applications can be in many areas – production, training etc. With this thesis we will research if the development of an AR application is useful and what we have to take into consideration when developing the application. For the current work there is a paper manual of how the Festo FMS should function - how to start, how to give orders and how to shut down the system. This was the starting point for developing the application. According to the paper manual, the operation of Festo FMS was tested. All the steps were checked. The paper manual was updated with additional photos and texts. The idea was to see if somebody uses the paper manual or the AR application for the first time, is the AR application more efficient and easier when starting to operate the FMS for the first time. All the steps from the paper manual were overtaken to AR application. The Unity program was used for developing the project.The application is based on QR-code recognition. The FMS machines, which must be operated, are equipped with QR code. If users start the AR application, it provides information about what to do and where to start the procedure. It directs the user to the correct machine and explains what steps must be done to operate the FMS. There are pictures and explanations and in some cases the arrows, showing where the operating buttons are located. In the experiment participated 11 persons. Before the evaluation both versions were many times tested successfully.
For the evaluation questionnaires are used - System Usability Scale (SUS), NASA Task Load Index (NASA TLX). Also performance is measured as the time which is spent when operating the FMS. We measure the time for both versions - AR application and paper manual.

With these questionnaires and performance information we can analyze the data that we have gathered and draw some conclusion on the application usability and perceived task load on the operator. With performance data we can calculate if the AR application is financially profitable or not. If we can save time because of shorter training time, then we can calculate what is the payback time for this AR project. The users can give feedback during and after the testing. After testing users are filling the questionnaires, where more data will be collected.

1.1 Problem Statement

This work focuses on how to improve the training for the users who will operate the FMS for the first time. There are different immersive technologies we can use here. For example Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), Extended reality (XR). The XR consists of all of them - from AR, where only the additional information is overlaid over the real world or the other end where is the XR. With XR technology we can take advantage of all these immersive technologies - from overlaying only the information and also we can interact with real world objects.

We have chosen for the current thesis the AR technology. Festo FMS is located at Taltech, in the Department of Mechanical and Industrial Engineering Research center of Smart Industry and Robotics. FMS includes an automated storage system, a mobile robot and a CNC lathe with an industrial robot serving it. The system is based on the Industry 4.0 and flexible manufacturing concept. There we can see how the system starts to fulfill the order with the push of a button, during which the mobile robot takes the product from the warehouse system and takes it to the CNC lathe for processing. The machined part is stored into an automated storage system with a mobile robot when the CNC lathe has manufactured the product. The system works as long as the entire order is fulfilled [1].

In Industry 4.0, the focus was on sustainability and production volume, whereas in Industry 5.0, the primary focus is on human centricity. In the context of Industry 5.0 the AR enhances operational efficiency and creates a more responsive, human-centric and sustainable industrial environment [2].

As mentioned above, our current Festo FMS for current case study is based on Industry 4.0. There is a paper manual for all these steps. The goal of the thesis is to develop and design an AR application for improving the non experienced users efficiency and to test it with users to have data if it is more efficient, effective and satisfying compared to the paper manual.

For developing an AR application we should solve next issues:

- Finding proper AR application developing engine
- Choosing correct plug-ins for the developing engine
- QR-code Target image recognition
- Programming language for AR developing Engine
- User Interface(UI)
- Testing

1.2 Methodology and structure of the thesis

This thesis is based on a practical approach. It means in this work we give more attention to the development of the AR application, its use in the context of the test bench FMS system and testing with end users. The thesis is organized in such a way that it clearly provides information about each step of application development and presents it in a logical sequence. Thesis consists of four chapters.

In the first chapter we introduce the thesis and explain the thesis's progress, as well as its aims and issues. At the same time, we set up the strategy for achieving the goals.

In the second chapter we review literature and theoretical concepts. We get to know what type of different Immersive technologies there are. We explore the opportunities, where we can use Augmented Reality.

In the third chapter we focus on Case Study. The FMS is explained - what machines are there and how the system works. The AR program development is described. And finally the experimental protocol data are shown and analyzed.

Chapter four is the Financial analysis. We will take a closer look if using the AR application is financially more cost-effective compared to paper manual or not.

In the summary, we will examine the findings from our experiment. We will briefly analyze the collected data and present our conclusions, assessing whether the experiment's results support the development of the application in this Case Study.

2. LITERATURE AND THEORETICAL CONCEPTS

In the 21st century the immersive technologies, Augmented Reality (AR), Virtual Reality (AR), Mixed Reality (MR) and Extended Reality (XR) (under the umbrella term that covers all these) have significant impact on our society. Immersive technology is a technology that allows people to feel fully immersed in a virtual or augmented world. Some examples of immersive technology:

- Virtual Reality (VR): VR is a technology where users see only a totally simulated environment. Users see the environment through the headset or some other device which can make such an environment.
- Augmented Reality (AR): Augmented Reality is technology, where the additional information is overlaid over the real world objects- it happens in real-time and improves the user experience[3]
- A hybrid technology called mixed reality (MR) overlays an interactive virtual environment over the physical world by fusing AR and VR. It creates a new experience where physical and 3D digital objects live and interact in real time by fusing the real and virtual worlds. Users are presented with 3D holographic representations of digital items superimposed on their actual surroundings, which they can manipulate by adjusting their positions, dimensions, and shapes, as well as by rotating and moving them [4].

  Current way to call the MR now is the Extended Reality (XR). XR covers all these immersive technologies in one umbrella.

These are just some examples of the different types of immersive technology available today. As technology continues to advance, we can expect to see even more innovative and exciting ways to immerse ourselves in digital environments.

Augmented reality is a real-time view of information overlaid on the real world [5]. It can be defined as a coincident combination between a real world and virtual objects - which can interact in real time - and has three-dimensions virtual object registration [6]. With AR we can extend this additional information and there are no limits. We can add through programming any objects that we can imagine. We can use the AR to a very large extent. For example in training, learning, industry, medicine, security, service, maintenance etc.

Figure 2.1 represents the levels of different immersive technologies and their relation with the real world scenario. The graph is called “Virtual Continuum” (VC) made by Paul Milgram [7].

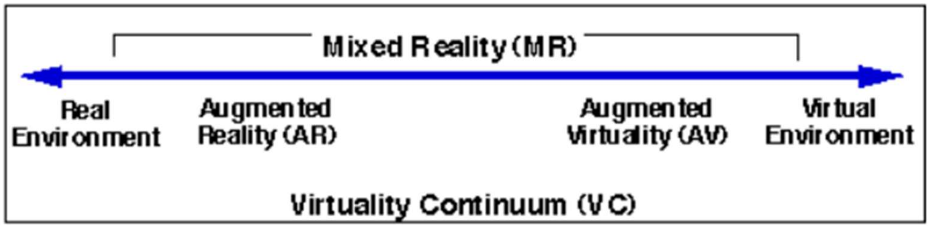


Figure 2.1. Simplified representation of a “virtuality continuum” by Paul Milgram [7]

In the Figure 2.2 is represented the Extent of World Knowledge(EWK).

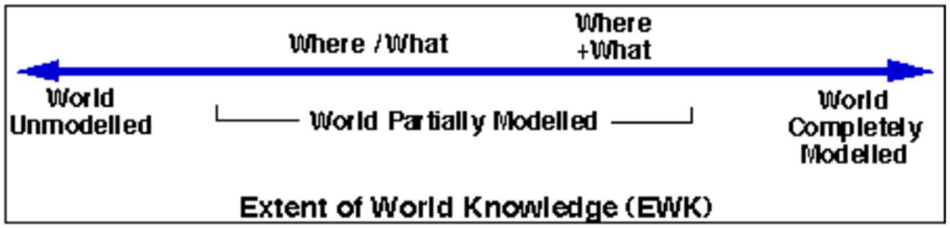


Figure 2.2 Extent of World Knowledge (EWK) dimension [7]

On the left, is the case in which everything displayed is real and unmodelled. The other end of the EWK dimension on the right - a completely virtual world is displayed, in the 'conventional' sense of VR[7].

Figure 2.3 illustrates the reality-virtuality continuum in an automotive scenario example.

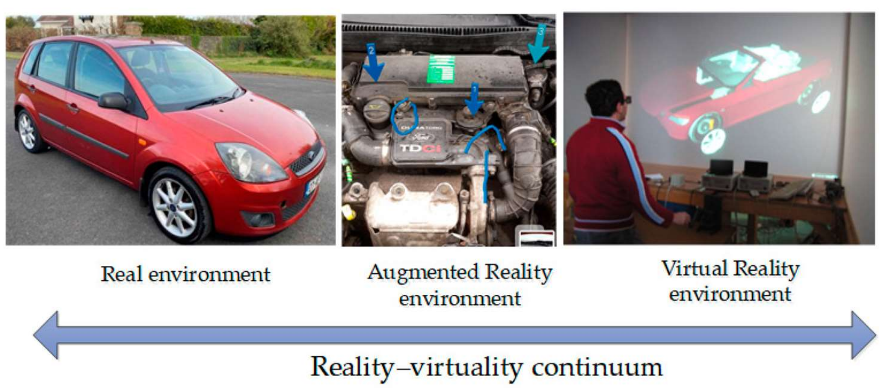


Figure 2.3. Automotive industry version of Milgram’s reality-virtuality continuum [8]

2.1 Augmented Reality

AR is a set of technologies which help to integrate digital and real content in the same interaction and visualization scope [9].

Modern technology has a big influence on how humans perceive the environment. AR is a well known innovation in this regard, it overlays the digital information and objects over to real objects and effects on user cognition. Day to-day, this combination affects how we live. It can be useful and popular because AR apps recently are well widespread [10]. One reason that's causing this, is the use of handheld devices such as phones or tablets. Below are examples of AR applications through recent history and use cases. In Figure 2.4 is the photo from one of the first versions of the HMD .

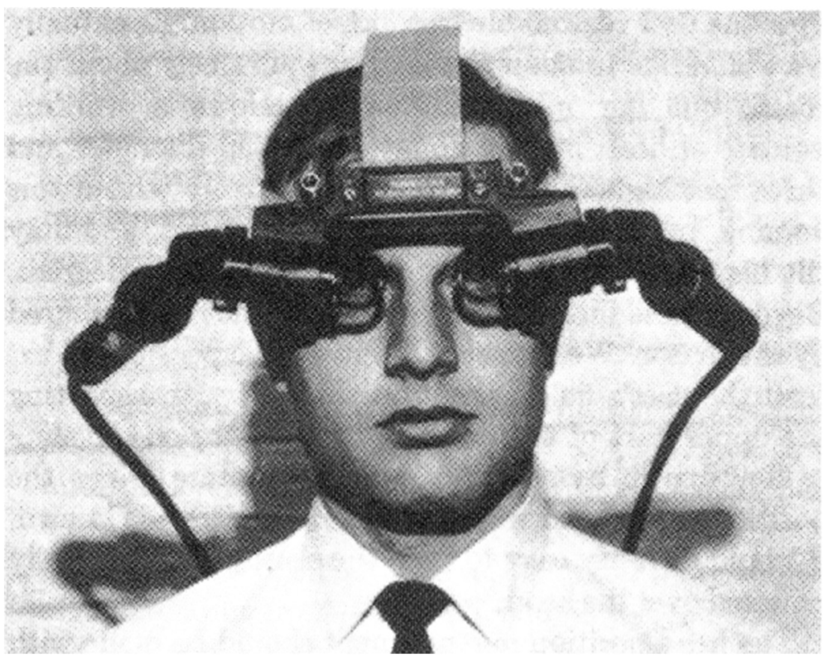


Figure 2.4. The head-mounted display optics with miniature CRT's (cathode-ray tube) [11]

The images will be presented through cathode ray tubes. HMD will make the images larger and for the user is presented a new virtual image. The wires have also grounded shields to give additional protection. [11].

Figure 2.5 below is from Boeing, where HMD was used to assist the workers by displaying the wire bundle assembly schematics [12]. The application was developed in 1992 by Caudell and Mizell at Boeing.

Figure 2.5. Researchers at Boing looking through HMD guiding the assembly of wire bundles [12]

Mastering the skills to assemble, disassemble, or repair machines is essential in many professions. Service mechanics often spend substantial time reading and studying manuals and documentation. They have to know exactly every procedure, it is most challenging. With Augmented Reality (AR) we can project instructions directly onto the worker's display. This approach helps to improve the performance and eliminate the errors even for the beginners [12].

Another example of AR technology used in maintenance applications. In Figure 2.6 and Figure 2.7 we can see how operators see the additional information. When viewing through the application we can see warnings where there are dangerous areas.

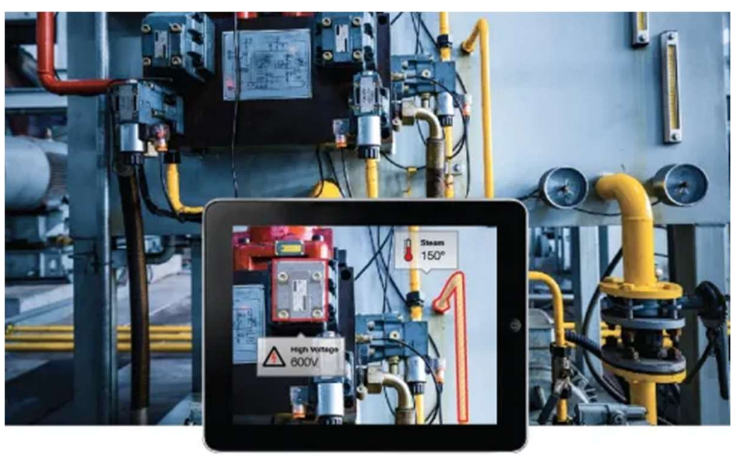


Figure 2.6. Augmented Reality maintenance screen. The digital data is aligned with the real world elements [13].

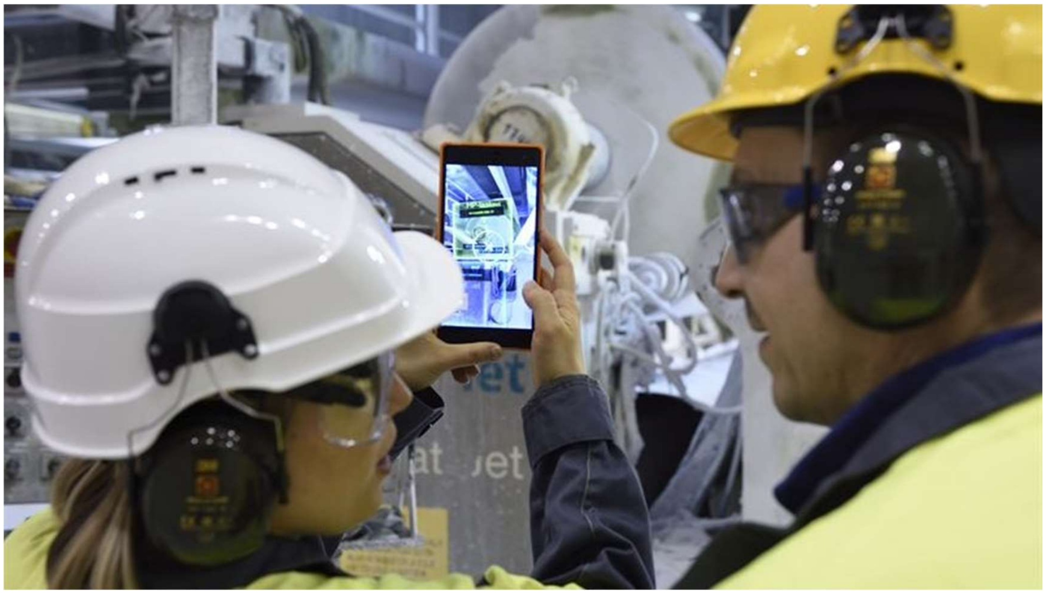


Figure 2.7. Stora Enso the first in the forest industry to utilize it in mill maintenance [14].

Stora Enso's Oulu mill uses during maintenance the AR application where real-time information is displayed on the screen. This technology is used to improve the reliability of the mill [14].

2.2 Augmented Reality in Maintenance

Maintenance is one the most operational fields in using AR. The aim of this content is to enhance the efficiency of industrial maintenance [10, 15, 16] and decrease the time consumption and error during the process [17], by putting contextual or animated virtual content on the specific equipment [15, 18].

Service workers are vital for making the systems reliable. But still fatal accidents happen during service works because of human errors. AR possibilities can simplify complex maintenance tasks and this reduces failures. AR guides workers by providing online information and can cut costs and time. Also AR minimizes paper documentation and safety will be at a higher level. And most important, AR can help to reduce human error [17].

With the increasing inclusion of electronic components in equipment, service workers now must memorize large amounts of information. They have to perform tasks correctly and on time. To reduce the workers' errors they need a remarkable amount of time for training. If workers are changing often, then the training must be carried through more often. This will cause additional costs for companies. Because of this Companies are searching for other available solutions [17].

In Figure 2.8, 2.9 and 2.10 are examples of maintenance and service with AR application. In the first one the display shows how to check and replace the brake, the second shows the schematic and step by step repair instructions. In Figure 10 we can see the AR training application for training the service technicians.

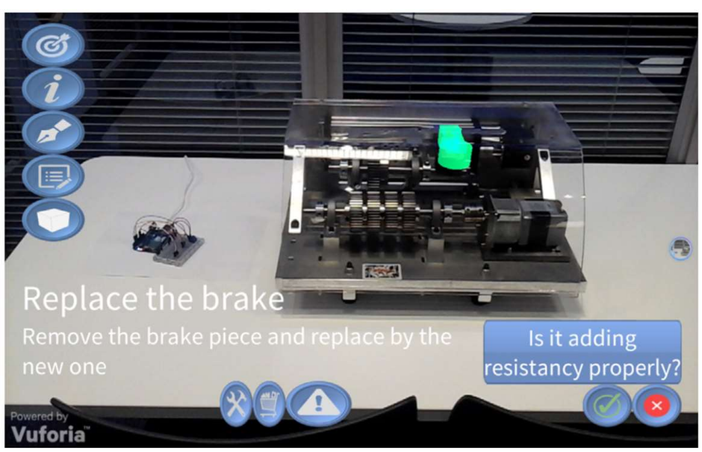


Figure 2.8. Equipment repair example[15]. Developed in 2017 with AR system prototype called ARAUM(Augmented Reality Authoring for Maintenance)

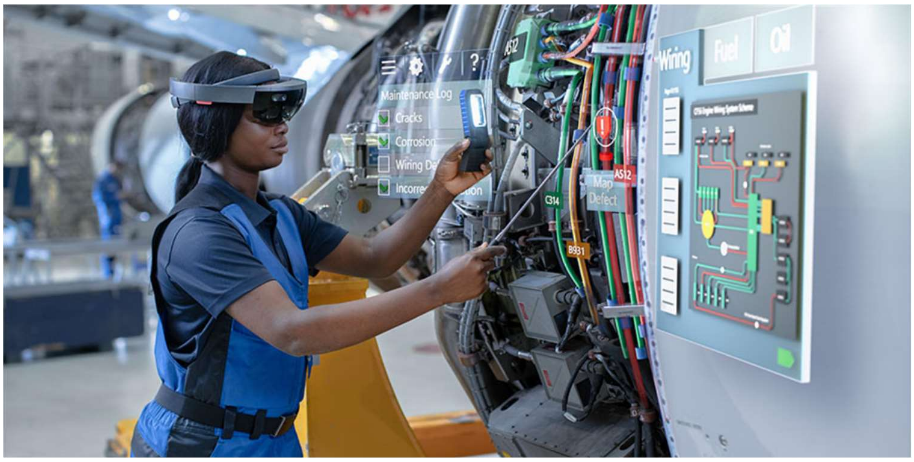


Figure 2.9. Maintenance and Service with Microsoft Hololens[19]

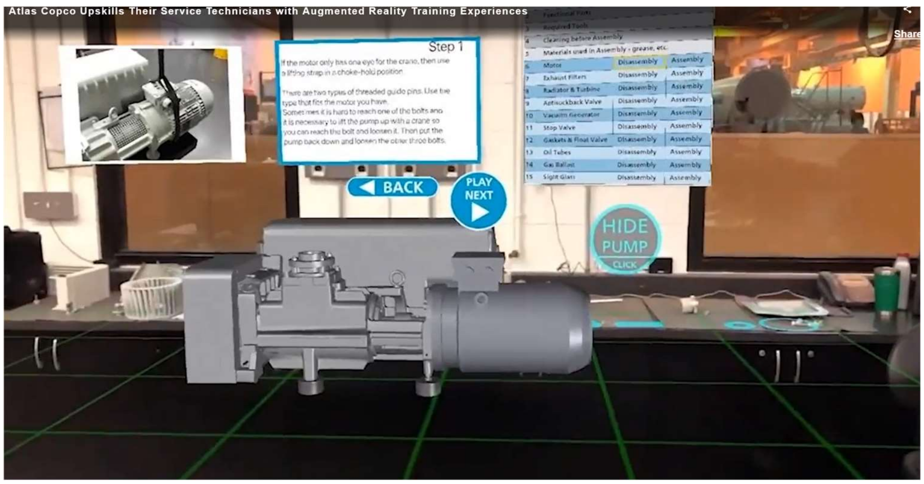


Figure 2.10. Service Technicians AR Training [20]

The service works are often costly and the time is limited. E.g. in the aircraft or railway industry. The time schedule is very tight and all work must be done according to schedule and mistakes are not acceptable. If something happens during service or a mistake is made, then it can carry a huge amount of cost. The industries are looking for a better way to manage these works. Under stress can happen more errors because of human factors. Great amount of time is spent on searching the manuals, to carry the maintenance works on time [17].

Different studies choose this well growing topic. To some extent Lima et al.[21] focused on maintenance of vehicles by the help of AR. Neges et al. [22] employed AR in maintenance of pipelines. Benbelkacem et al.[23] also helped repairers to enhance their capability and decrease the risk of the accident. As it can be observed, employing AR in learning maintenance has a great potentiality. For instance, Fiorentino et al.[24] presented an AR app that trains maintainer assembly skills. Abramovici [25] produced an app that not only helped maintainer to repair the machine but also create an opportunity for AR based team collaboration. Yew presented in [26] a AR remote maintenance with robots.

Programming skills have been the most challenging issue when creating AR. In the study by Erkoyuncu [15] the program was developed. This program provided the possibility to let workers use the AR in service even without the programming skills. An AR program was developed. The development program is called ARAUM. It means Augmented Reality Authoring for Maintenance. With this program the users are able to create a service related AR application without needing programming skills. The results showed the improved efficiency during service. The research conclusion still recommends further testing [15].

Ramirez et al.[27] developed a similar program to the previous chapter. This program enables the companies to make themselves the AR service application. And also here the programming skills are not needed. Their program is called "ManAR". With this program it is possible to make both applications - service and training. You can add the pictures, texts, 3D models etc. to this application. [27].

Schall and Garza et al. [28, 29] did show that using AR application has better performance by 30% compared to paper manuals. [30]. Also, Benbelkacem et al. [23] had a similar performance increase. The workers who were trained with AR application, gave an increase in performance when compared with traditional paper manual trained workers. The AR is very complicated in the service process and Palmarini et.al [31] considered the single text illustration is more practical.

The working habits and surroundings are reshaped by the accelerated advancement of new innovations. New innovations support the development of smart applications. These applications are the possible way to reduce the maintenance and Occupational Safety and Health (OSH) issues. It is possible to reduce the workers errors and to improve the performance and quality. And because of the new machines every year in industries the workers need new training. This is a costly process and the new innovative solutions can help to reduce the costs and improve performance. [17, 32].

2.3 Augmented reality in education and training

Augmented reality-based training is already being used in different scenarios across multiple fields and it has already emerged as a key-value creator for numerous companies and organizations depending heavily on continuous skill development to stay ahead of the competition or just to stay efficient as per the latest benchmarks [33]. For example Soldamatic [34] developed Augmented training technology for welding. Training can be used for welders and for students who are learning welding. See Figure 2.11. The reported benefits related to simulator are the following:

- more qualified welders
- reduction in learning time
- reduction in costs and environmental impact
- less accidents

Figure 2.11. Welding simulator [34]

AR-based training is particularly beneficial for all high-risk scenarios and industry segments [33]. The best thing about AR-based training is that it can easily imitate all aspects of real-life dangers and vulnerable scenarios and helps build skills with exposure to true-life scenarios.

We can outline the advantages of AR training as following:

- **Training Costs:** The AR training hardware and software price can be hight. But we have to take into consideration that it is reusable and people can use their existing phones [35].
- **Safety:** With the AR application users can test and try without a risk of injuries [35].
- On the job site, AR **improves learning and understanding.** It can enhance employee engagement and safety awareness, lower learning costs, and decrease learning times. [35].

- **Cognitive Barriers:** Job training can sometimes be difficult. Many careers need a long learning period. With this AR application approach gives a better and quicker understanding how things work [35].
- **Engagement:** AR enables hands-on interactive learning. Trainees can use physical devices to test and try different works. And very important is that they can learn at their own tempo. There is no time pressure. Most important is they can learn and test and are able to use it in real action [35].
- The manufacturing industry significantly benefits from AR technology, as it facilitates a **faster transition from theoretical knowledge to practical**. By combining AR instructions and graphics, trainees can begin hands-on practice earlier in their learning process [30].

Many educators and trainers think that learning with AR is the learning process faster and more effective. Figure 2.12 illustrates the participants' answers in the (Erasmus+ KA2 AROMA project) survey. We can see that over 90% of them think that AR technology might be useful in their jobs. In Figure 2.12 we can see respondents answer [36].

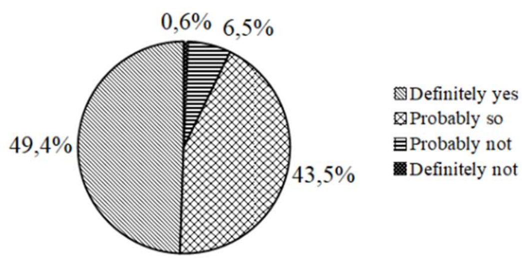


Figure 2.12. The participants answered whether they think AR innovations can be useful in their work. [36]

3. DEVELOPMENT OF AUGMENTED REALITY BASED OPERATION GUIDE

Let's look at the Festo FMS closer and see what the machines are and what they do.

The choosing of software and hardware is handled in this chapter. After choosing the needed software and hardware we can proceed with the AR application development. After the application development the experiment is carried out and the results are presented in different tables.

3.1 Festo FMS System. Machines and descriptions

Festo Flexible Manufacturing System(FMS) is located in the Department of Mechanical and Industrial Engineering Research center of Smart Industry and Robotics. The solution is based on the Industry 4.0 and flexible manufacturing concept. The Festo FMS is used at the university to introduce and test the Industry 4.0 concept to students and companies. Operator gives the orders to the system and the Festo FMS fulfills the orders fully automatically.

The FMS consists of the following machines: Main computer, Automatic Storage Retrieval System (ASRS), CNC machine center (Conveyor + Turning machine robot + Turning machine + Turning machine computer) and transporting robot with conveyor. The Festo FMS is controlled by the main computer. Operator can give orders to the system on this computer.

When order is given, then the transporting robot moves to ASRS. ASRS has warehouse, where the ready products and raw material is stored. ASRS takes from warehouse according to order the suitable box with raw materials. ASRS gives out the materials to transport robot and it delivers the package to the turning machine input conveyor. Turning machine conveyor delivers the materials to the takeover point at the turning machine. Turning machine robot takes from the box the suitable raw material and places it inside the turning machine. Turning machine can start working with the detail. When detail is ready, the robot takes it out and places it on the outfeed conveyor. Transport robot moves to the takeover point at the outfeed conveyor and it is ready to receive the detail. After the transport robot has received the detail it moves to the ASRS machine and the ASRS machine takes the detail and places it to the warehouse.

Let's take a closer look at the machines and their functions in the Festo FMS.

- **Turning machine EMCO Concept Turn105** shown in Figure 2.13.
  The machine is in table format and PC-controlled. Turning machine has 2-axis. Turning machine is executing the programmed order. The machine is very stable - the vibration-damping is present. It is very well equipped with hardware - enough power and very precise [37]

Figure 2.13. Turning machine EMCO Concept Turn105

The control of the turning machine is integrated through PC (Figure 2.14). The turning machine computer has the WinNC installed [37].

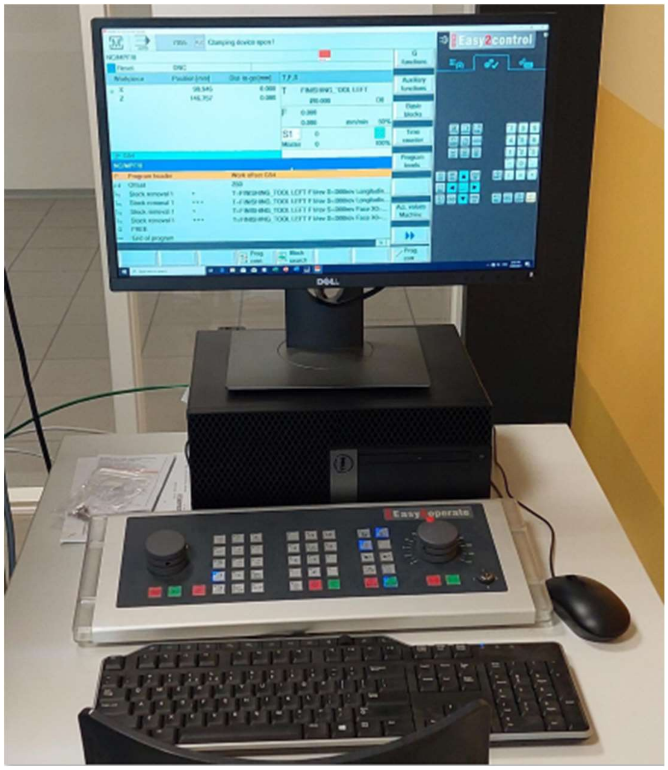


Figure 2.14. Turning machine controlling computer

- **Mitsubishi Electric Industrial Robot RV-4FL-D**

The robot is equipped with a Festo pneumatic gripper. In Figure 2.15 we can see on the left side the robot with a gripper. Behind the robot is the turning machine and on the left at the table is the controlling computer.

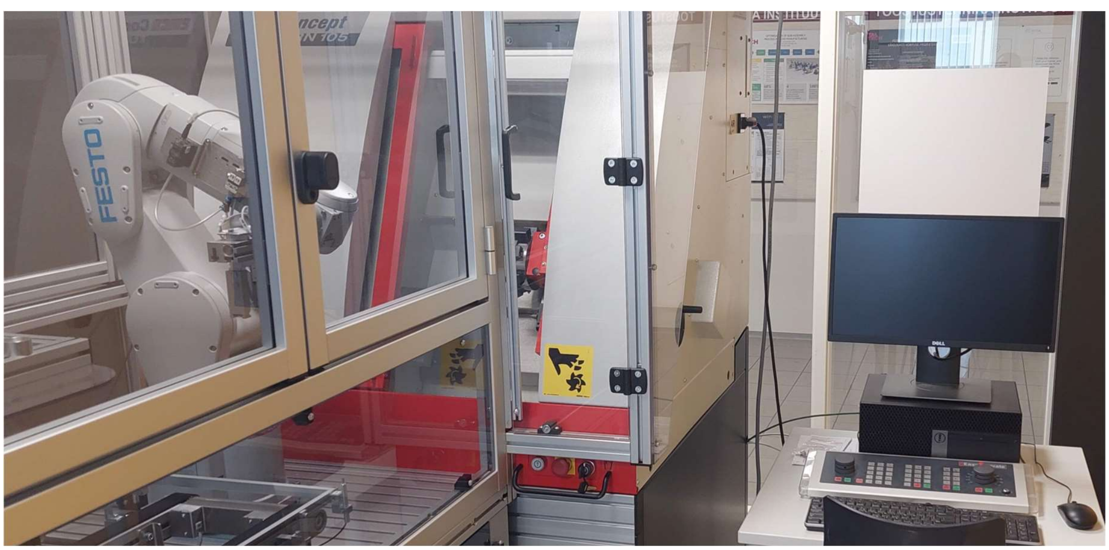


Figure 2.15. Turning machine and computer, Mitsubishi Electric robot

- **Moving Robot Festo Robotino RO03-BG-LDGT-KPL with conveyor on top** (Figure 2.16)

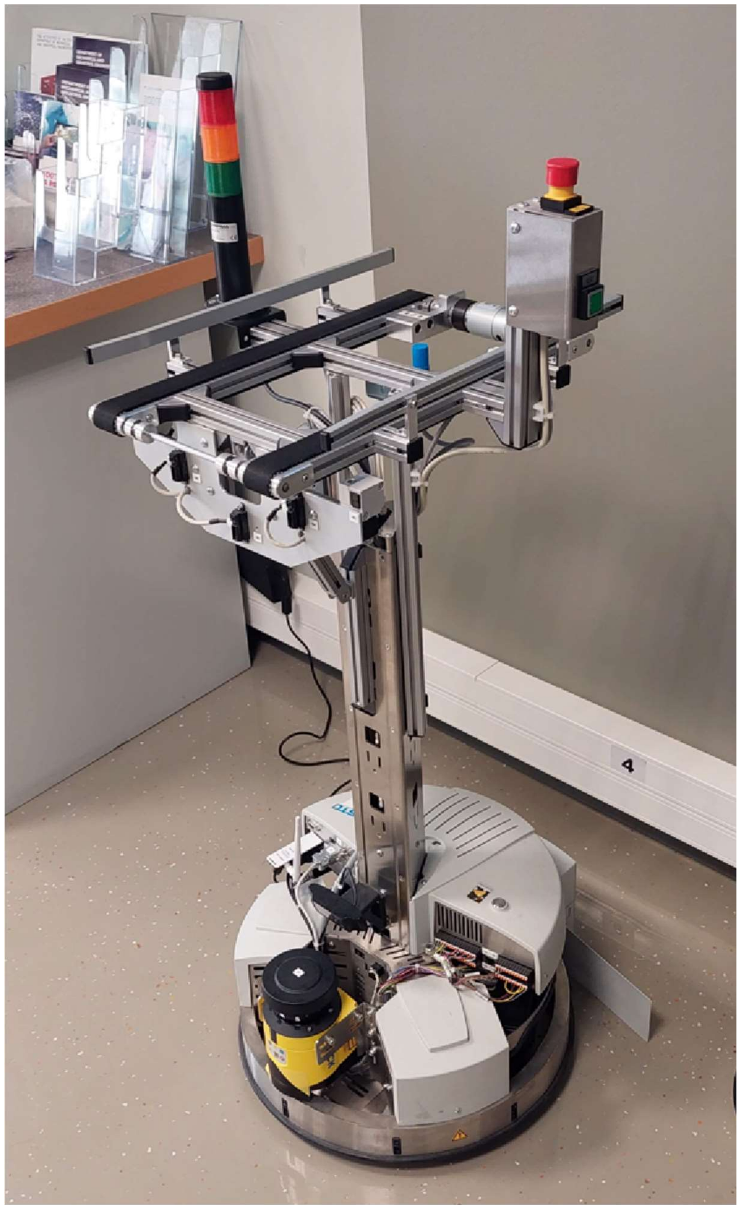


Figure 2.16. Robotino RO03

- **Automatic Storage Retrieval System** (ASRS) shown in Figure 2.17
  In the storage are stored the raw products and ready products. When the order is given to the ASRS, then it will deliver to the exit conveyor the needed box containing the materials for the CNC machine.

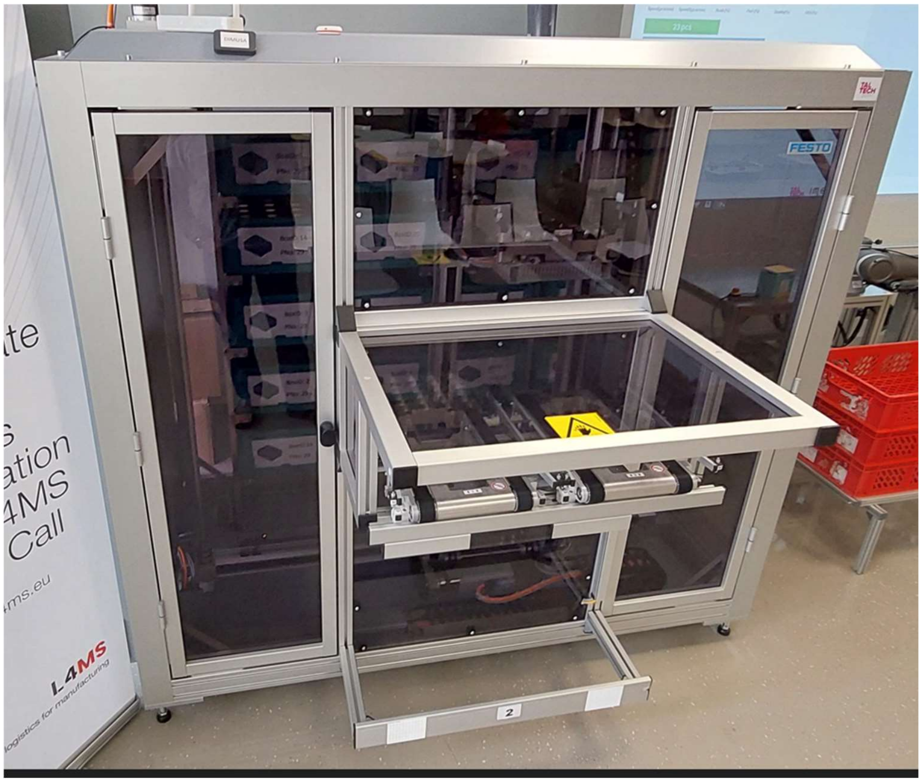


Figure 2.17. ASRS

- **Main computer workstation** for the Festo FMS system (Figure 18)
  From this computer the operators can control the whole FMS system.

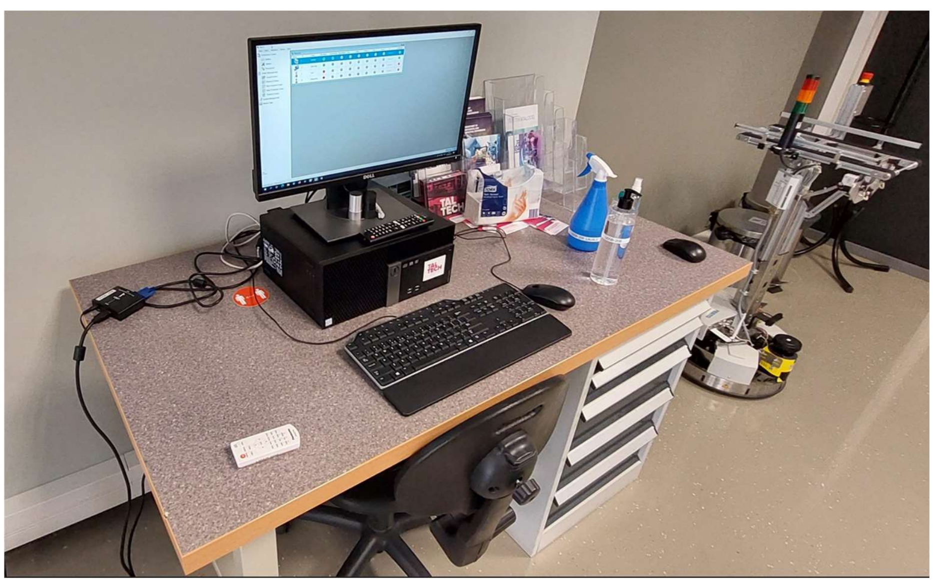


Figure 2.18. Main Computer for running the FMS system

The controlling software in workstation MES4. From the program we can see the machine connections and give the order to the system.

3.2 Software components selection

For AR program development to be successful it is crucial to choose the proper software components. The following criterias have been used for the selection:

- Possibility to support AR functionalities
- Available for free
- possibility to use image and QR code targeting
- multiplatform capabilities (Android, iOS)
- online documentation and software support

There are many programs available for the development of this application. We consider here only the most used and known AR development software and game engines for interactive content creation including XR applications, a Software Development Kit (SDK) for the integration of AR functionalities in the application.
In this Case Study we have chosen for comparing 3 programs:

- Unity
- Unreal Engine
- Vuforia Studio

Unity is the most known platform when creating immersive technology content. It is utilized by a wide range of creators. Unity's platform has a wide range of solutions for creating the interactive applications for different devices ranged form phones to consoles.[38]
Unity uses C# programming language. The scripts are attached to GameObjects. The GameObjects are all the objects in the program.
There are different product versions offered by Unity. It is a payed software, but offers free usage for students and personal applications.
Unity provides very good learning materials. It is easy to start from zero - there is enough material available online. There are special learning plans [39].

Unreal Engine[UE] is the second most known game engine by Epic Games. It has a visual quality in very high level. The games and immersive applications like AR and VR can be created with this platform.[51]

Vuforia Studio is aimed at creating AR experiences without the need for in-depth programming knowledge. It provides an interface where you can drag-and-drop the objects. It allows users to quickly and easily assemble AR experiences.
Vuforia Studio is designed with enterprise users in mind, focusing on industrial AR applications. It allows for the integration of 3D models, CAD data, and IoT data into AR

experiences. This makes it ideal for creating interactive manuals, assembly instructions, and remote assistance tools for the workforce. Vuforia Studio is tailored towards enterprise users and businesses looking to create industrial AR applications (https://www.ptc.com/en/products/vuforia/vuforia-studio).

Program selection according to criterias is in the Table 3.1 below.

Table 3.1. Program selection

Criteria Program	Possible to create AR solution	Available for free	QR code reading	Cross-platform	Learning materials availability online score from 0-5
Unity	Yes	Yes	Yes	Android, iOS, PC, macOs, Linux, Consoles, TV platforms +	5
Unreal Engine 5	Yes	Yes	Yes	Android, iOS, PC, macOs, Linux, Consoles...	4
Vuforia Studio	Yes	No	Yes	Through Vuforia View app can be used on Android and iOs devices.	3

From the Table 3.1 above we can compare the different programs and make the decision which one to use in this thesis. Very important is that it is free for use. The Vuforia Studio is not available online for free download. This program falls out.
The Unity and Unreal Engine 5 are very close to each other to choose.
Unity is chosen because of the easier learning and available material online. There are a lot of learning materials and examples and free plugins available for download.
In the following sections we take a short look at the programs and software development kit's (SDK) used in the work.
The Unity Hub was downloaded. When opening the Unity Hub it is possible to choose the version of Unity which will be downloaded - version 2020.3.30f1 was used in this Case Study. After the program is running and working it is time to install the needed

SDK's for the AR application development. Then the needed packages were installed: Vuforia Engine, ARKit XR Plugin, ARCore XR plugin. Description of the selected SDK's:

Vuforia Engine is a software development kit (SDK). It enables the creation of AR applications. When we want to identify the QR codes then we need to add this SDK to the Unity program. With this SDK we can develop the application for diverse devices [40] [41].

The ARCore XR Plug-in. This plugin provides ARCore support for the Unity platform [42].

ARKit XR Plug-in. The package provides ARKit support for the platform Unity [43].

Visual Studio(VS) program for writing C# code. The program can be downloaded for free. It is easy to use and code can be tested inside the Visual Studio.
VS makes your code appear in different colors so you can better identify the coding sections easier. During the code writing,the Visual Studio gives you suggestions how to complete the lines and provides fixes for the mistakes you make. You can also use the debugger in VS Code to step through each line of code and understand what is happening [44].
For writing the code in C# Visual Studio was used. When clicking in the Unity the C# code, automatically opens the Visual Studio program.
Unity has an online store for plugins - Unity asset Store. There are all types of plug-ins available for free and for purchase. It is possible to download suitable assets and attach them to the project. This way you don't have to make an application from scratch. To do this you must have a good understanding of what you want to do. And when attaching the assets you have to study them so the result can be what is expected.

3.3 Hardware selection

Choosing the right AR hardware depends on the specific requirements of the project, the complexity of the AR experience and the level of immersion and interaction needed. Android and iOS systems provide broad accessibility and are well-suited for AR applications, with developer platforms in ARCore and ARKit. On the other hand, Microsoft HoloLens offers a more specialized, high-end option for complex, interactive AR applications in professional and industrial settings. Each platform has their strong and weak elements.

By selecting the hardware next criterias are selected:

- AR device must be easily available - purchase or already there
- Camera - good quality(above 16MP camera)
- Cost - target is medium, low price(target 200€-300€)
- Size - display 8 -11" inches
- Lidar sensor - provides more precision, advantage

Table 3.2. Hardware selection. Higher number better result

Device	**Availability 0-5**	**Camera quality 0-5**	**Cost 0-5**	**Lidar scanner present**	**Screen size 0-5**
Hololens 2 [19]	2	5	1	-	5
Galaxy TAB A7 L 8,7"	5	4	5	-	5
Apple Ipad Pro 11"	5	5	2	+	5

The approximate prices are for the devices: 3475€ Hololens 2, 200€ Galaxy TAB A7 L, 1080€ iPad Pro 11. The Ipad and Galaxy can be purchased here locally but the closest Hololens 2 reseller is located in Finland (atea.fi). The availability for Hololens 2 is difficult. The camera can compare between both tablets using their specification and it shows better results for Ipad 11 Pro - higher pixel amount in Ipad and also iPad has the lidar sensor for improving the AR experience.

From Table 3.2 and the discussion above we can see that Hololens glasses and Apple products have a very good quality and high price. When we take into consideration that

when a company is taking into use the AR application, then the device cost will be significant. We can buy 15 android devices or only 1 Hololens glasses. That is the reason why the Hololens is not selected here. For this work are 2 options - Ipad or Android Tablet device. When looking at Table 3.2 we can see the advantages of using an iPad for augmented reality (AR) applications. It has a superior camera and the additional LiDAR scanner. These features contribute to a more responsive and immersive AR experience. Nevertheless, the selected Android device has good sides and the cost is small. We could buy 5 or more normal Tablets for the price of one Ipad.
Because of the cost will be the chosen one the Android Device. It fulfills the demands for this project. Device model is Samsung Galaxy A7 L.

3.4 AR application development

First the information about the FMS is gathered - how it works and what documentation is available. There was a paper manual on how to start the FMS. First the paper manual was studied. Then the first tests were executed to find out how easy or complicated it is starting the FMS according to the paper manual. There were some steps which were not completely explained so external help was needed. After testing the FMS system starting and shutting down, more information and pictures were added to the paper manual. When the paper manual was ready we proceeded with the AR program.

The purpose is to make an application, where we scan the QR-code sticker on the machine and we can use our AR instructions in context based on the one provided in the manual, but in a much more accessible way. The developed AR application helps us to start the FMS. When we complete the application given steps, the machine is ready for taking orders. We give the order through the main computer. After giving the order to the system, the FMS will be running fully automatically. When the machine is finished the orders and we can proceed to the next step - shutting down the machine.

3.4.1 AR application architecture

We are developing the AR application for the android phone and tablet. The main source for creating the user interface tasks is the paper manual. In the paper manual are all the steps described, what the user must do to operate the Festo FMS. The same structure must be overtaken into AR application. The tasks in the application must be gathered in such a way that it is logical for the user. The main task for the program is to recognise the QR code on the machine. According to recognised QR code the application will start giving the tasks what operator must do to have the desired result. First we have to find out what are the best places for the QR code on the machine and how many QR codes we have to use. The places were selected based on a test and trial approach. The QR code place had to be free, on the flat surface near the user operating location. If the QR code location is too far or not in the flat surface then there will be a lot of errors because of losing the QR code location. Another important condition is a good light - when light is poor, then errors are easy to occur. When the possible locations were fixed, then it was easy to fix the amount of the QR codes. If we would take into use only one QR code, then the room would have to be 3D scanned and developed accordingly. Because in the current thesis we use only QR codes, then there have to be more of them, because the FMS consists of more than one machine and the user has to go to every machine and operate there. Different places were tested with preliminary AR application. Some places were better and according to these results these were chosen.

The total amount of QR codes needed for current application is 5 pcs.:

- NR1, the main FMS computer
- NR2, the ASRS machine on the back
- NR3, the ASRS machine on the side
- NR4, the CNC machine computer
- NR5, CNC system HMI screen

The QR code places are chosen so that they are almost always visible when operating the machines. When the QR code is always visible for the tablet camera, then it helps the application to show the screen without disturbances.

Below in Figure 3.1 is the system architecture where we can see an overview of software and hardware components used in the development of the application.

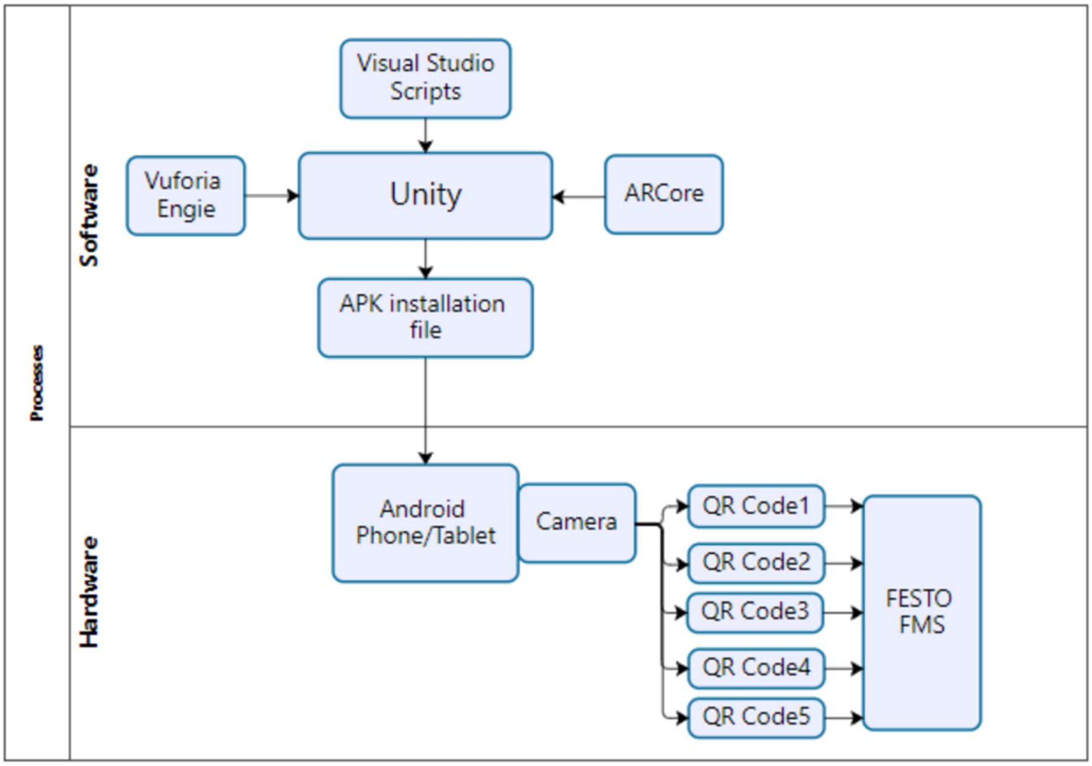
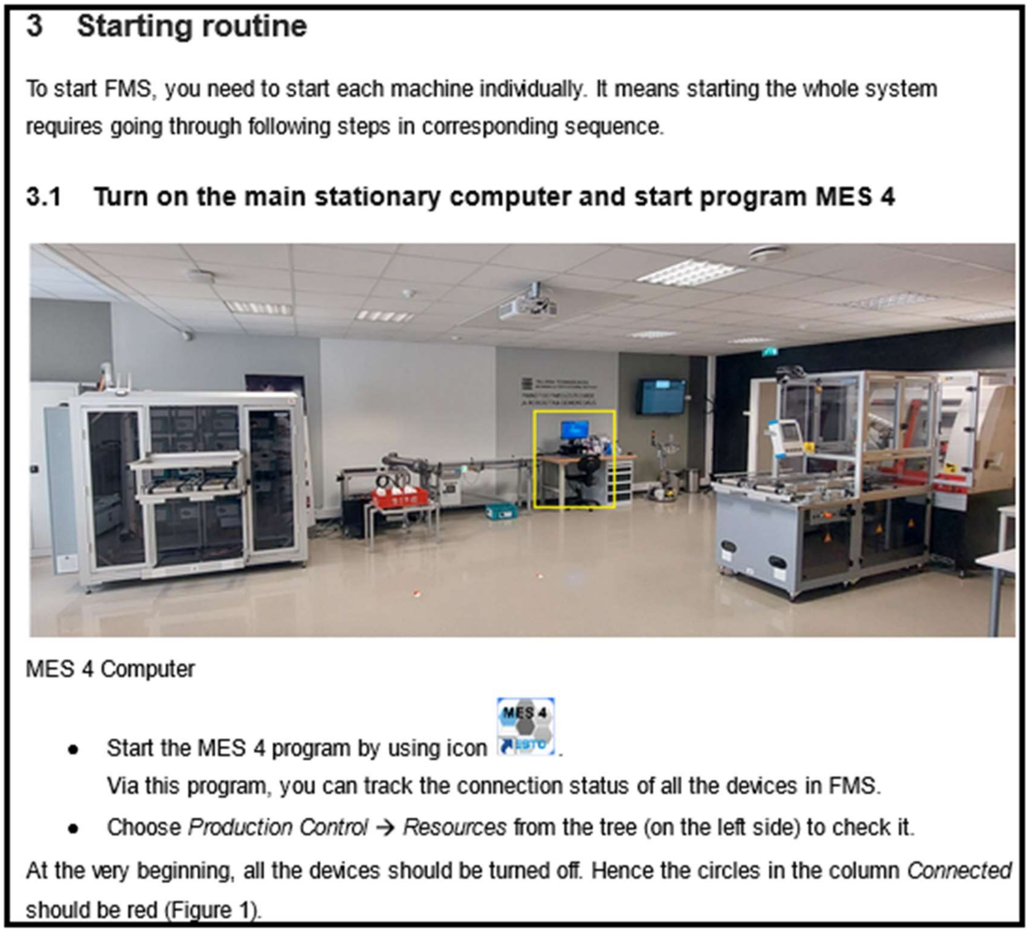


Figure 3.1. System Architecture

3.4.2 AR application user interface

The User Interface (UI) should be easy to read and use. Designing and developing the graphical elements has a crucial impact on how the application will be understood. Users will be in interaction with the AR application during all the process. We have to determine what is the goal and what functionality should the application have. In the beginning when the application starts, it shows a short explanation of what the application does and gives the user the possibility to choose the needed subprogram. When a subprogram is chosen then a new scene is opened. The aim is to create the scenes in Unity in a way that when the user is operating one machine at a time, then this sub-program will be developed in one scene. The scenes are the assets in Unity which contain only the objects needed for the current scene. When the user finishes with the AR application at the machine then the next machine scene will be opened. There are in total 20 different scenes created.

When the user finishes with one FMS machine and proceeds to the next machine then the next scene in Unity is opened. Let's take a look at the paper manual version below in Figure 3.2.



3 Starting routine

To start FMS, you need to start each machine individually. It means starting the whole system requires going through following steps in corresponding sequence.

3.1 Turn on the main stationary computer and start program MES 4

MES 4 Computer

- Start the MES 4 program by using icon .
  Via this program, you can track the connection status of all the devices in FMS.
- Choose *Production Control* → *Resources* from the tree (on the left side) to check it.

At the very beginning, all the devices should be turned off. Hence the circles in the column *Connected* should be red (Figure 1).

Figure 3.2. Starting routine page from paper FMS operating manual

All the same steps described in the paper manual will be also in the developed AR application.

Requirements for UI:

- not too much information on the user screen
- Users must see on the screen only a couple of steps, which they have to do
- information about current machine progress visible on the screen.
- additionally information about the total progress
- the same layout of the UI when executing different subprograms - starting FMS, new order in FMS, shutting down the FMS

In the following section is described the UI development.

The first AR application screens are informative with explaining text - Figure 3.3 and Figure 3.4. Figure 3.3 is displayed when the application is loading.

Figure 3.3. AR application loading screen

Figure 3.4. Starting screen

If we push the START button in Figure 3.4, then we land on the page we can see in Figure 3.7.

First we create the new scene by clicking the right mouse button at the Assets section (Figure 3.5) and select the Create-> Scene. The new scene is created and we can start with creating the GameObjects in the program. In total 20 scenes were created. The GameObjects are all the objects in the program. When we give GameObjects the properties, then it will act as described.

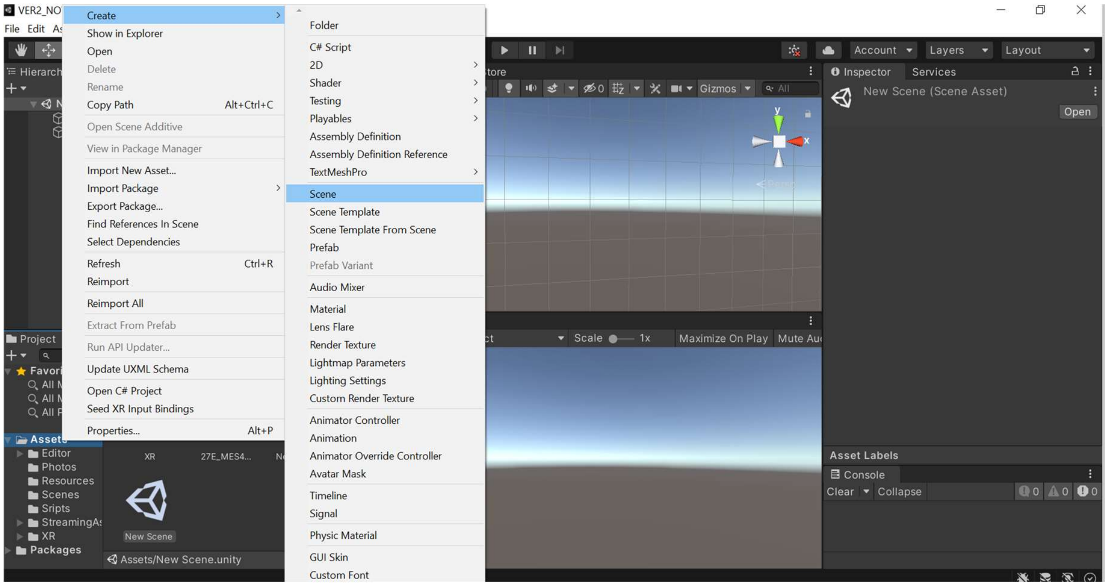


Figure 3.5. Create a scene in the Unity program

In the current application development we use two different options for building scenes. One is where the objects in the UI are fixed in a certain location on the tablet display and we can see only the information that is provided in the program for the current scene. The other option is where we use an augmented reality approach. We look through the device's camera QR code and the application starts to interact with the user. When we move the camera, then the AR content will stay in the place where it is programmed to be in the scene.

Let's look first at the scene version, where the interactive camera is not used. This scene is used in cases, where information is provided for the user and no interaction through camera is needed. For example below in Figure 3.6 we see the first scene. In the UI will be the START button and the text. We can start making new Canvas and Game Objects. All UI objects should be inside the Canvas. The Canvas is a Game Object. The UI objects have to be the children of these Canvas. The Canvas location is visible in the Scene View [45].

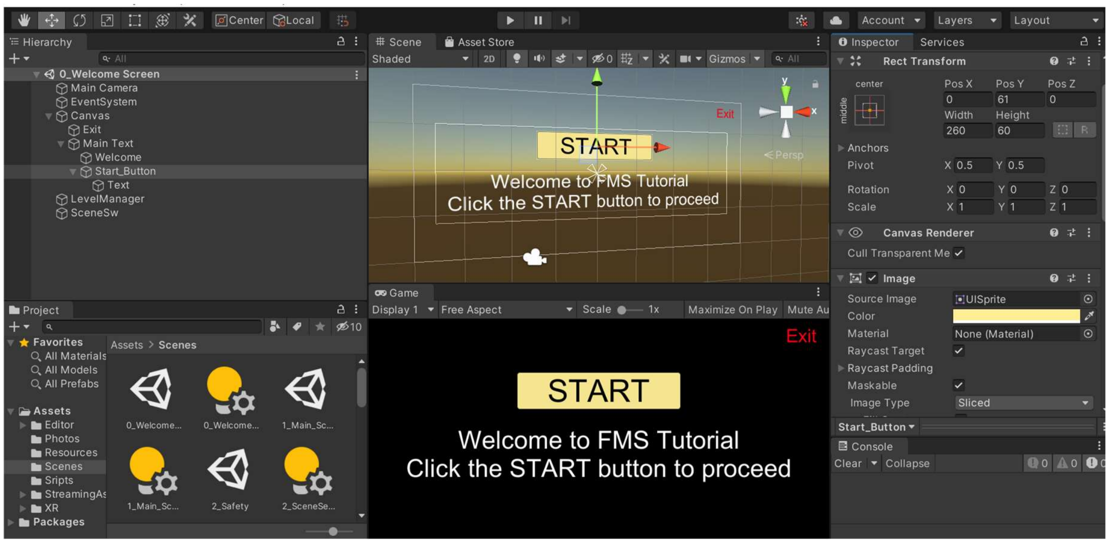


Figure 3.6. The first scene

In the Unity interface we can see on the left side the hierarchy of the created scene and project assets. The inspector is located on the right. If we choose from the left in the hierarchy canvas row, then in the inspector we can change its properties and also add a script if necessary.

In the central tab two windows are visible. The upper one is where we can add and change the UI. The lower window is where we can see the actual screen which will be visible to the end user. There is one informative text and two buttons - “START”, “Exit”. First we create the texts and place them on the screen. We can place the text exactly to the location where we want it to be in the user screen. Because the user can have a tablet with different display ratios, then we can put the text always in the center or in the corner, etc. During programming you have to check how the UI will act with different display ratios.

For the text “START” and “Exit” were added the button functions. When you press the button “START”, the application opens the scene that is programmed under this “START” button function. And when you push the text “Exit”, the program closes.

All application screens have below the same buttons: EXIT, BACK, HOME, Scan next machine code, and Show/Hide buttons. When we push “EXIT”, the program will close. Pushing “BACK” we can go back to the previous screen. Pushing “HOME” we will land at the home screen of the AR application - Figure 25. From the button “Show/Hide Buttons” we can hide or show the buttons “EXIT”, “BACK”, “HOME”, “Scan next machine”. Starting the program we have to follow the instructions on the screen step by step. After every step we confirm actions with the button “Done/Next”. After pushing the “Done/Next” button the next step will be displayed. In Figure 25 we can see the next scene where we can choose the next action. This screen is also the Home Screen which is accessible from any other application page.

Figure 3.7. Program selection / Home screen

If we push and hold for example the button “FMS Start”, then it will change color. We can see below Figure 3.8 it is a different color.

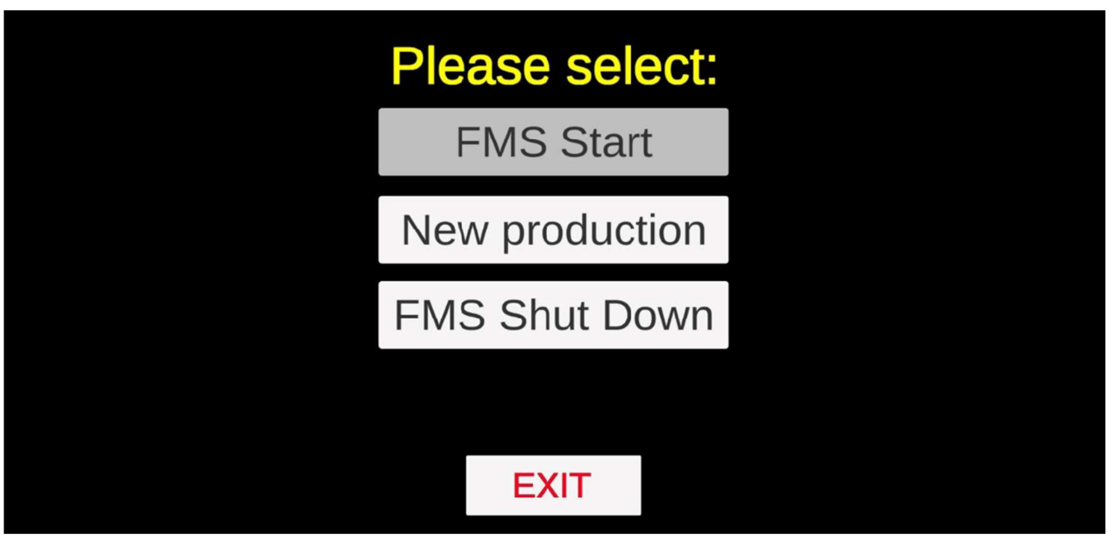


Figure 3.8. Program selection / Home screen “FMS Start” pushed

In the next Figure 3.9 we see a short explanation about safety.
Before using the program it is always mandatory to make the safety instructions by the supervisor.

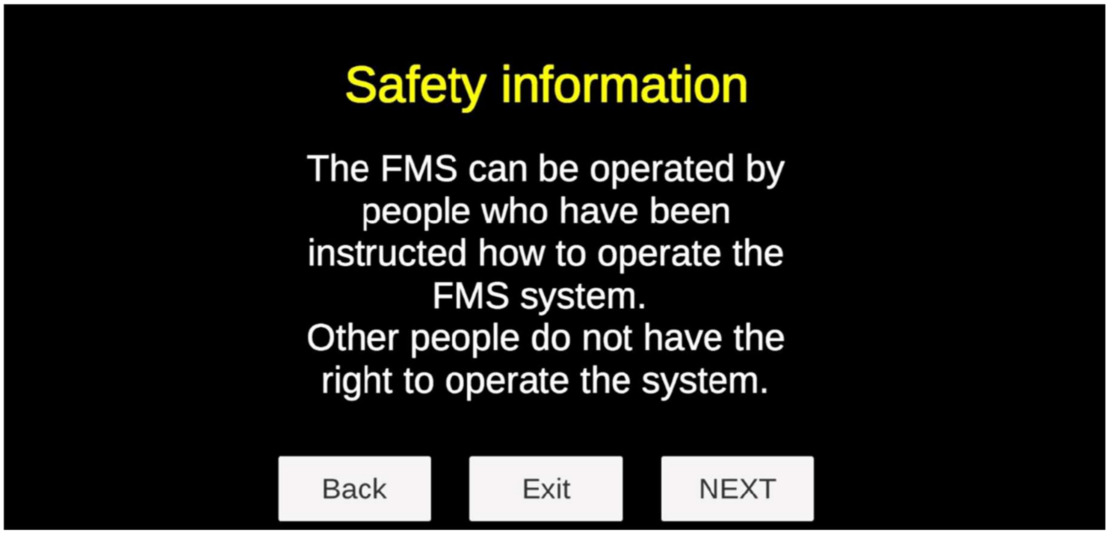


Figure 3.9. Safety instruction

By tapping "Next" on Figure 3.9 will have the screen in Figure 3.10.
After a short explanation in Figure 3.10 we push "Next" and the AR will be helping us to start the machines and programs.

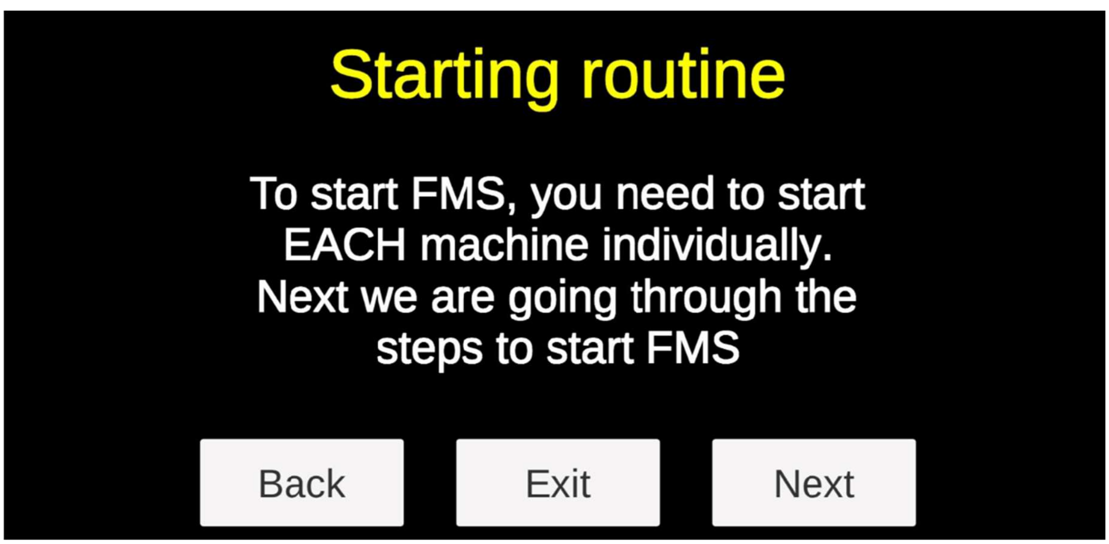


Figure 3.10. Starting routine

In the next steps the AR application asks to scan the QR code. After this instructions are displayed on the screen. After accessing each step information the operator has to press the button Done/Next and the screen will show the following step.

Next we can see example Figures from the application of how the steps are seen on the screen. In Figure 3.11 we see where the MES4 program is opened and all dots are in red color. This means all devices are not connected to the automatic system. If we push "Done/Next" we will land on the next page and the application tells us to move to the next machine and scan the next machine QR code.

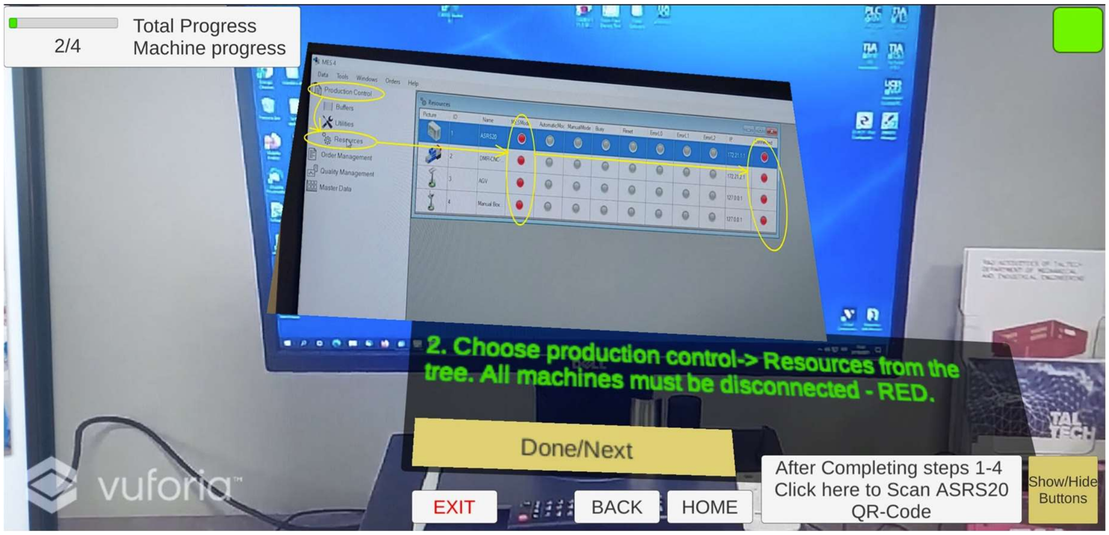


Figure 3.11. Main computer

On the upper left corner we can see "Total progress" in the green bar. If the green bar will be full then all steps are completed and the system running. And it also shows how many steps must we do on the current machine. In Figure 3.11 is 2/4. It means the second step and the total is 4 steps on this machine.

On the upper right corner is a green colored rectangle. When it is green, it means the QR code is recognised and the AR application knows where this machine is located in the room. If the rectangle turns red, then the QR code is lost and must be scanned again. Application will say "Scan the machine QR code".

Below in Figure 3.12 we can see the hierarchy of this scene above. Now we are using the Image Target. We delete in the hierarchy the system Camera and use the ARCamera. The AR camera uses our given database, where we have the QR codes. From this database we choose the needed Image Target(QR code) for this scene. When we see through the camera the selected QR code, then the scene that we programmed, will be displayed.

One part of the screen is always showing the buttons in the same place and the other part of the program is AR. The AR part moves according to how the user moves the device(camera).

Below in the scene folder Figure 3.12 and 3.13 we can see the above mentioned two parts. One folder is named “ImageTarget1” - there are all objects which are connected to the AR part of the UI.

And the second folder is named “Fixed_Screen_Canvas” - there are all objects which are connected to the fixed part of the UI screen.

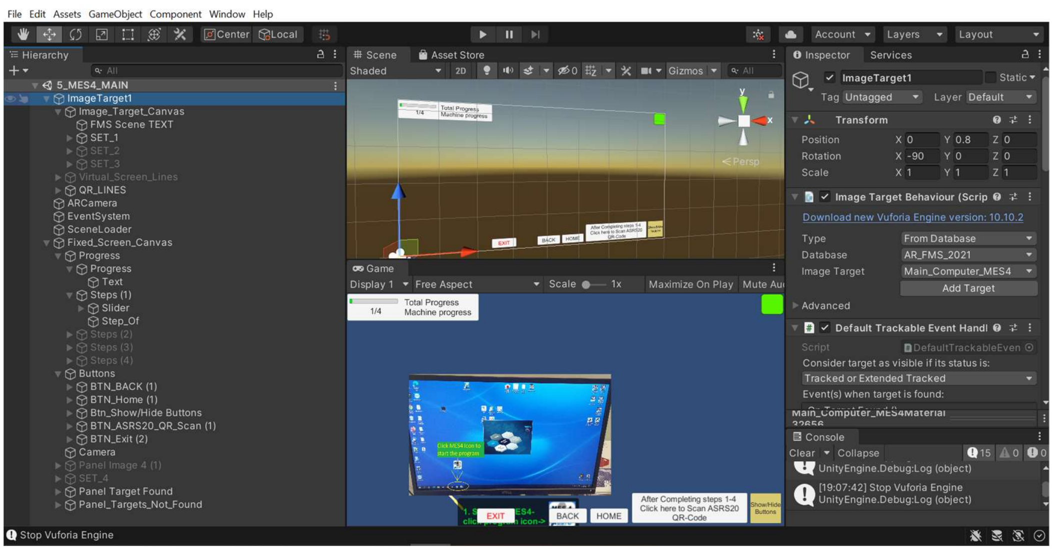


Figure 3.12. Scene hierarchy

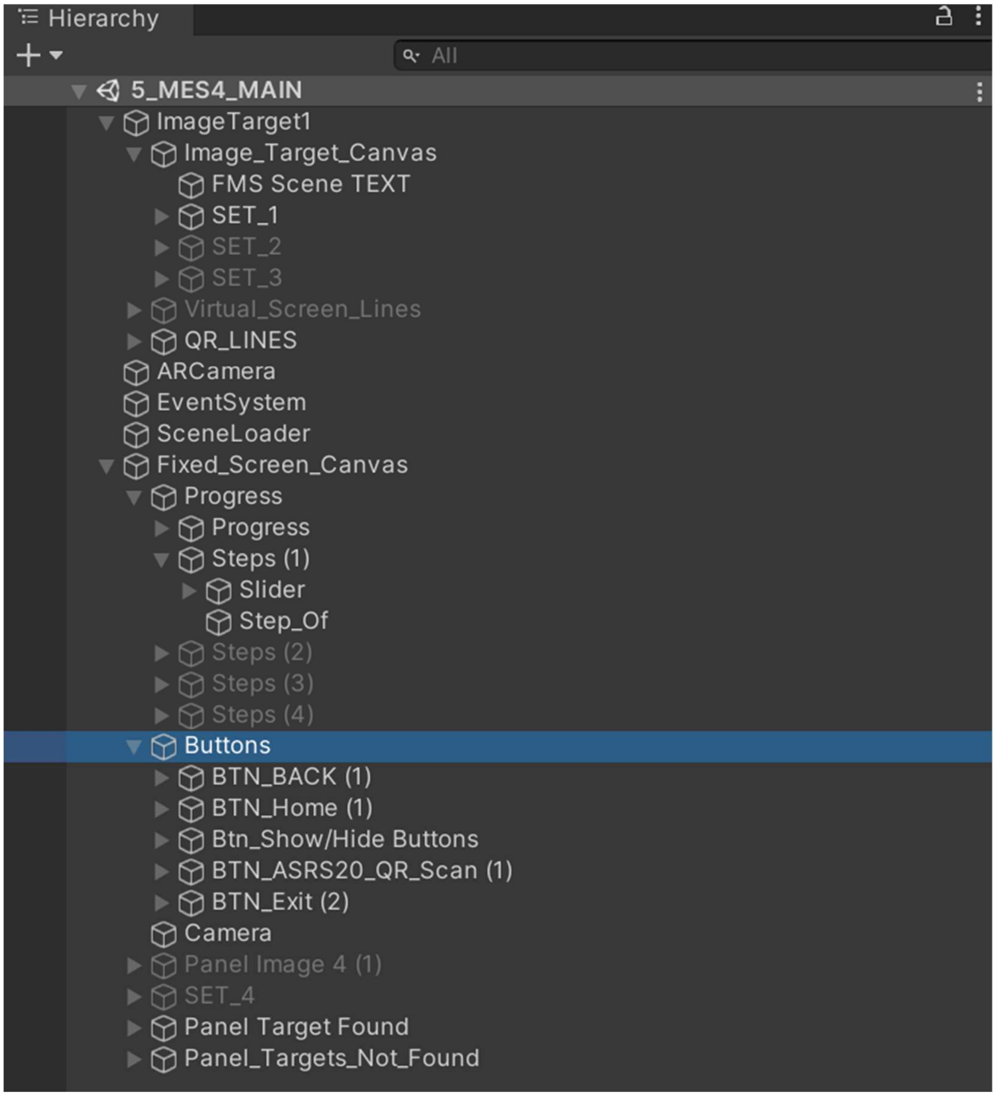


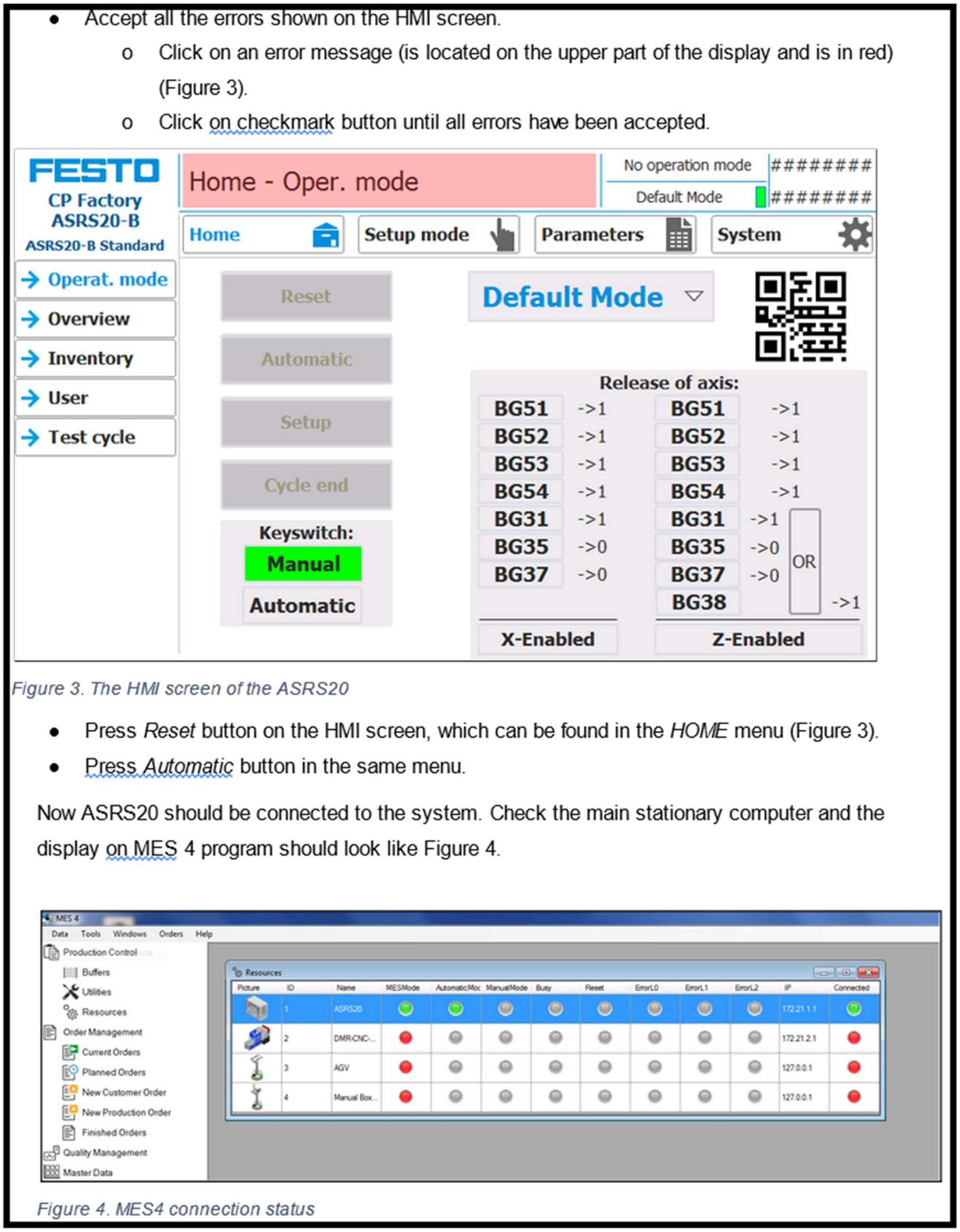
Figure 3.13. Scene hierarchy

Let's have a closer look at the Fixed Screen objects - the object locations are always in the same place on the tablet display(Done, Next, Exit, etc.). There are folders Progress, Steps1(Slider), Steps2, Step3, Steps4, Buttons, Set_4, Panel_Target_Found, Panel_Target_Not_Found, etc.When the scene is opened, then all the objects which are highlighted, will be visible on the screen.The Gameobject Progress specifies what is displayed in the upper left corner - it shows the overall progress as a slider and a progress from the current scene. In Figure 3.13 it shows the progress of the 1-st step of 4 steps -1/4. The "Buttons" object is highlighted and these are the buttons in the lower area of the screen (Figure 3.13). "Set_4" object is the last step of this scene. If this is executed, then the scene will be closed and the next scene is opened. "Panel_Target_Found" displays the green box in the upper right corner of the screen, when the Image target is found - the QR code. If the QR-target is not found or the AR loses the tracking, then no green box is displayed. “Panel_Target_Not_Found” displays the text if the Image target is lost or not found. It displays the text “Scan MES4 QR-Code”. If a target is found, then this text disappears. Every scene has its own Image Target. So if the image target is lost, it displays the image target text. For example - “Scan MES4 QR-Code”, “Scan CNC Computer QR-Code”, etc.

Now we look at the AR objects in the parent GameObject “Image Target_Canvas”. There are folders SET1, SET2, SET3, Virtual screen lines, QR_Lines etc. When the scene is opened, then first are displayed the Fixed screen objects. To be able to see the AR we need to scan the QR code. In the screen will be displayed “Scan MES4 QR-Code”. When we scan the correct QR code, then the SET1 objects will be displayed. The text and photo will appear on the screen and say what we have to do. We will interact with the application and when we push the button, the next step will be opened - SET2. And we will proceed until all the steps are completed.
There are objects Virtual screen lines, QR_Lines. These are not displayed, these were used for helping to develop the application.

ARCamera is needed to be able to make the AR application. When all steps are completed, then with the last command the script “SceneSwitcher” is used. When the image target is closed, the next scene will be opened. The scene order is defined during compiling the program. Before compiling all the needed scenes will be chosen and if needed, the order will be adjusted. From there the program will have the information which scene needs to be opened. The scene switcher code is added to appendixes.

The goal is to perform all the steps provided by the AR application. When all steps are completed we will have the result - starting the machine, new order or shutting down the machine.



- Accept all the errors shown on the HMI screen.
  - Click on an error message (is located on the upper part of the display and is in red) (Figure 3).
  - Click on checkmark button until all errors have been accepted.

Figure 3. The HMI screen of the ASRS20

- Press *Reset* button on the HMI screen, which can be found in the *HOME* menu (Figure 3).
- Press *Automatic* button in the same menu.

Now ASRS20 should be connected to the system. Check the main stationary computer and the display on MES 4 program should look like Figure 4.

Figure 4. MES4 connection status

Figure 3.14. Paper manual ASRS HMI page

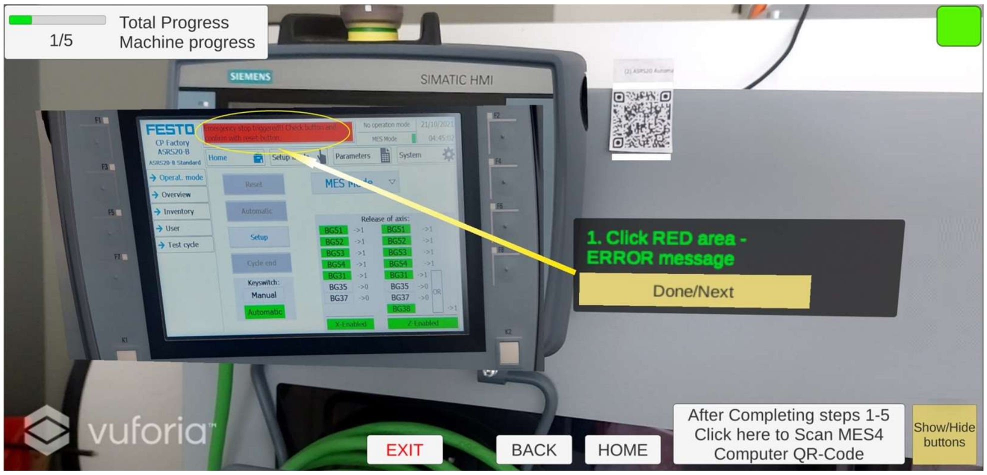


Figure 3.15. AR application ASRS step 1/5

Figure 3.16. AR application ASRS step 2/5

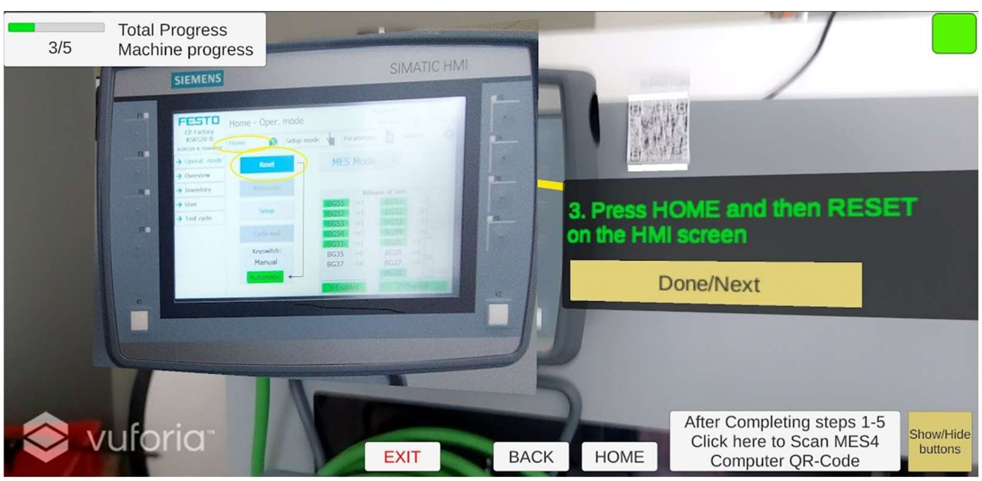


Figure 3.17. AR application ASRS step 3/5

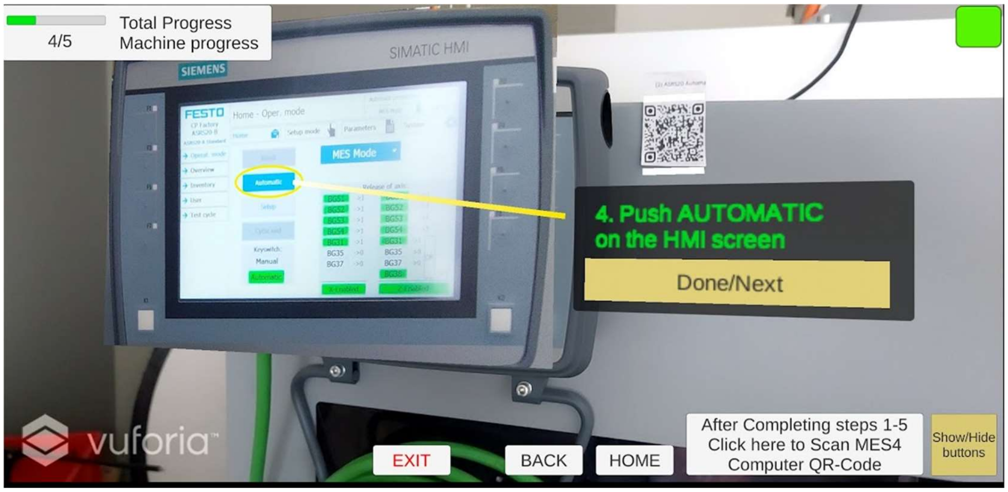


Figure 3.18. AR application ASRS step 4/5

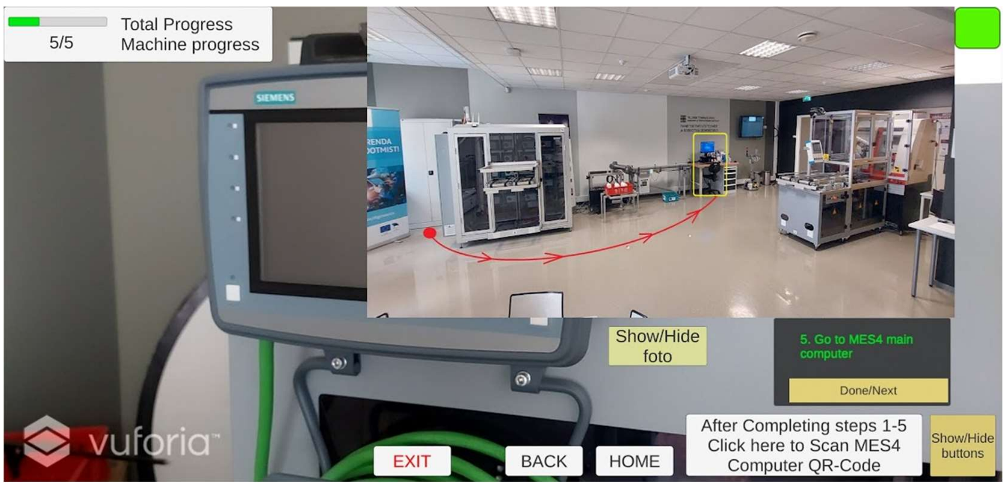


Figure 3.19. AR application ASRS step 5/5

Figure 3.20. AR application MS4 computer step 1/3

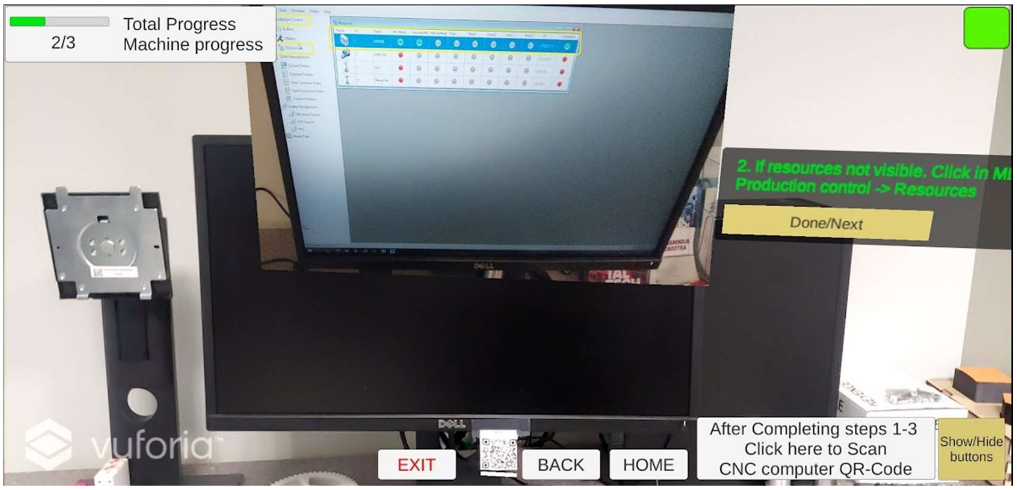


Figure 3.21. AR application MS4 computer step 2/3

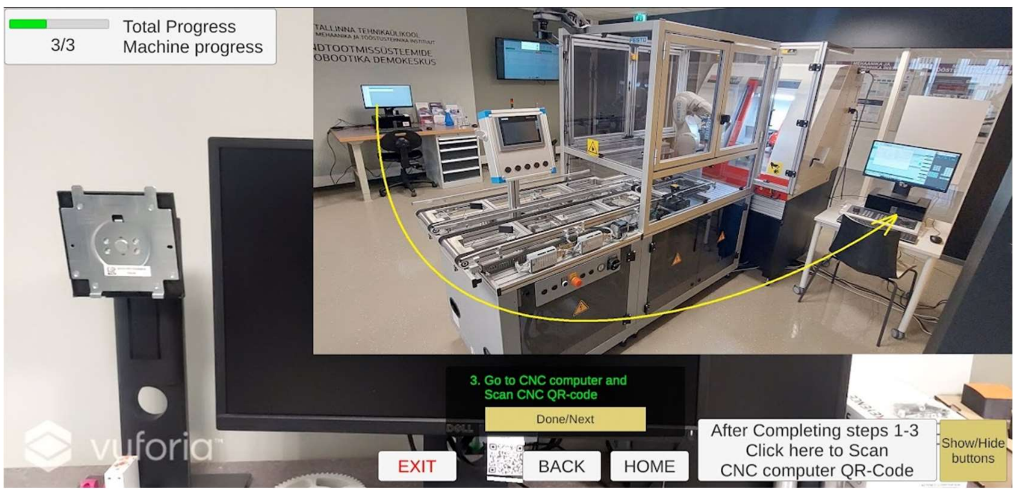


Figure 3.22. AR application MS4 computer step 3/3

In the AR version we can see on the screenshots a lot more information compared to the paper manual version. For every step there is a UI screen updated and the current step is thoroughly explained with the text and photos. Also where possible the arrows are showing the location of the buttons. In the paper manual it can happen that the user skips the row and this will cause problems. In the AR version you have to read the text and after this you tap the button and proceed to the next step. It is possible to hide some buttons in the AR screen which are not necessary but for information. The advantage of the AR application is that it provides simultaneously only a small amount of information, what needs to be done. When operating with a paper manual, the user always has a lot of paper in front of him and the user needs to be very precise in which row he is exactly. It is easy to miss a row. If we push on the screen in the right lower corner the button "Show/Hide buttons", then we can hide from the screen the buttons in the lower area - Exit, Back, Home, "After completing steps 1-3 Click here to Scan

CNC computer QR-Code". The button "Show/Hide buttons" will stay visible and if we push it again the hidden buttons will be visible again.

For generating the QR codes the web page https://qr.io/ was used. There we can choose your favorable shape of the QR code and write the text. Then the web page generates the QR code. When scanning this QR code with a phone camera, it shows the text that was written in the web page when generating the QR code. The QR codes were inserted into the AR program as image targets. When we run the AR program and scan them, then the program will respond accordingly and show the AR program contents. In the developed application five QR codes were used which we can see on Figure 3.23 and 3.24.

MES4 ASRS20(1) ASRS20(2)

Figure 3.23. QR codes

CNC machine CNC Conv. HMI

Figure 3.24. QR codes

Comparing the AR application UI with paper manual.

Let's see how similar or not similar they are. All the steps made by the operator must be the same. For example we take the previous section where the ASRS machine is powered on and we are standing on the side of the ASRS at the HMI. Both versions will start the task explanation from this point. With the paper manual it is a bit more difficult because there is only one picture and we have to understand the HMI functioning better. But with the AR application after every step we complete we push the button, it is done. Then the application shows the next task with the next picture and it should be easier to understand. In Figure 3.14 we can see the paper manual screenshot with explanation. In Figure 3.15, 3.16, 3.17, 3.18, 3.19, 3.20. 3.21 and 3.22 we can see how an AR application displays the same tasks.

3.5 Experimental protocol

In the current experiment we are assessing the efficiency and performance of an AI guidance interface for starting the Festo FMS, making new production orders and shutting down the FMS. The goal is teaching them how to make standard procedures more efficiently - starting FMS, new production order in FMS and shutting down the system.

The experimental protocol consists of two different sessions. One session is where users are using the paper manual and are operating the FMS. The other session is the same but using the Augmented Reality application with a Tablet device.

The users are divided into 2 groups - **Group 1** starts the experiment with a paper manual and **Group 2** starts with the AR application. Further in the thesis we express as Group 1 or Group 2.

The goal of the current experiment is to assess which way is easier, faster and more efficient. Also which way is more user friendly and attractive according to users feedback. 11 users participated in the experiment. The experimental group is composed of users that never operated this system before. The experimental sessions were counterbalanced and users divided into two groups utilizing different guidance to start the system (paper manual or the AR app) From 11 users 5 started the experiment with the AR version and 6 users started with a paper manual.

Before the experiment users were instructed about the following:

- safety measurements
- machines functions and how the FMS works

Additionally before the experiment they were asked to sign an "Informed Consent for Participants" document providing all the necessary information on the experimental protocol. Users filled the Demographic questionnaire.

After the experiment users filled the following questionnaires:

- System Usability Scale(SUS) questionnaire
- NASA Task Load Index(TLX) questionnaire

During the experiment the users were asked to comment whatever they want concerning the task. Think-aloud protocol was used. The information is gathered and is commented on in the summary. For measuring the performance we use the **time** spent on each task and compare both operator guidance versions.

The System Usability Scale (SUS) offers a fast and straightforward, yet reliable, method for assessing usability. It comprises a 10-item questionnaire with five response options ranging from Strongly Agree to Strongly Disagree. Developed by John Brooke in 1986, SUS can be used for different products and services, including hardware, software, mobiles, websites, and applications. According to exploration, a SUS score above 68 is considered above normal, while a score below 68 is considered below normal [47].

The **Nasa Task Load Index (Nasa TLX)** is a diverse procedure which measures different workloads - Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, Frustration. With Nasa TLX we can have the weighted average for all the 6 workloads mentioned above [48].

There has been an update for this calculation - it is to remove the weights. If the weights will be removed, then it is much easier to use the procedure. It is called Raw TLX (RTLX). In multiple studies the Nasa TLX and RTLX are compared. The studies show all possible results in one or another favor. In result you can choose which one you prefer [48].

3.6 Experiment results, feedback and improvement

The following section reports the main experimental results and some analysis of the data.

3.6.1 Performance measurement

The time that was spent to accomplish the given tasks was measured. Below is Table 3.3 with time data. Time was measured when users tested both versions. And in the table is also marked which version was the first one they used.

Table 3.3. Performance data

		Group 1			Group 2		
User ID	**Started with**	**Start**	**New Order**	**Shut Down**	**Start**	**New Order**	**Shut Down**
101	**AR**	00:22:00	00:01:00	0:06:30	0:25:27	00:01:00	0:07:50
102	**Paper**	00:26:30	00:00:50	0:06:35	0:17:17	00:00:37	0:06:30
103	**Paper**	00:26:30	00:00:50	0:06:35	0:17:17	00:00:37	0:06:30
104	**AR**	00:11:40	CNC Robot fail	0:12:30	0:25:53	00:00:59	0:08:02
105	**AR**	00:11:40	CNC Robot fail	0:12:30	0:25:53	00:00:59	0:08:02
106	**Paper**	00:24:38	00:00:46	0:09:29	0:19:55	00:00:42	0:06:13
107	**Paper**	00:24:38	00:00:46	0:09:29	0:19:55	00:00:42	0:06:13
108	**Paper**	00:27:50	00:01:00	0:12:10	00:18:14	00:00:50	0:05:50
109	**Paper**	00:27:50	00:01:00	0:12:10	00:18:14	00:00:50	0:05:50
110	**AR**	00:15:55	CNC Conv fail	-	00:34:22	CNC Conv fail	-
111	**AR**	00:15:55	CNC Conv fail	-	00:34:22	CNC Conv fail	-

We can see that data in Table 3.3 differ significantly from each other. But on average the performance times from tasks is not so huge. The users 110 and 111 did only the

FMS starting with both machines and their performance will not be in the calculations, because during the test there occurred too many errors with the FMS system - the CNC machine HMI did not work anymore. From Table 3.3 above we can also see that the first version that users tested was always slower compared to the second version they used. Because users operated the FMS for the first time, then with the first version they had to learn more about the FMS. And with the second time using the same system but with different manuals (AR or paper), they had learned and were more aware of the system functions. As previously mentioned we divided the users into 2 groups - Group 1 who started with a paper manual and Group 2 who started with AR application. In Table 3.4 we can see the differences in minutes and in percentage.

Table 3.4. Performance measuring. Comparing users who started for the first time the FMS using the paper manual vs. AR application

Task	**Group 1**	**Group 2**	**Difference mm:hh:ss**	**Difference in percentage**
Starting FMS	00:26:19	00:25:44	-00:00:35	-2,22%
New production order	00:00:52	00:00:59	+00:00:07	+14.10%
Shut down FMS	00:09:25	00:07:58	-00:01:27	-15.35%
Total time Start+New Order+Shut down	00:36:36	00:34:42	-00:01:54	-5,21%

As a starting point we take the paper manual. If the time spent operating the FMS with AR application is larger than with a paper manual then the result is displayed as "+" and when users did spend less time with AR application, then it is displayed "-". Table 3.4 shows that starting the FMS system and shutting down the FMS system takes less time with AR application. And the new production order is faster with a paper manual version but only for only 7 seconds. For the total process Starting FMS+New order+Shut Down the FMS takes with AR application 1 minute and 54 seconds less time compared to paper manual - a total of -5,21%. Normally the starting of the FMS and shutting down the FMS should not take place very often during the day. Let's take a look at the production order performance data. This should take place many times during the day. It is 7 seconds slower with AR application. This is a very small difference and as we did see in Table 3.3 always the second time of operating the machine when making the new order is alway more efficient. In total there was better performance with AR application.

3.6.2 System Usability Scale(SUS)

With the SUS we can measure the usability. It allows us to evaluate for the current case study the hardware and software application [50]. The SUS score above a 68 would be considered above average and anything below 68 is below average [46]. In Table 3.5 we compare the SUS scores when operating the FMS. One the left columns are the data from the group who started the experiment with AR application and on the right column are the data for the group who started with the paper manual version.

Table 3.5. Comparing AR application and Paper Manual version SUS scores

	Comparing SUS scores	
Participant ID.	**Group 2**	**Group 1**
101	67.5	
102		57.5
103		75
104	87.5	
105	87.5	
106		50
107		82.5
108		70
109		75
110	72.5	5
111	65	
Average	**76.0**	**68.3**

We can see that there is a difference in results. The higher score of 76 points for Group 2 is a good result and it is higher than in Group 1 with 68.3 points.

They are over 68 points [46], which means that according to SUS they are both above the average and acceptable. But the AR application has an edge over the paper manual in this comparison.

3.6.3 NASA Task Load Index (NASA-TLX)

Below are NASA-TLX Scoring worksheets for both versions Group 2 (Table 3.6) and Group 1 (Table 3.7). In this experiment we are using NASA Raw TLX - without weights.

Table 3.6. NASA-TLX Scoring Worksheet for Group 2

NASA-TLX Scoring Worksheet							
Group 2 scores							
Raw Scores (According to the TLX Scoring Manual)							
User ID	**Mental**	**Physical**	**Temporal**	**Performance**	**Effort**	**Frustration**	**Individual Scores Raw/Unweighted Mean**
101	65	15	45	90	55	20	48.3
102	30	35	30	30	45	50	36.7
103	20	20	10	30	10	20	18.3
104	5	5	5	20	15	15	10.8
105	30	20	30	10	25	10	20.8
106	30	10	30	55	65	55	40.8
107	70	5	50	25	70	85	50.8
108	20	20	30	20	20	25	22.5
109	5	30	45	5	15	5	17.5
110	40	5	15	25	20	30	22.5
111	10	10	10	5	10	20	10.8

From this NASA TLX scoring worksheet Table 3.6 we can see individual scores. Users had very different score levels. Some users had the scores in all sections with low numbers and some users had all scores at higher level. And if we take a look at the individual unweighted mean scores, then it varies in huge numbers from 10,8 to 50,8. Later we compare the group result scores in Table 3.7.

Table 3.7. NASA-TLX Scoring Worksheet for Group 1

NASA-TLX Scoring Worksheet							
Group 1 scores							
Raw Scores (According to the TLX Scoring Manual)							
User ID	**Mental**	**Physical**	**Temporal**	**Performance**	**Effort**	**Frustration**	**Individual Scores Raw/Unweighted Mean**
101	30	10	40	30	35	20	27.5
102	75	35	30	55	55	70	53.33
103	20	15	10	25	10	25	17.5
104	75	5	60	40	80	15	45.83
105	60	25	30	6	25	20	27.5
106	50	10	40	35	80	70	47.5
107	20	5	50	3	5	20	20
108	60	20	55	30	65	80	51.66
109	25	5	60	5	25	5	20.83
110	20	5	15	10	10	30	15
111	5	15	10	5	10	10	9.16

Also in this Nasa TLX scoring worksheet we can see huge number differences in individual scores - from 9,16 to 53,33. It has similarities with Table 3.6. There are users who have higher scores everywhere and users with lower scores in all sections. We can also observe users individually - some of the users prefer paper manuals and some of them prefer AR application.

We take the data from Tables 3.6 and 3.7 and calculate the group overall results. The results are divided into 2 separate groups - one group who started with a paper manual version and another group who started with AR application. The results are presented in Table 3.8.

Table 3.8. NASA-TLX Raw scores Group 1 vs. Group 2

NASA TLX scores comparing Group 1 vs Group 2		
Raw/Unweighted	**Group 1**	**Group 2**
Overall	35.14	22.67
Diagnostic Subscores		
Mental	41.67	30.00
Physical	15.00	11.00
Temporal	40.83	21.00
Performance	28.33	30.00
Effort	40.00	25.00
Frustration	45.00	19.00

The overall score for Group 2 is 22.67 and for Group 1 is 35.14. The result for Group 2 is significantly lower, which means it is less demanding and easier for the user compared w Group 1. Both have low physical demand and the same performance in user opinion. But all other points are showing that the AR application is less demanding to the user.

3.6.4 Feedback from users, issues during testing

During the testing and after the testing users gave the feedback, what could be better or in a different way.

Here are some suggestion from users:

- The android tablet is too heavy
- QR code is lost sometimes, when moving the tablet fast.
- some program step is in a different order in paper manual compared to AR application
- can the application be only with one QR code and application recognises all machine in the room
- more fixed screen information, not AR
- hard to visualize both tablet and the machine at the same time
- more information to AR application when some error occurs are necessary

The Android tablet in the experiment is too heavy. Some users complained that when using the tablet for a long time then the hand will be tired. The tablet did not have any special cover. When using a tablet, then there should be designed a holding handle for the tablet. The cover with a handle should be placed. When the user holds the hand behind the tablet, it will be easier to hold and move the tablet. At the moment there was a standard cover and it was not ergonomic.

QR-Code lost sometimes. The losing of QR code was mostly present when the users moved the tablet too fast or just moved it around. When moving slowly, it helped and the application was stable. The android tablet used in the experiment was with a low price. The camera and the processor speed were on medium level. The application was tested also with a higher quality android phone and the result was better.

Some program steps are in a different order in the paper manual compared to AR application. This was fixed during the experiment.

Can the application be only with one QR code and the application recognises all machines in the room. If we could scan the room with the machines, it would be possible to do so. But this is not the case of this experiment. We are using image targets here.

More fixed screen information, not AR. We are using the QR codes. The AR application will place the information according to qr code location and it moves when we move the tablet device. If we would remove the AR part and leave only the fixed screen information, then it is not an AR application. It would be a digital manual.

Hard to keep an eye tablet and the machine both at the same time. When we are using the AR application then we have to hold the tablet in a certain place to see the AR content. If we hold the tablet in the wrong place, we are not able to see what we have to do. This is the place that can be improved by testing. This was improved during the testing. The QR Code locations are crucial for this.

More information to AR application when some error occurs. In case some error occurs, then it is not explained in the current AR application. For example there was a case, when we could not connect the CNC robot - FMS computer showed a yellow warning dot, that it has problems with a connection. We found out that at this time the battery inside the robot was empty. The AR application could have also error locating section. This would be the next level of this AR application.

3.6.5 AR Application UI improvement

AR application development was developed during a longer period. Many versions were made and tested in real life before testing it with users. Still there were sometimes small updates required. Somewhere the number was missing or text did not fit in the text box.

Some QR code locations were changed for having a better user experience. In some cases there occurred camera focusing issues - this was fixed with additional code. Most of the issues were with first time AR application users. When the users scan the QR code then the application says or shows what they have to do or where they have to go. But when users are moving the tablet fast around the room, then the application loses tracking. Application says that they have to scan the QR code again, but for first-time users it is very confusing. One thing that can improve this tracking issue, is to have better hardware - high quality camera and better processor. I have tried the application with a better android phone and the tracking is better. Also using the Iphone with Lidar sensor can improve the tracking. Overall we can say, the improvement of the UI and using a high quality hardware will significantly improve the user experience. And accordingly the results of the experiment could be improved. For the future when improving the AR application, the error detection is also an important part to be considered. Sometimes errors occur which are not simple to find. If the errors are described in the application then it will be easier to locate and fix these for the user. Other improvements would be the interactive information from the FMS and integration of other tasks. The live data could be obtained from the system and displayed on the tablet screen - orders in progress, how many orders done, how much raw material available in stock (ASRS). The UI design can be improved and further testing is needed.

4. FINANCIAL ANALYSIS

For calculating the cost of the current AR application development we take into consideration two different options. First will be the option where we outsource all project development and the other option would be where the company employee will develop the project. The outsourced version includes all costs in the price. When company workers develop the program, then the Unity program license must be purchased. It is available on a monthly basis. When the company revenue is below 1 000 000$ (928350€), then monthly fee for Unity Pro is 185$ (172€) and when company revenue is above 1 000 000$, then it is 450$ (418€) monthly for Unity Industry.

For the current project development took approximately 180 hours.
This amount of work hours we take as a target in our calculations. First we find out what the hour costs are.
C_O - the hour cost, when outsourcing the project;
C_E - the hour cost of the employee in the company including all taxes;

- **Calculating hour cost when outsourcing.**

The precise hour price when outsourcing the project is not available online. But for the calculation we can take the hour cost similar for IT services. The approximate hour cost in the IT service would be 90€/h([49], [50].
C_O = 90€/hour

- **Calculating hour cost of the company employee.**

According to palgad.ee(04.2024) is the average net salary for an android developer 1467 - 4381€. For calculation we take the medium net salary (1467€+4381€)/2= 2964€

Calculation of the monthly cost for the company:
C_{net} = 2964€/month - net salary
T_p = 2% - pension monthly percentage
T_{UEW} = 1,6% unemployment tax for the worker
T_w = 19,28% income taxes for worker
C_{gr} - gross salary of the worker

Below we calculate the company worker gross salary per month.
$C_{gr} = C_{net} / (1-(T_p + T_{UEW} + T_w)/100)$
$C_{gr} = 2964 / (1-(2 + 1,6 + 19,28)/100) = 3483$€/month
We have a gross salary of 3483€ per month. Further we calculate the total cost for the company in a month and in an hour.

T_{UEC} = 0,8% unemployment tax for the company

T_{SOC} = 33% social taxes

C_{ME} - Total monthly cost for the company

C_E - hour cost of the employee in the company including all taxes;

H_M = 160 hours. Amount of working hours per month.

$C_{ME} = C_{Gr} * (1+(T_{UEC}+T_{SOC})/100)$

C_{ME} = 3483 * (1+(0,8+33)/100) = 5142€

$C_E = C_{ME} / H_M$ = 5142€ / 160h = 32,14 €/h

C_E = 32,14 €/h

- **The cost of application development.**

H - Development time.

H = 180 hours

C_{TE} - total cost in case of company employee

C_{TO} - total cost in case of outsourcing

C_E = 32,14 €/h

C_O = 90€/hour

$C_{TE} = H * C_E$ = 180 x 32,14€ = 5785€

$C_{TO} = H * C_O$ = 180 x 90€ = 16 200€

If we can make this project within 2 months, then the additional fee for the program license is 2x172€ = **344€** In case company revenue is less than 928350€.

C_L = 2 x 172€ = 344€

$C_{TO} - C_{TE} - C_L$ = 16200 - 5785 -344= 10 071€

In case the company has development employees working, then they can save compared to outsourcing **10 071€**. We don't take into consideration the hardware costs, because the hardware is already available and the depreciation of the hardware during this time is marginal.

When developing the AR application the cost using the company employer during 2 months is 5785€+344€=**6129€** and in case it is outsourced, then the cost is **16200€**.

- **Payback period(PBP)**.

In the Case study section we have Table 3.4. There we compare the time data between the AR application and the paper manual version.

We can see that according to current case study there is no noticeable time saving one or other way.

We can not calculate the PBP - it is not a profitable project for the company. There are only additional costs without visible payback time.

There can be non-financial benefits and maybe long-term strategic gains.

SUMMARY

Augmented Reality (AR) is increasingly adopted into our daily life. AR is transforming educational and professional training environments, delivering immersive and interactive experiences. This enhances learning outcomes and the acquisition of skills.

An AR operator guidance application was developed to investigate whether AR offers a more straightforward approach than traditional paper manuals. The AR project was conducted at Taltech on the Festo Flexible Manufacturing System (FMS) which served as the subject of Case Study for this research.
The first chapter provided a brief introduction to augmented reality (AR) and outlines the methodology of the research.

In the second chapter we explored existing literature and theoretical frameworks. We explored the variety of immersive technologies available and highlighted the distinctions between them.

The application was tested against a paper manual on a subject group made of 11 subjects.

In the current experiment we assessed the efficiency and performance of an AR guidance interface compared to ordinary paper manuals. Experiment consisted of two different sessions. One session with an AR application using the tablet and another session using a paper manual. The goal of the current experiment was to assess which way is easier, faster and more efficient. Also which way is more user friendly and attractive according to users feedback.

The test results showed benefits for the AR application. Performance was almost similar but operating the FMS with the AR application had a small advantage over the paper manual version. System Usability Scale (SUS) results showed that AR application version has 11% better result and is more sustainable. Both have the results above 68(76.0 and 68.33) which means both versions are acceptable solutions.
NASA TLX scores for AR application significantly lower results(22,67 vs. 35.14), which means test persons felt less workload when working with AR application.

To summarize, the thesis concludes that there is no financial advantage for developing the current AR application because there will be additional costs and no significant performance improvement.

The final result took mainly into consideration the financial advantage. It depends on the company's strategy - if the company decides to adopt advanced technology and is willing to stay at the forefront of technological innovation. The users, who participated in the experiment were asked, which version they would prefer to use in future at work - most users choose the AR version.

Developed AR application can be improved to be more responsive. The camera and processor of the used hardware is crucial to have better user experience. If the development would continue, we would have even more satisfaction and better performance. The main problem with the AR application is when moving too fast the tablet with low hardware specs, the QR code can be lost and must be scanned again. This confuses first time users.

If a company wants to be on the forefront of technological innovation, then it needs innovative new workers in the company. As mentioned above, most users in the study would like to use AR applications in future working places. This could give the company the edge over other companies to have innovative people to come to work there.

KOKKUVÕTE

Liitreaalsus (AR) on muutunud meie igapäevaelus üha enam levinumaks. Liitreaalsus muudab haridus- ja kutsekoolitus keskkondi, pakkudes kaasahaaravaid ja interaktiivseid kogemusi. See parandab õpitulemusi ja oskuste omandamist.

Käesoleva lõputöö raames loodi liitreaalsuse operaatori juhendamise rakendus, millega uuriti kas liitreaalsus pakub lihtsamat lähenemisviisi kui traditsioonilised paberkujul kasutusjuhendid. Töö viidi läbi Taltechi Festo paindtootmissüsteemil (FMS), mis oli selle uuringu uurimisobjektiks. Esimeses peatükis antakse sissejuhatus litreaalsusest ja kirjeldatakse uuringu metoodikat.

Teises peatükis uurisime olemasolevat kirjandust ja teoreetilisi raamistikke. Käsitlesime erinevaid kaasahaaravaid tehnoloogiaid ja tõime välja nende erinevused.
Liitreaalsusel põhinevat rakendust testiti paber kasutusjuhendi vastu katserühmal, mis koosnes 11 kasutajast. Eksperimendis hinnati liitreaalsusel põhineva juhendi tõhusust ja jõudlust võrreldes tavalise paber kasutusjuhendiga. Katse koosnes kahest erinevast sessioonist. Üks sessioon liitreaalsuse rakendusega tahvelarvutis ja teine sessioon paberkujul kasutusjuhendiga. Praeguse eksperimendi eesmärk oli hinnata, milline viis on lihtsam, kiirem ja tõhusam. Samuti, milline viis on kasutajasõbralikum ja atraktiivsem vastavalt kasutajate tagasisidele.

Testi tulemused näitasid liitreaalsusel põhineva rakenduse eeliseid. Jõudlus oli peaaegu sarnane, kuid paindtootmissüsteemi käivitamine liitreaalsuse rakendusega andis väikese eelise paber kasutusjuhendi versiooni ees. Süsteemi skaala (SUS) tulemused näitasid, et liitreaalsuse rakenduse versioon on 11% efektiivsem ja jätkusuutlikum. Mõlemal juhul olid tulemused üle 68 (76,0 ja 68,33), mis tähendab, et mõlemad versioonid on vastuvõetavad lahendused. NASA TLX skoorid näitasid liitreaalsuse rakenduse jaoks oluliselt madalamaid tulemusi (22,67 vs. 35,14), mis tähendab, et testis osalejad tundsid AR-rakendusega töötades vähem koormust.

Kokkuvõttes võime lõputöös järeldada, et praeguse liitreaalsusel põhineva rakenduse arendamisel pole finantsilist eelist, kuna kaasnevad lisakulud ja olulist jõudluse paranemist ei ole.

Lõplik tulemus arvestas peamiselt finantsilist eelist. Tulemuse tõlgendus sõltub ka ettevõtte strateegiast - kui ettevõte tahab omaks võtta uuendusliku tehnoloogia ja soovib olla tehnoloogilise innovatsiooni esirinnas. Katses osalejatelt küsiti, millist versiooni nad eelistaksid tulevikus töötades kasutada - enamik kasutajaid valis liitreaalsuse versiooni.

Arendatud liitreaalsuse rakendust saab muuta tundlikumaks, et see paremini reageeriks. Kasutatud riistvara kaamera ja protsessor on olulised parema kasutajakogemuse saavutamiseks. Kui arendus jätkuks, saavutaksime veelgi suurema rahulolu ja parema jõudluse.

Liitreaalsuse rakenduse peamine probleem on see, et kui liigutada tahvelarvutit, millel on madalad riistvaralised spetsifikatsioonid, liiga kiiresti, võib rakendus QR-koodi asukoha kaotada ja seda tuleb uuesti skaneerida. See ajab esmakordseid kasutajaid segadusse.

Kui ettevõte soovib olla tehnoloogiliste uuenduste esirinnas, siis vajab ta innovaatilisi uusi töötajaid. Nagu eespool mainitud, soovib enamik uuringus osalejaid tulevikus oma töökohtadel kasutada liitreaalsuse rakendusi. See võiks anda ettevõttele eelise teiste ees, meelitades tööle innovaatilisi inimesi.

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LIST OF FIGURES

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APPENDICES

Appendix 1: Informed Consent for Participants

Participant ID code:

Augmented reality interface and paper manual guidance for starting the Festo Flexible Manufacturing System, making new production order and shutting down the FMS.

PURPOSE OF THE STUDY

Dear participant,

you are being asked to take part in a research study. Before you decide to participate in this study, it is important that you understand why the research is being done and what it will involve. Please read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information.

The purpose of this study is to assess the user experience, usability, and efficiency of augmented reality interface versus paper manual guidance.

EXPERIMENTAL PROCEDURE

During the experiment, you will be asked to start the Festo Flexible Manufacturing System, making new production order and shutting down the Festo FMS.
To fulfill current assignments two versions of guidance will be fulfilled.
One version is to start the Festo FMS using an augmented reality application with a Tablet device and the second version is to make the same procedures according to the provided paper manual.
At the end of each session, you will be required to fill in some questionnaires that will help collect information on the user experience, usability, and efficiency of the specific interaction method.
Before the experiment, we will collect some personal information for demographic assessment and statistical analysis purposes.
All procedures and tasks will be supervised by the investigators involved in the research. The investigators will introduce you to the tasks, hardware and software involved in the experiment.
There are no foreseen risks related to this experimental procedure.
You may ask for more information and additional explanations at any time during the experiment. You may decline to answer any or all questions and you may terminate your involvement at any time if you choose.

CONFIDENTIALITY

Your responses to the questionnaires and all data collected during the study will be anonymous. Every effort will be made by the researcher to preserve your confidentiality including the following:

- Assigning code names/numbers for participants that will be used on all research notes and documents.
- Keeping notes, questionnaires, and any other identifying participant information in a safe personal possession of the researcher.

All collected data will be employed for scientific purposes only including statistical analysis, scientific reports, and publications.

Participants' data will be kept confidential according to the UE 2016/679 regulations.

CONTACT INFORMATION

For any further question please contact:

Kerd Kaarus
Tallinn University of Technology
kkaaru@taltech.ee

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign a consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study. I understand that my identity will be kept anonymous, and that collected data will be kept confidential and used for scientific purposes only.

Participant name and surname ____

Participant signature _______________________________ Date __________

I hereby declare that I have provided the participant with all necessary information about involvement, experimental procedure, risks, purposes of the study, personal data handling, and anonymity. I declare that the participant was provided with a copy of this consent form.

Investigator signature ______________________________ Date __________

Appendix 2: Demographic questionnaire

Participant ID code:

- **Age:____**

- **Gender:**

  Male ☐

  Female ☐

- **Education Level**

  High school ☐

  Bachelor Degree ☐

  Master Degree ☐

  PhD ☐

  Other:………………………………

- **Familiarity with Augmented reality or Virtual reality applications, hardware and controllers.**

I have experience with augmented reality or virtual reality controllers and applications

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

- **How do you evaluate your knowledge about industrial machines and their working main principles**

I have high knowledge about industrial machines

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Participant ID code:

- **Familiarity with gaming consoles and controllers**

I have experience in using gaming consoles and controllers.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

- **Fill the next questions, when completed both experiments - augmented reality and paper manual.**

- **Which version of experiment do you find easier, quicker to learn**

I find easier to use

Augmented reality				Paper manual

- **When starting to work at new workplace or with new machine I would prefer to use**

Augmented reality				Paper manual

Appendix 3 NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

Appendix 4: System Usability Scale (SUS)

PARTICIPANT ID CODE_____________

SESSION Augmented reality / Paper manual

This is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement after completing the task using the specific user interface interaction method.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongl y Agree
1. I think I would like to use this system frequently.					
2. I found the system unnecessarily complex.					
3. I thought the system was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this system were well integrated.					
6. I thought there was too much inconsistency in this system.					
7. I would imagine that most people would learn to use this system very quickly.					
8. I found the system very cumbersome to use.					
9. I felt very confident using the system.					
10. I needed to learn a lot of things before I could get going with this system.					

Appendix 6: Programming in UNITY. Main computer Scenes

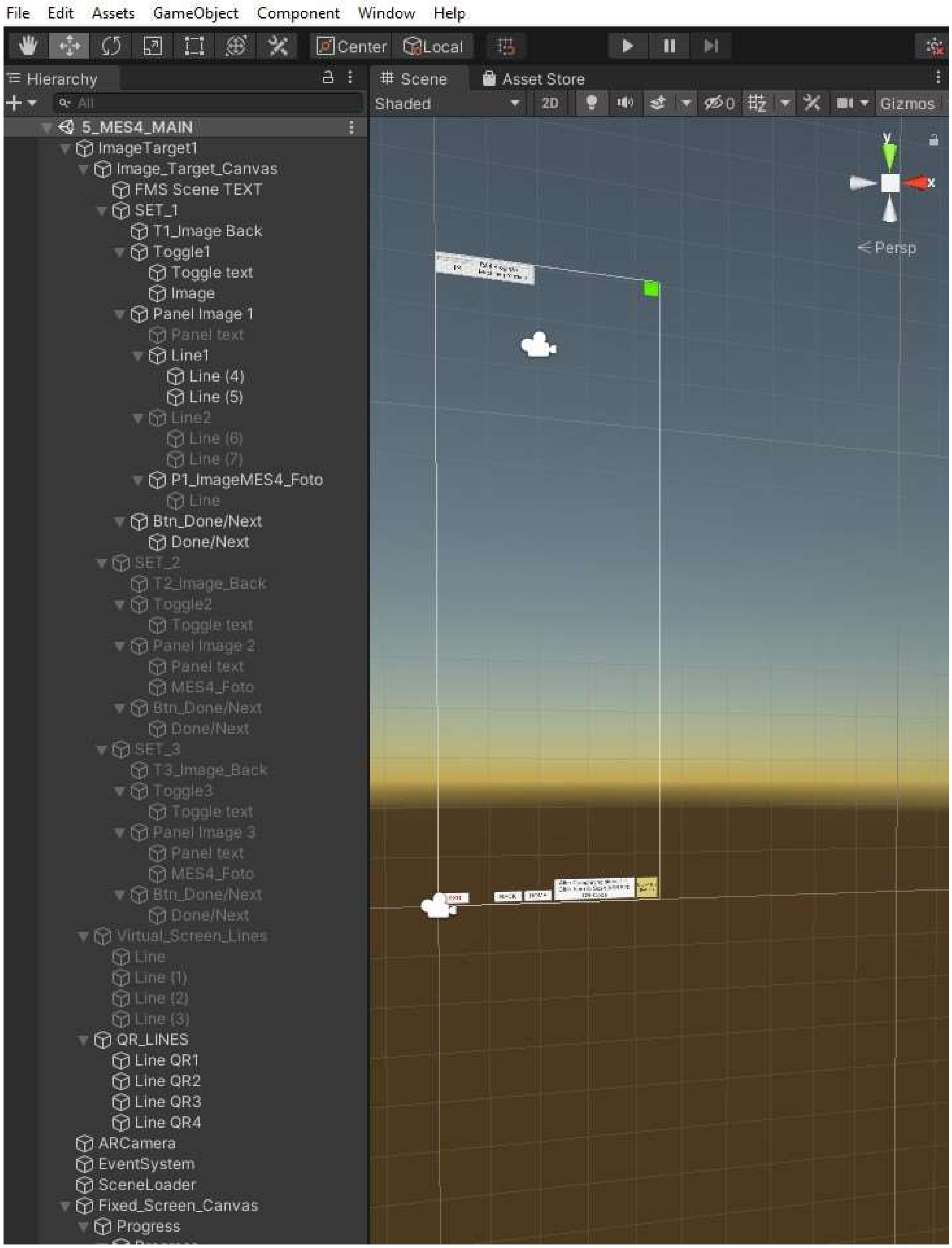

Figure 3.25. FMS Main computer scene

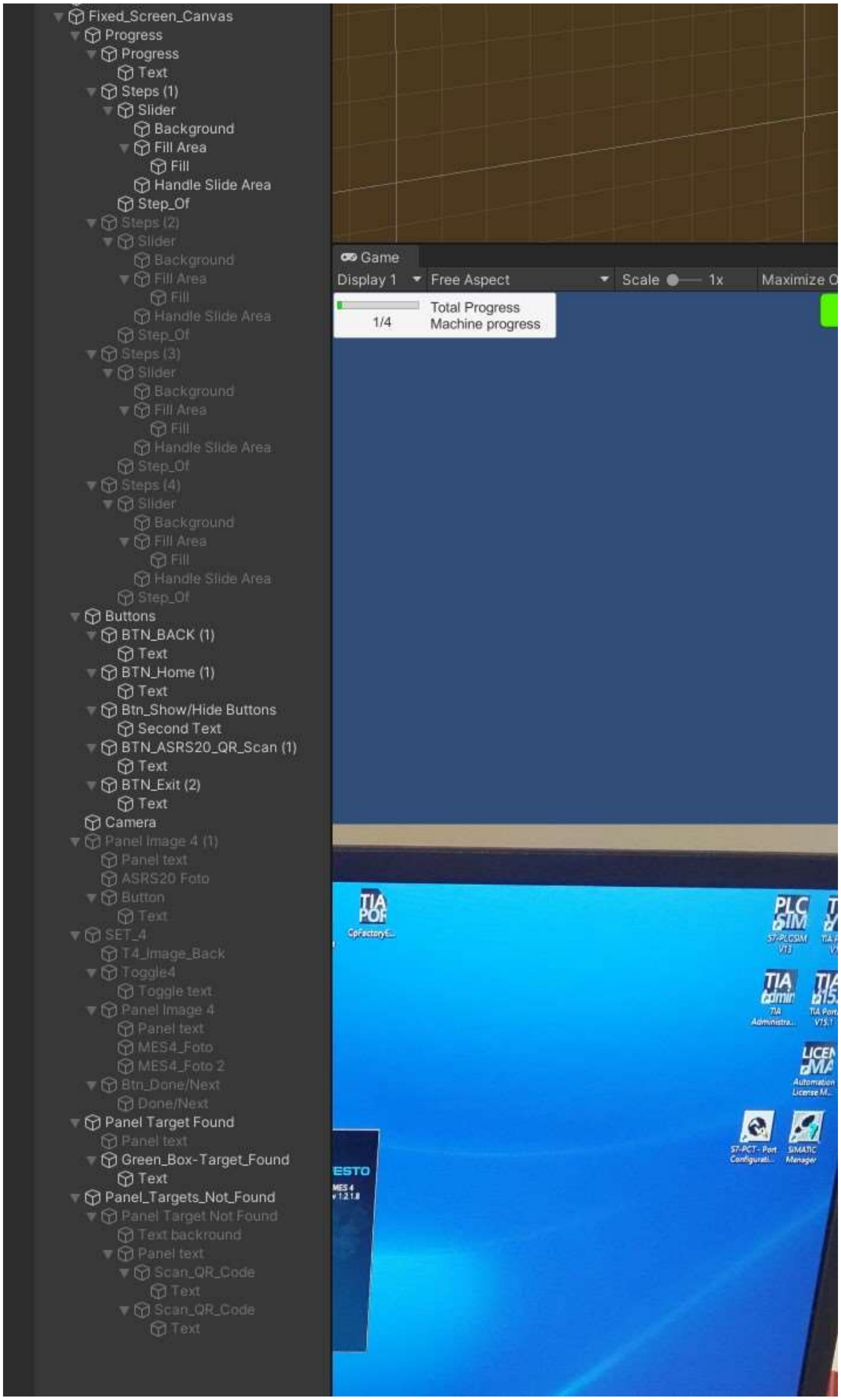

Figure 3.26. FMS Main computer scene 2

Scene Switcher code:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class SceneSwitcher : MonoBehaviour
{
        public void NextScene()
        {
        SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex + 1);
        }
        public void Back()
        {
        SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex - 1);
        }
        public void MainScene()
        {
        SceneManager.LoadScene("1_Main_Scene");
        }
        public void MES4_Computer()
        {
        SceneManager.LoadScene("5_MES4_MAIN");
        }
        public void Maintenance()
        {
        SceneManager.LoadScene("100_Maintenance");
        }
        public void WelcomeScreen()
        {
        SceneManager.LoadScene("0_Welcome Screen");
        }
        public void MaintenanceStatus()
        {
        SceneManager.LoadScene("101_Maintenance");
        }
```

```
        public void Safety()
        {
        SceneManager.LoadScene("2_Safety");
        }
        public void QuitApplication()
        {
        Application.Quit();
        Debug.Log("Quit!");
        }
        public void Starting_Explanation()
        {
        SceneManager.LoadScene("3_Starting_Routine_Explanation");
        }
        public void FMS_Shut_Down2()
        {
        SceneManager.LoadScene("20_FMS_Shut_Down");
        }
        public void FMS_Shut_Down_1()
        {
        SceneManager.LoadScene("19_FMS_Shut_Down");
        }
        public void MES4_New_Prod_Order()
        {
        SceneManager.LoadScene("30_MES4_New_Prod_Order");
        }
        public void CNC_Machine_Original()
        {
        SceneManager.LoadScene("14_CNC_MachineUpdated");
        }
        public void CNC_Machine_Diff_Target()
        {
        SceneManager.LoadScene("14_CNC_Machine_Diff_Target2");
        }
}
```

Camera autofocus Code [

[https://stackoverflow.com/questions/42221422/unity-vuforia-xcode-build-error-undefined-symbols-for-architecture-arm64]

```
using UnityEngine;[]
using System.Collections;
using System.Collections.Generic;
using Vuforia;

public class CameraFocusController : MonoBehaviour
{
	private bool mVuforiaStarted = false;
	void Start()
	{
	VuforiaARController vuforia = VuforiaARController.Instance;
	if (vuforia != null)
	vuforia.RegisterVuforiaStartedCallback(StartAfterVuforia);
	}
	private void StartAfterVuforia()
	{
	mVuforiaStarted = true;
	SetAutofocus();
	}
	void OnApplicationPause(bool pause)
	{
	if (!pause)
	{
	if (mVuforiaStarted)
	{
		SetAutofocus();
	}
	}
	}
	private void SetAutofocus()
	{
	if
(CameraDevice.Instance.SetFocusMode(CameraDevice.FocusMode.FOCUS_MODE_CON
TINUOUSAUTO))
	{
```

```
        Debug.Log("Autofocus set");
        }
        else
        {
        Debug.Log("this device doesn't support auto focus");
        }
        }
}
```

Panel Toggle code:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Panel_Toggle : MonoBehaviour
{
        public GameObject Panel;

        public void OpenPanel()

        {
        if(Panel != null)
        {
        bool isActive = Panel.activeSelf;

        Panel.SetActive(!isActive);
        }
        }
}
```

Panel OFF code

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
```

```
public class Panel_OFF : MonoBehaviour
{
        void Start()
        {
        }
        void Update()
        {
        }
}
```

Scene loader code - Exiting.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class SceneLoader : MonoBehaviour
{

  public void QuitApplication()
   {
   Application.Quit();
   Debug.Log("Quit!");


        }
}
```