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Development of an Augmented-Reality Worker Guidance in Assembly by using Microsoft HoloLens

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Wien, im Mai 2019

Xuefeng Li

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Kurzfassung

Augmented Reality (AR) spielt eine wichtige Rolle in Industrie 4.0 und steht im Mittelpunkt der aktuellen Forschung. Die AR-Technologie hat sich in verschiedenen Anwendungsfeldern entwickelt, darunter Industrie, Medizin und Bildung. Darüber hinaus eignet sich AR besonders für Maschinenmontage- und Wartungsarbeiten. Angesichts der zunehmenden Komplexität von Produktionsprozessen und Produkten müssen die Arbeitnehmer größere Verantwortung übernehmen und strengere Herausforderungen bei der Arbeit bewältigen. Derzeit führen die Experten in der Regel eine persönliche Schulung der Mitarbeiter durch, um sie mit neuen Montageprozessen vertraut zu machen. Leider ist diese Methode zeitaufwendig und teuer. In dieser Masterarbeit wird daher versucht, mithilfe der AR-Technologie eine realistische dreidimensionale Informationsumgebung zu erstellen, um die Effizienz des Montageprozesses zu verbessern und Schulungskosten zu senken. Mit der AR-Technologie können Techniker die Installation und Wartung von Geräten in kurzer Zeit ohne spezielle Erfahrung beherrschen. Daher hat AR ein großes Potenzial in Bezug auf Betriebseffizienz und Betriebszeit. Darüber hinaus gibt es umfangreiche Literatur sowie vergleichende Studien in diesem Bereich. Daher bietet diese Masterarbeit auch einen umfassenden Überblick über AR-basierte Montagestudien mit einem Schwerpunkt auf der Anwendung von AR-Technologie auf Industrie 4.0, wobei AR verwendet wird, um höhere berufliche Anforderungen ohne professionelle Schulung zu erfüllen, und HoloLens-Anwendungen entwickelt werden, um komplexe Montageprozesse durchzuführen. Weiters werden die aktuellen Trends in AR-Anwendungen beschrieben, wobei der Schwerpunkt auf Werkerführung und Schulung der Mitarbeiter liegt. Durch die umfangreiche Literatur wird deutlich, dass AR ein zuverlässiges und effektives Werkzeug ist, mit dessen Hilfe Mitarbeiter ihre Montageanforderungen besser verstehen und erfüllen können. Im praktischen Sinne bietet diese Master-Arbeit eine zuverlässige, intelligente Methode mit verbesserter Anpassungsfähigkeit und eine effektivere Synchronisation gemäß den Anforderungen der Fertigungslinie. Nach Identifikation der Forschungslücke in der bestehenden Forschung wird eine Anwendung entwickelt, mit der die Mitarbeiter Produkt oder Maschine zusammenbauen können. Darüber hinaus werden die Software-Schnittstelle, die Anwendungsrichtlinien und ihre Auswirkungen beschrieben. Abschließend werden die Perspektiven für den Einsatz von AR in der Montage diskutiert. In dieser Masterarbeit wird schließlich versucht, ein AR-immersives System auf der Grundlage der Anforderungen der Mitarbeiter einzurichten und zu entwickeln, mit dem Benutzer eine Verbindung zu einer Datenbank herstellen können, welche Echtzeitinformationen bietet, wodurch die Interaktionen zwischen Software und Mitarbeitern verbessert und die Montage von 3D-Druckern erleichtert wird. Eine solche Software muss flexibel, in Echtzeit aufnahmefähig und in unterschiedlichen Umgebungen einsatzfähig sein.

Abstract

Augmented Reality (AR) plays an important role in Industry 4.0 and is the focus of contemporary research. AR technology has developed in several training fields, including industry, medicine and education. Moreover, AR is particularly suitable for machine assembly and maintenance tasks. Faced with the increasing complexity of production processes and products, workers must assume greater responsibilities and overcome more rigorous challenges at work. Currently, workers usually engage in face-to-face employee training with experts in order to familiarize themselves with new assembly processes. Unfortunately, this method is time-consuming and expensive. Hence, this master's thesis seeks to use AR technology to generate a realistic three-dimensional information environment in order to improve the efficiency of assembly tasks and reduce training costs. With AR technology, technicians can master equipment assembly and servicing in a short time without specialized experience. Hence, AR has great potential in regard of operational efficiency and uptime. In addition, there exist many systematic literatures for comprehensive comparative studies in this area. This master's thesis also provides a comprehensive overview of AR-based assembly studies with a focus on applying AR technology to Industry 4.0, using AR to enable workers to meet higher job requirements without professional training and developing HoloLens applications in order to meet complex assembly requirements. Next, current trends in AR applications are outlined with an emphasis on assembly guidance and worker training. Through the rich literature, it is clear that AR is a reliable and effective tool that can help employees to better understand and meet their assembly needs. In the practical sense, this master's thesis provides a reliable, intelligent method with enhanced adaptability and more effective synchronization according to production line requirements. After analyzing the shortcomings in the existing research, an application is developed which can help workers to assemble products. Moreover, the software interface, usage guidelines and its effects are outlined. Finally, the prospects for the use of AR in assembly technology are discussed. Ultimately, this paper seeks to establish and develop an AR immersive system based on worker requirements whereby users can connect to a database offering real-time information, thereby enhancing software-worker interactions and facilitating 3D printer assembly. Such software must be flexible, real-time, recordable and adaptable to different environments.

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1 Introduction

1.1 Initial Situation

This master thesis is dedicated to the development of software that guides the worker step by step through the assembly process. This thesis identifies the needs of software development, analyzes the current situation and problem, conceived the concept of software design. Finally, a software to solve this problem using the Microsoft HoloLens is developed.

Industry 4.0 refers to the fourth revolution taking place in manufacturing. From the first industrial revolution (mechanization through water and steam power) to the mass production and assembly lines based on electricity in the second, the fourth industrial revolution builds on the foundations of the third that started with the adoption of computers and automation by incorporating smart and autonomous systems fueled by data and machine learning.[1] With the introduction of Industry 4.0, the concept of smart factories is beginning to emerge. Smart factories are set to create responsive, adaptive and connected manufacturing.[2] The introduction of new technologies, such as big data, automation and Augmented Reality (AR), impacts traditional workflows and methods. Moreover, this offers great potential for increasing efficiency and accuracy. The German Industry 4.0 strategy describes this in more detail as the integrated Cyber Physical System (CPS), which closely connects the physical real world through the Internet of Things and applies the advanced computing power of cyberspace to the real world so as to realize the "smart factory".[3] "Industry 4.0 enables ubiquitous sensors, embedded terminal systems, intelligent control systems and communication facilities to form an intelligent network within the CPS."[4]

AR plays an important role in smart factories. The "smart factory" is a key component of future intelligent infrastructure, the focus of which is on intelligent manufacturing systems and processes as well as the implementation of networked distributed production facilities.[5] AR realizes 3D information visualization, thus rendering information more intuitive to show mechanical equipment assembly and maintenance techniques. Workers wearing head-mounted AR glasses can easily obtain information about the required assembly, thereby improving worker productivity.

[1] https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/ (16.12.2018)
[2] https://www2.deloitte.com/insights/us/en/focus/industry-4-0/smart-factory-connected-manufacturing.html (16.12.2018)
[3] https://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Industrie-4-0/Industrie-4-0/industrie-4-0-what-is-it.html (16.12.2018)
[4] Zhou, Liu, & Zhou, 2015, p. 2148
[5] Zhou, Liu, & Zhou, 2015, p. 2148

Furthermore, technicians can quickly understand how to disassemble, proactively service and repair faulty devices in record time without prior experience with a device. This highlights the potential that AR has in operational efficiency and uptime.[6]

This thesis has the following objectives:

- Study the relevant literature on worker guidance and AR
- Conduct state-of-the-art research on existing solutions
- Derive the requirements
- Develop the general and fine concept
- Develop and program the worker guidance for AR
- Document the process

1.2 Problem Statement

Due to the diversity of product customization, there is an increasing number of product variants. Because different types of products are assembled in different ways, workers must possess adequate product assembly knowledge. At present, existing manufacturing enterprises' level of informatization requires improvement to smoothly transform manufacturing enterprises into individualized production.

Varied and customizable production has increased the need for information during product assembly. Factories contain more and more digital tools based on Information and communications technology (ICT).[7] The most advanced component identifies the specific requirements for modern worker management and considers current information and communication systems. With the systematic consideration of existing systems, no system can fully meet such requirements. In addition, previous standard systems were often only used in conjunction with complex and expensive system landscapes. These vulnerabilities are analyzed, evaluated and applied as the basis for developing a target demand profile.

As processes and products grow in complexity, each assembly faces greater responsibility and more demanding challenges. The most commonly used method at present is for experts to provide face-to-face employee training to workers so that they understand the new assembly procedure. Unfortunately, this method is time-consuming and expensive because it requires an available expert. Another common technique involves workers using screens to obtain information. This thesis uses AR technology, through which a realistic 3D information environment can be generated, thus improving the efficiency of assembly tasks. At present, there is no structured

[6] http://www.aberdeenessentials.com/opspro-essentials/augmented-reality-energizes-smart-manufacturing/ (09.12.2018)
[7] Mohamed Anis Dhuieb, 2013, p. 501

literature available for conducting a comprehensive comparative study in this field. Hence, this thesis seeks to provide a comprehensive overview of AR-based assembly studies.

1.3 Research Question

In the TU Wien Pilot Factory Industry 4.0, workers assemble various 3D printer models. Most assembly tasks must be done manually or semi-manually. Therefore, the traditional flow line production is no longer applicable. However, individual processing requires advanced worker skills and proficiency. Thus, in TU Wien Pilot Factory Industry 4.0, AR technology (such as Microsoft HoloLens) must be introduced. Thus, the first research question is:

1. How will AR technology be integrated in Industry 4.0?

The use of AR can help workers to complete complex and varied processes. AR technology can help to resolve difficulties, improve efficiency and reduce costs. Moreover, AR technology is set to become a key technology for industrial upgrading. In fact, many applications have been demonstrated in science fiction, but real-world AR technology needs refinement. Some technical difficulties must be conquered. At present, this process is accelerating. Hence, the next question is:

2. How can AR be used in such a way as to enable these workers to meet higher job requirements without professional training?

AR has great potential in industrial manufacturing, not just maintenance. Flexible production is the core proposition of Industry 4.0, which requires constant operation at high speed as well as the reduction of operation costs.[8] When choosing AR as a solution, one can use images, sounds, animations and texts to present information to workers. Thus, the next research question emerges:

3. How can the HoloLens App be developed such that it meets the requirements of complex assembly, such as in the personalized assembly of 3D printers?

1.4 Research Objectives

The purpose of this thesis is to build and develop an AR immersive system based on worker's requirements, while also connecting databases, providing real-time information, and enhancing software and worker interactions to assist workers in installing 3D printers. This system has the following advantages:

[8] http://files.messe.de/abstracts/68353_Mitsubishi_Electric_Puetz.pdf (14.11.2018)

- The system is mobile (with Microsoft HoloLens) rather than being assigned to a specific workstation or employee.
- It is further developed using open source technology and is designed to be independent of other Product-Lifecycle-Management (PLM) solutions.
- It informs staff of the sequence and provides visual support for the work steps to be performed using animations.
- It is capable of measuring and analyzing the time required for work feedback, thus allowing the likelihood of improvement to be determined.
- It allows data to be created using pre-existing and industry-proven work preparation software.
- It enables employees to display 3D model as needed.
- The system is flexible, such that workers can call up different assembly methods depending on the model.
- The system works in real time, thus allowing workers to retrieve data quickly through HoloLens.
- The system is recordable as the relevant assembly information is transmitted back to the server after completion.
- The system is very interactive with menu options allowing workers to control the assembly process and dispense with unnecessary information.
- The system is very adaptable as workers wearing Microsoft HoloLens can work in many different environments, including noisy environment thanks to the option to use gesture control instead of sound control.

Finally, an assessment is conducted with the help of a user questionnaire. After determining whether the requirements have been met, user's suggestions are used to identify areas for improvement.

The following four goals must be achieved: Define the requirements, outline and explain the design, demonstrate functionality and evaluate the developed solution.

Defining the requirements

After these issues have been raised, the following objectives must be achieved:

After receiving the task of developing Microsoft HoloLens App, the specific requirements of the project must be determined. Through the interaction of workers and HoloLens glasses, the accuracy and efficiency of workers in installing 3D printers can be improved. Programming requires the use of unity 3D [9] to achieve the script based on c#. Because different printers have their own assembly methods, MySQL is

[9] Unity, also known as Unity 3D, is a multi-platform, integrated game development tool developed by Unity Technologies that allows players to easily create interactive content such as 3D video games, architectural visualizations and real-time 3D animation.

needed to create a database and use sockets for data transmission.

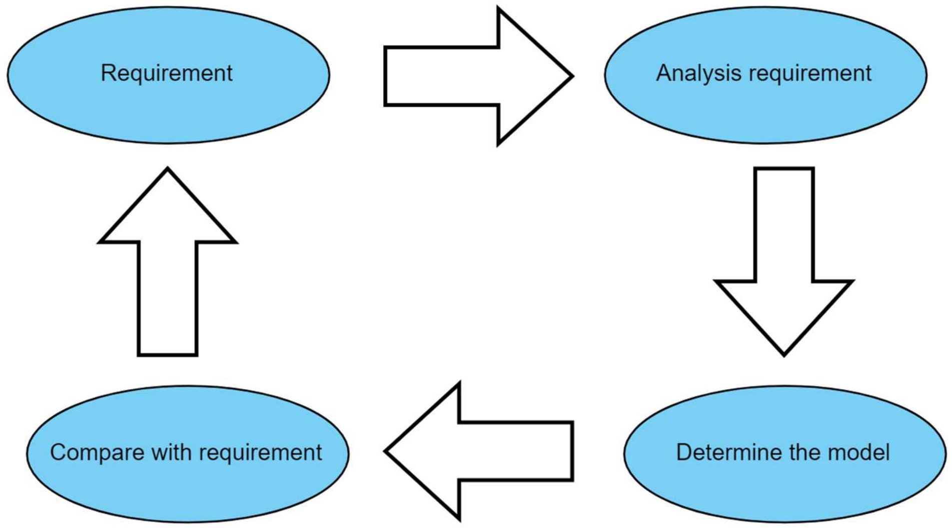

Figure 1: Defining the requirements[10]

Outlining and explaining the design

The Microsoft HoloLens software design is completed in two steps:

First, an outline design is produced, which translates the App requirements into the data structure and software system structure. With reference to industry standards and their own actual situation, workers can choose the template of the outline design. This project suggests applying templates when writing design documents, but these need not be limited to the template format. Through the outline design, the general system architecture and the relationship between components are planned.

Next, a detailed design is produced. Through the refinement of the structure representation, the detailed data structure and App algorithm are retrieved. The detailed design describes the key algorithms, specific design ideas, database design, human-computer interaction details, interface style, font size and more.

Demonstrating functionality

The program supports three kinds of control methods, which are divided into head movement control, gesture control and voice control. When wearing Microsoft HoloLens, after running the program, the worker sees a cursor in front of their eyes. Through HoloLens, the worker sees a world in which unity 3D modeling is integrated with a realistic 3D printer as supported by HoloLens' depth camera support based on gesture control. Through voice control, WIFI is used to call the appropriate assembly

[10] https://medium.com/omarelgabrys-blog/software-engineering-software-process-and-software-process-models-part-2-4a9d06213fdc (14.11.2018)

method from the database and install it step by step according to Microsoft HoloLens prompts. After assembly is complete, the results are fed back to the database.

Evaluating the developed solution

It is necessary to verify that the design meets the requirements of the analysis model and that all the implied task requirements are fulfilled. Next, program legibility and understandability must be considered. Other programmers must be able to read the code. A complete picture of the software is provided, including data, functions and behavioral domains seen from an implementation perspective. The program should be modular so that the software is logically divided into components that perform specific functions and subfunctions. The data, architecture, interfaces and components of the program must be clearly represented.

1.5 Methodology and Procedure

This thesis examines the current state of AR- assembly worker guidance system, identifies the limitations of existing AR- assembly worker guidance system and develops a complete Microsoft HoloLens App to assist workers during assembly. In this section, the organization and process of the thesis are presented, followed by the process of software development.

The following table summarizes the contents, goals and methods used in each chapter of this thesis:

Chapter	Content	Goal	Methodology
1	Topic introduction: AR- assembly worker guidance system	Describe the initial situation state the problem and identify the research questions and goal of the work	Literature and internet research
2	Theoretical basis of AR and software development	Outline the theoretical basis of AR and choose the software development model accordingly	Literature, research and the waterfall model
3	Analysis state-of-the-art of AR	Study the status of AR-assembly worker guidance system and identify any defects	Literature and research
4	The author's approach to concept design	Develop a concept and provide an overview of the system	Brainstorming and concept creation
5	Software implementation	Develop the Microsoft HoloLens App and SWOT[11]-Analysis	Software development
6	Critical appreciation and outlook	Provide a critical appreciation and outline future developments	Evaluate the results and research

Table 1: Methodologies and Procedures

Chapter 1:

The introduction of AR technology through the concept of Industry 4.0 demonstrates the application of AR technology in contemporary industry. AR- assembly worker guidance system are an important component worthy of industrial application. Furthermore, the problem statement is proposed, and the ease of AR- assembly worker guidance system compared to traditional assembly is examined. Based on the problem statement three research questions are created. In using the App to solve the problem of AR- assembly worker guidance system, the research objectives and goals are proposed.

Chapter 2:

The process of literature research is described. This chapter, through its in-depth literature review based predominantly on reputable journals and books, starts with the concept of Industry 4.0 and extends to cover the application of AR technology in Industry 4.0. Next, the scope is further narrowed to focus on the use of AR technology in production assembly. Then, the current situation of assembly line workers using AR technology is described. This chapter provides a theoretical basis

[11] Strengths, Weaknesses, Opportunities and Threats

for AR technology and its suitability to complex tasks in assembly lines, especially those with high-demand and high flexibility. Then, Microsoft HoloLens and some other types of Head-Mounted Display (HMD) devices are described in detail. Finally, different Software developing model and advantages of Waterfall model in developing AR- assembly worker guidance system software are discussed.

Chapter 3:

This chapter outlines the current research status and trends in AR applications. Moreover, the existing research results are comparatively studied, and relevant background information is provided to the study participants. Moreover, the results of the study are evaluated, including its suitability for AR design guide assembly and maintenance training tasks. The focus of this chapter is on AR technical assistance worker training and assembly guidance. This is achieved through the development of an assembly tool based on Microsoft HoloLens. Finally, based on the current research status, the limitations facing the most advanced AR applications are clarified. Applications for various industries are of importance to assembly lines in Industry 4.0.

Chapter 4:

Based on the theoretical basis of Chapter 2 and the current research limitations of Section 3, the solution to the problem is proposed. Moreover, the development environment and programming language to be used are identified. Next, the APIs to be used are determined and an overall problem-solving framework is proposed. Finally, the objects, processes, and steps of software development are proposed.

Chapter 5:

This chapter predominantly describes the process of software development, specifically its implementation. Next, the programming process is described and important code for implementing interactive features is shown alongside screenshots. Furthermore, the system development of information storage and transmission through the Web server is shown. The user interface and all software features are explained. Finally, Through the SWOT-Analysis, the advantages and disadvantages of the software are analyzed, and some suggestions are made, how to improve it.

Chapter 6:

This section evaluates the results of software development and looks ahead to the future development of AR technology and assembly worker guidance system.

2 Theoretical Basics

This chapter provides a hands-on view of the current literature on the modern assembly lines in an Industry 4.0 environment to build a case for the emergence of the use of AR for worker guidance in assembly lines. A view is provided on how the modern assembly line get useful data and why there is a requirement of completely new tools for workers to adopt and understand the information.

Based on the assembly line requirements a review of literature about AR is presented, which shows AR is an appropriate tool for satisfying the high demand and variability of complex tasks in assembly lines. A case of Microsoft HoloLens is promulgated as a reliable and efficient AR tool which can enable the workers to better understand the assembly requirements and adopt to them on the spot. Several published articles in reputable journals, working papers and product specification documents are analyzed to interpret the enabling technology of Microsoft HoloLens and its potential in assisting the workers on the assembly lines in complex tasks.

In this regard, this thesis provides a reliable and intelligent way of empowering the assembly line workers for better adaptability and efficient synchronization with the assembly line requirements. Content analysis technique is utilized for the in-depth review of literature, the sources of information include reputable publication journals and books as well as secondary data to fully capture the current scenarios and requirements of assembly lines and the potential of AR for worker guidance.

2.1 Industry 4.0

The new CPS being increasingly deployed in the production facilities have given way too much more complex assembly lines where processes must be reinvigorated and changed according to the designs rigorously.[12] In such situation fast adaptability is required from the assembly line work force which must work in conjunction with intelligent robots and assembly requirements.[13] Either the production facility is automated or semi-automated, assembly line workers are required to collaborate with robots on the assembly lines. Hence, the task becomes much more complex and confusing when product variability is high. This requires the assembly workers to quickly understand and respond to the assembly tasks. However, with the traditional ways of instructions and guidance workers are unable to adapt to perform their jobs efficiently.[14]

[12] Hirsch-Kreinsen, 2016, p. 2
[13] Krueger, Lien, & Verl, 2009, p. 628
[14] Schwald & Laval, 2003

CPS are used to fully digitize the manufacturing facilities which enable complete end-to-end cross linking between inter and intra enterprise subsystems in a decentralized and self-organized structure.[15] The control and automation are made possible using a perception layer integrated to the cloud infrastructure. The perception layer includes much of sensors and actuators targeted to collect information and use the collected data to automate processes.[16] The cyber physical systems exchange real time data streams through cloud enabled virtual networks such as IoT hubs[17], integrated with real time processing capabilities of cloud allows the systems to make intelligent decision in parallel with general operations. Furthermore, the CPS utilize human-machine-interface infrastructure to gather input from operators in a manufacturing facility.[18] These clouds enabled infrastructures allow for enough processing power for the cyber physical systems to integrate big data through deep analytics to make truly smart decision by anticipating future occurrences and preparing the systems accordingly. The integration of big data allows machine learning and intelligence which can foster better decision making by considering a many of factors for optimization and efficiency of the systems.[19] Research shows, Industry 4.0 has the character of a “promising technology” based on the premise that advances in digital technologies will bring about new and positive technological, economic and social advantages.[20]

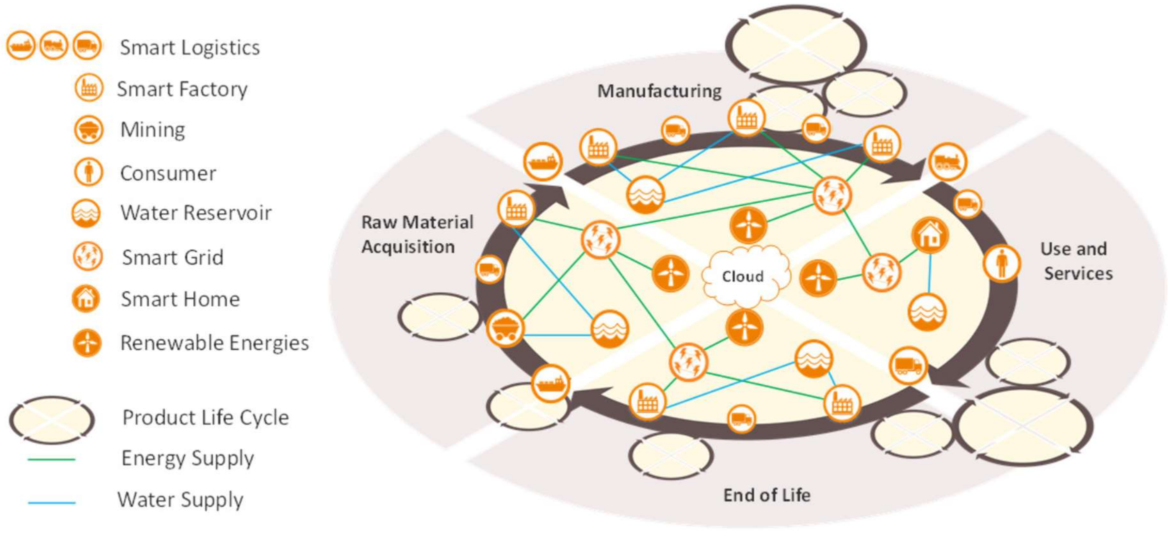

Figure 2: A demonstration of interlinking between value chains in the macro perspective of industry 4.0[21]

[15] Barthelmey, Störkle, Kuhlenkötter, & Deuse, 2014
[16] Bilal, 2017, p. 5
[17] IoT Hub is a managed service, hosted in the cloud, that acts as a central message hub for bi-directional communication between your IoT application and the devices it manages.
[18] Hirsch-Kreinsen, 2016, p. 2
[19] Kagermann, Wahlster, & Helbig, 2013, p. 56
[20] Hirsch-Kreinsen, 2016, p. 2
[21] Stock & Seliger, 2016, p. 537

The macro perspective of Industry 4.0 uses the big data to make intelligent decisions. Because flow of information across value chains are tremendous, it enables acquisition of huge quantities of data in a smart factory by using cloud processing powers aided with in house servers, in order to perform accurate prediction and change the processes accordingly.[22,23] Such decision making using big data analytics is applied throughout the product lifecycle in an industry 4.0 system; hence, enabling the smart factories and smart products to self-monitor, self-organize and self-learn during the lifecycle using the cyber physical systems.

As a product passes through the integrated processes controlled at the final stage it contains comprehensive information about the processes and equipment utilized for its production.[24] Smart logistic systems similarly allow for the intelligent and informed flow of material between different entities within the supply chain, which is also, enabled through cyber physical systems. The big data allows the decentralized cyber physical systems to make precise estimations about the amount of a material required for operation in advance which further increase the efficiency of processes at every stage of manufacturing. Similarly, a smart grid system is utilized to intelligently predict electricity requirements throughout the product life cycle.[25]

22 Tang, Herrema, & Romero, 2003
23 http://www.sdil.de/de/ (05.11.2018)
24 Stock & Seliger, 2016, p. 537
25 Richardson, 2016

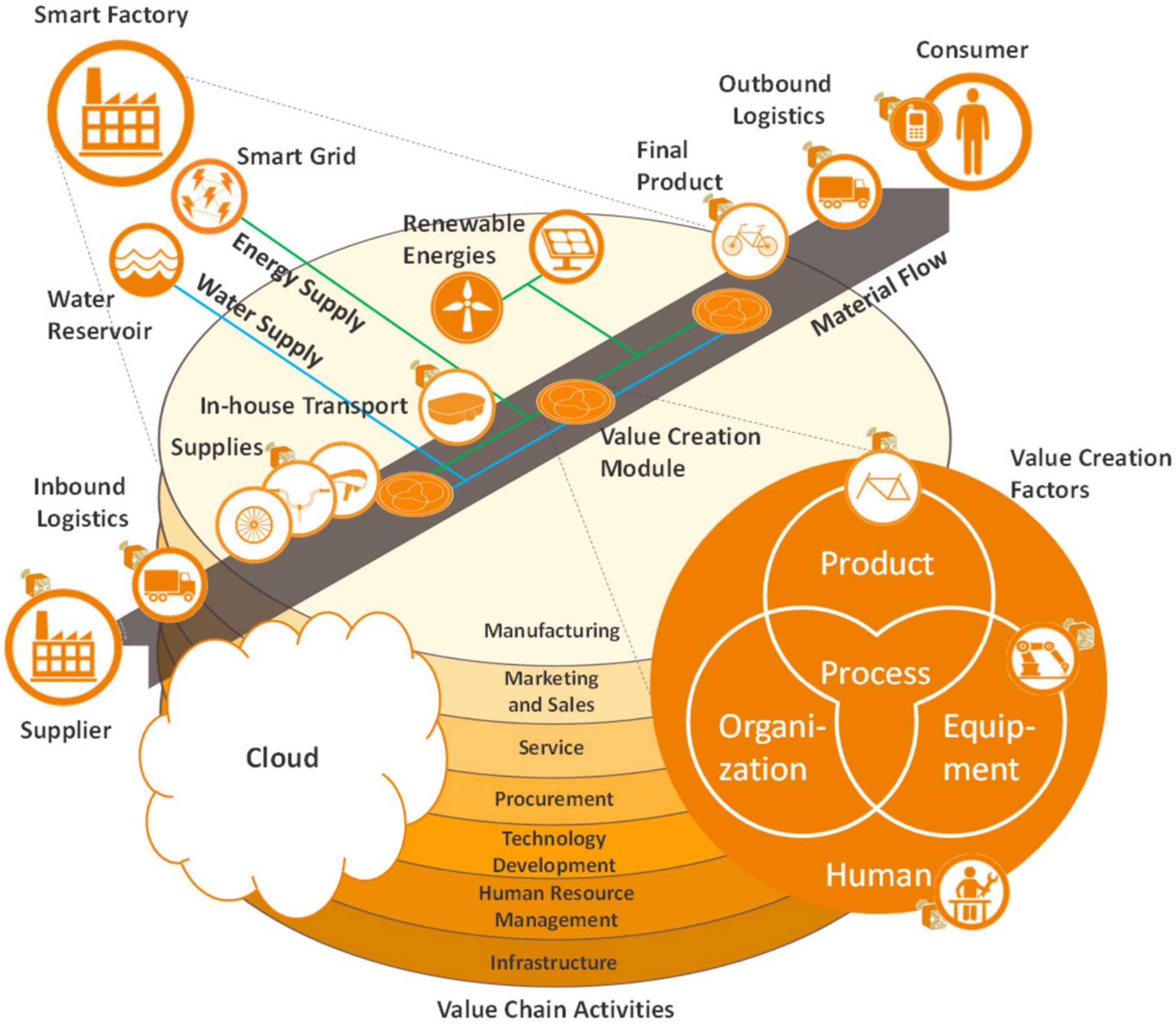

Figure 3: The value creation modules flow within the perspectives of industry 4.0[26]

As it can be extrapolated from the figure above in industry 4.0 environment all the systems involved in manufacturing and delivery are integrated and information is constantly flowing for better efficiency and predictability in the chain. In this context the assembly line workers require more information to handle the requirements of the assembly accordingly such that they can understand the requirements with more precision and can add value effectively.[27] As the AR tools allow for the real time in-situ data modelling, the information in the assembly line and all other manufacturing processes can be understood without the requirement of referring to long notes and specifications. Hence, in an industry 4.0 environment using AR technology present greater benefits and can enable the maximum efficiency to be achieved through understanding of cyber-physical systems.

[26] Stock & Seliger, 2016, p. 538

[27] https://www.bcg.com/de-at/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx (15.11.2018)

2.2 Augmented Reality

AR is a term first defined by Thomas Caudell, a researcher at Boeing Company, in 1990.[28] It mainly refers to three-dimensional space or physical reality.

AR is a technology that enhances the user's ability to see, feel and hear. In general, AR applications involve the visualization of virtual objects, superimposed in the real world, and supplement the real world with useful information.[29] A layer of computer-generated assistant information technology is superimposed on the world. Because AR technology integrates multimedia, audio, video, three-dimensional (3D), animation, and other technologies, it can "stick" a real object with a layer of key information for interpreting or displaying the operation or indicating the relative position of the object.

From the perspective of computer software design and development, AR technology is a technology that uses computer technology as the core, comprehensively uses various new technologies, integrates sight, sound, and touch to imitate the reality of three-dimensional space reproduction. It involves Aerospace, education, medical treatment training, industry and other fields, which will be described in detail in Chapter 3.3.

The appearance of the virtual objects displayed in the AR application and their postures and positions can be based on the reference marks recorded by the camera, which operate as position reference points.[30] The tag may consist of a picture or pattern recognized by a specific AR application, such as a Quick Response Code (QR code) or a barcode.[31] The following table shows several features of the AR technology and its concepts:

Target Recognition	Use the AR glasses camera to detect and confirm the target object and track its position. Analyze the distance between the AR user's current position and the target object.
Information Gain and Display	The system will interact with people through voice, gestures and other interactions and display them in front of AR users.
Processing, sensing and scanning	The AR device can track the user's movements and positions, thereby quickly performing a 3D scan of the wearer's environment.

Table 2: AR concepts

[28] https://whatis.techtarget.com/definition/augmented-reality-AR (29.11.2018)
[29] Francisco Ramos, 2018, p. 2
[30] Kan, Teng, & Chou, 2009
[31] Kan, Teng, & Chou, 2009

The AR application in assembly can still be summed by the following conclusion by Billinghurst:
"Researchers in the field have made tremendous advances since the 1960's, but in many ways the full potential of Augmented Reality is still to be realized". [32]

The emergence and the speculated takeoff of Augmented Reality AR usage and application can be extrapolated from the recent industrial trends: AR is forecasted to reach $80 billion in market revenue by 2021 by various sources.[33] This is the reason why the giants such as Google, Apple and Microsoft are investing heavily into the technology and its enhancements. Such serious commitments from investors and entrepreneurs project that in near future the technology of AR will further mature and will be integrated in various industrial operations, to increase effectiveness and efficiency.[34] AR represents a revolutionary technology which allows any display to be spatially overlaid by 3D content using various image capturing and content generation tools. Hence, complex information and computer-generated models can be interpreted in real time as an interactive overlay over live vision. The information conveyed by the virtual objects helps a user perform real-world tasks.[35] As the user changes his perspective on the workpiece, the graphical indicator appears to stay in the same physical location.[36] From industrial applications to computer gaming this technology has transcended to reinvigorate the way information is interpreted and used in operations. AR has been specifically proven unprecedented benefits to manufacturing and assembly such as leading to shorter lead-time, reduced cost and improved quality.[37] A review of literature in AR for assembly shows that a guidance mechanism can be achieved for accurately positioning the assembly parts without the need of intensive training of the workers-which essentially is one of the biggest bottleneck in enabling product customization.[38] This has further advantages in assemblies where due to increased complexity workers cannot keep pace in learning to efficiently handle different assembly parts. As AR provides interactive interpretation of information in various forms (signifiers, 3D models, visual feedback and animations) alongside a 3D vision in real time the need for understanding and reading detailed instructions can be eliminated.[39]
A conceptual precedence can be set for this chapter by the review of the following conclusion drawn in a recent study by Hoover:

[32] Billinghurst, Clark, & Lee, 2015, p. 237
[33] https://www.thevrara.com/blog2/2017/12/5/ar-amp-vr-revenues-to-reach-79-billion-by-2021-new-report (15.11.2018)
[34] Evans, Miller, Pena, MacAllister, & Winer, 2017, p. 3
[35] Azuma, 1997, p. 3
[36] Caudell & Mizell, 1992, p. 660
[37] S. K. Ong, 2008, p. 2708
[38] Nee, 2013, p. 1312
[39] Wang, 2016

“This research shows that AR guided assembly instructions presented via a modern optical see-through HMD, like the Microsoft HoloLens, can be better alternative than tablet AR instructions (and traditional 2D instructions) for large-scale assembly tasks, especially when mobility is important to the assembly process. This is because the use of HMD instructions, as opposed to Tablet AR and 2D methods, can reduce assembly times while maintaining, and in some cases, improving assembly accuracy.”[40]

Regards of the advancements in the application of AR in assembly and manufacturing, the delivery methods employed previously have somewhat restricted the technology in bringing its full potential to realization. Literature study on the domain represent that much of the work conducted was entirely for research purposes and it lacked much applicability or testing in commercial use scenarios. The applications which were built were not tested for their effectiveness or were not supposed to capture the need for industry 4.0 assembly line.[41] Due to technological constraints most of the AR based research and application has been restricted to usage of individual tools such as mobile phones or bulky HMDs. There is a lack of a comprehensive assembly management system based on AR integrating all the available state of the art tools and techniques. It was further noted that much of the available AR assembly solutions does not allow for hands free operations which impedes the efficiency which can be achieved if the user is free to interact with the physical world. Such techniques do not allow the user to scan the information and interact with the physical world at the same time, which influence the efficiency of movement as well as the pace of understanding.[42] This issue can be addressed effectively if the recent advancements in computing power and display technologies is utilized to their maximum capabilities all at once in a singular AR assembly application. In order to overcome the constraints distilled in the previous applications of AR in this thesis the utilization of hands free Head Mounted Displays (HMDs) which are designed to integrate large streams of data alongside shall be focused on; this can be potentiated as the likes of Microsoft HoloLens, Smart helmet by DAQRI, Meta 2, Magic Leap, and Google Glass 2.0 are becoming commercially available and have the processing power and technology which if used effectively can work wonders for the assembly and manufacturing industry.[43,44] If realized to its full potential the assembly workers can be potentiated to keep pace with the changing requirements as well as achieve maximum efficiency.

40 Hoover, 2018, p. 46
41 Arthur Tang, 2003, p. 73
42 Elizabeth D. Mynup, 1997, p. 211
43 https://www.businessnewsdaily.com/9704-ar-vr-mixed-reality-platforms.html (4.11.2018)
44 Some of them will be described in chapter 2.2.4

A conceptual precedence can be set for this chapter by the review of the following conclusion drawn in a recent study by Hoover: [45]

“This research shows that AR guided assembly instructions presented via a modern optical see-through HMD, like the Microsoft HoloLens, can be better alternative than tablet AR instructions (and traditional 2D instructions) for large-scale assembly tasks, especially when mobility is important to the assembly process. This is because the use of HMD instructions, as opposed to Tablet AR and 2D methods, can reduce assembly times while maintaining, and in some cases, improving assembly accuracy.”

AR is offered in three dimensions of Industry 4.0 in conjunction with IT-based technology solutions and their challenges.

2.2.1 Integration dimension

Horizontal Integration, through value chain integration

AR tools can assist in the client and contractor services-based conduct. Assembly and maintenance can be achieved in a better and informed manner using AR, because “AR can remove restrictions of time and location, leading to a much faster transfer of knowledge and a better understanding of the maintenance processes”[46]. Challenges in such implementation is related to ergonomic aspects as not all such systems have been tested in a real factory environment and there is a gap in the research that needs to be filled when it comes to integration. Services can be further enhanced by using AR for media streaming through intelligent algorithms such as the case of tele-operations or services related to consultation.[47] However, research is still limited for real industrial setups. Overlays of 3D models in real time are used through AR technology for critical features based on task of services and maintenance while at the same time being in contact with the client virtually or through phone to understand the requirements and complaints.

End-to-End digital engineering integration

3D production planning can be achieved using computer vision integrated into the AR tools which can allow the supervisors to plan and monitor through real time data acquisition from the deployed sensors.[48] Physical conditions can be replicated in AR using geometry adaptations. Interface digital media can flow seamlessly through the help of technology of AR and web to monitor product lifecycle stages. The industrial CAD models of the product can be visualized along with the physical conditions of

[45] Hoover, 2018
[46] Mauricio Hincapié, 2011, p. 3
[47] Shalini Kurapati, 2012 , pp. 48-49
[48] Arne Wagner, 1997, p. 457

the product perceived based on sensory information to depict the product lifecycle and precise behavior as well as performance.[49] Cyber physical systems can be simulated in 3D for real time understanding of the state for the supervisors. Real time simulations in 3D can be visualized for advanced product manufacturing systems such as nanomanufacturing and laser-based manufacturing.[50] However, one major challenge is the seamless integration of many systems and then the usage of Web based information all in parallel and real time which can require huge processing units. Although such processing power in small chips was limited earlier but as in advanced HMDs such as Microsoft HoloLens the processing power is great for such tasks.[51]

Vertical Integration for networked manufacturing systems

In demanding work condition such as the assembly lines, full virtual interfaces can allow the users to understand the customized requirements and adopt to them immediately. Information flows can be visualized to have the knowledge related to different machines as well as material within view while decision is being made at the facility. Planning production and facility management can be transformed using the simulation of virtual environment using AR tools. Factory scanning and 3D reconstruction can be analyzed through AR tools while in the presence of all integrated data models such that greatest efficiency and quality of production can be achieved.[52]

2.2.2 Product and production

Real time production data access in real time for optimized decision making

As industry 4.0 is integrated with mesh of sensors which produce data (also known as BIG DATA) for every measure and the state of machines and the environment, the culminated data can be used for interpreting models which can be visualized for AR based tools.[53] The Big data produced from the production facility can be integrated with design data already acquired for the AR tools for comprehensive view of the status of production.[54] The analytics system through AR can be used for both the engineers and the assembly line workers.

[49] Ming C. Leu, 2013
[50] Ming C. Leu, 2013
[51] The performance of Microsoft HoloLens will be described in Chapter 2.2.4.
[52] Ming C. Leu, 2013
[53] Hirsch-Kreinsen, 2016
[54] Hirsch-Kreinsen, 2016

Business model integration and service changes

Mobile interaction, WEB3D [55] and localization technologies allow for the digital coexistence of the design and manufacturability of the product. [56] Hence, customization can be carried our if at any time the realized virtual product does not seem to match the customer requirements.

Flexible manufacturing and adaptability management as according to individual customer or targeted audience

The end user is empowered to monitor and change the product orientation as the design and the assembly can be virtually assessed using AR tools remotely from the home of the consumer. [57] Option catalogues are generated automatically which are according to parameters defined for production based on users' preferences. Automatic compliance of the production and manufacturing requirements which can be visualized through an interactive interface which is easy to understand.[58]

Self-awareness of product through modelling of data related to product state and history

The infacility localization visualization system is integrated with Geographic Information Science (GIS) for tracking information to be available at all parts of the supply chain, reducing the logistics constraints considerably.[59]

2.2.3 Human factors

Improvement in human intervention for productivity enhancement by better organization and job planning

The mobile device must be synchronized with the AR tools used when using the Post- Windows, icons, menus and pointer (Post-WIMP) interface. [60] By linking SCADA systems, both the production plan and the data collected can be monitored and controlled using real-time visualized data models. The configuration can be activated via interfaces with Manufacturing Execution System (MES).

[55] Web3D was the idea to fully display and navigate Web sites using 3D.
[56] Lee, Bagheri, & Kao, 2015
[57] Lawson, Salanitri, & Waterfield, 2016
[58] Bahrin, Othman, Azli, & Talib, 2016
[59] Lu, 2017, p. 18
[60] Gabbard, Fitch, & Kim, 2014

Enable workers to be more skilled and learn quickly

Flexible production plan visualization through end user tool by employing localization data for machines and human resource. [61] AR tools can also be used for discussions on topics between engineers and workers while visualizing an identical scenario for more clarity. [62]

Professional development of assembly workers through the reuse of knowledge recorded from the tools used by experts.

The knowledge related to a worker and the steps taken in the assembly can be captured through multimedia retrieval that can be used for training novice workers in a specific task. Operational training can also be aided through 3D visualization tools and authoring through an easy to understand UI. [63]

Security and safety

Detection and contextualization of events can be done through the AR tool of cognitive computer vision, which can in turn enable better safety and security as any hazards can be predicted using data being modelled. Emergency response can be visually simulated in factories for enabling workers to save themselves if facility goes wrong.

2.2.4 Hardware

With the advent of industrial 4.0, AR technology has changed the carrier of information. The hardware used by the AR technology is HMD. HMD is a type of computer display device or monitor. As the name implies, it is worn on the head or is built in as part of a helmet.[64] Unlike traditional information media platform[65], HMD is wearable and emits optical signals to the eyes through the HMD's display screen. It can mix virtual objects and the real world together, the user will see a mix of virtual world and real world. HMD can be divided into two types: The first type of HMD was a monocular opaque HMD, and the second was a monocular see-though HMD. [66] Comparing monocular opaque HMD viewing with monocular direct monitor viewing reveals a non-significant 1% performance degradation. [67] The following describes several major HMD devices:

[61] Gorecky, Schmitt, Loskyll, & Zühlke, 2014
[62] Gorecky, Mura, & Arlt, A vision on training and knowledge sharing applications in future factories, 2013
[63] Gorecky, Schmitt, Loskyll, & Zühlke, 2014
[64] https://www.techopedia.com/definition/2342/head-mounted-display-hmd (22.02.2019)
[65] Such as paper, computer screens and tablets
[66] Baird & Barfield, 1999, p. 1
[67] Laramee, 2002, p. 9

Microsoft HoloLens

Microsoft HoloLens is essentially a holographic computer built into a headset that lets user see, hear, and interact with holograms within an environment such as a living room or an office space.[68] Microsoft HoloLens is an optical-see-through holographic lenses, it has 5 cameras[69] and 4 sensors, has 2.3M total light points.[70] Through these cameras, a virtual 3D environment is built in front of the user, and the sensor interacts with user by using the four sensors. It can generate Spatial sound, track the direction of the user's eyes (Gaze tracking), recognize the user's gestures, and recognize language commands.[71] Figure below depicts the Microsoft HoloLens HMD.

Figure 4: Microsoft HoloLens[72]

Meta 2

Meta 2 is like Microsoft HoloLens, it is also an optical-see-through device Integrated optical and inertial sensors for positional tracking.[73] It has a maximum resolution of 2560x1440 pixels, [74] which has a higher resolution than Microsoft HoloLens. Meta 2 do not support tetherless access, which means, the superior tracking, the

[68] https://www.trustedreviews.com/opinion/hololens-release-date-news-and-price-2922378 (22.02.2019)
[69] 4 environment understanding cameras plus 1 depth camera
[70] https://docs.microsoft.com/en-us/windows/mixed-reality/hololens-hardware-details (22.02.2019)
[71] https://docs.microsoft.com/en-us/windows/mixed-reality/hololens-hardware-details (29.04.2019)
[72] https://www.pcr-online.biz/2017/02/20/microsoft-to-jump-straight-to-hololens-v3/ (29.04.2019)
[73] https://www.schenker-tech.de/en/meta-2/ (2018.11.14)
[74] https://www.schenker-tech.de/en/meta-2/ (2018.11.14)

environment understanding feature, the ability to interact with holograms that are further from the user, speech control, and being tetherless are advantages that opens up use cases for HoloLens that are simply not possible with the Meta 2. [75] Meta has a collection of sensors and a 720p RGB camera for tracking and seeing the users hands.[76] Figure below shows the Meta 2 HMD with the connection cable.

Figure 5: Meta Company's Meta 2[77]

DAQRI

Daqri's HMD product is called Daqri Smart Helmet, it is the ancestor of HMD. In early 2014, Daqri launched an AR smart helmet driven by Android.[78] Unlike Microsoft HoloLens, which is expected to be a two-pronged approach to industrial and home applications, Daqri's AR heads are only targeted at industrial applications. [79]

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[75] https://vbandi.net/2016/03/04/hololens-vs-meta-2/ (2018.11.14)
[76] https://meta.reality.news/news/hands-on-up-close-personal-with-meta-2-head-mounted-display-0178607/ (2018.11.14)
[77] http://badgers.co.uk/virtual-reality-hire/ (2018.11.14)
[78] https://newatlas.com/daqri-smart-helmet-ar/33738/ (2019.03.01)
[79] https://daqri.com/ (2019.03.01)

Daqri Smart Helmet's core components include Intel Core™ m7-6Y75 Processor Dual-Core processor.[80]

Daqri Smart Helmet has a feature that is not available in Microsoft HoloLens and Meta2, and that is the Thermal Camera. Daqri Smart Helmet has integrated a thermal camera which is specifically for the detection of heat during the operation of industrial equipment, and then reflected the data in the form of an image on the AR display.[81] In addition, the battery can be changed and a battery pack can be connected while the glasses are still in use.[82] This is not possible with the Microsoft HoloLens. The belt pack is connected to the glasses via cable and weighs 425g.[83] In comparison, the Microsoft HoloLens are stand-alone devices, the Meta 2 is tethered to a computer.[84]

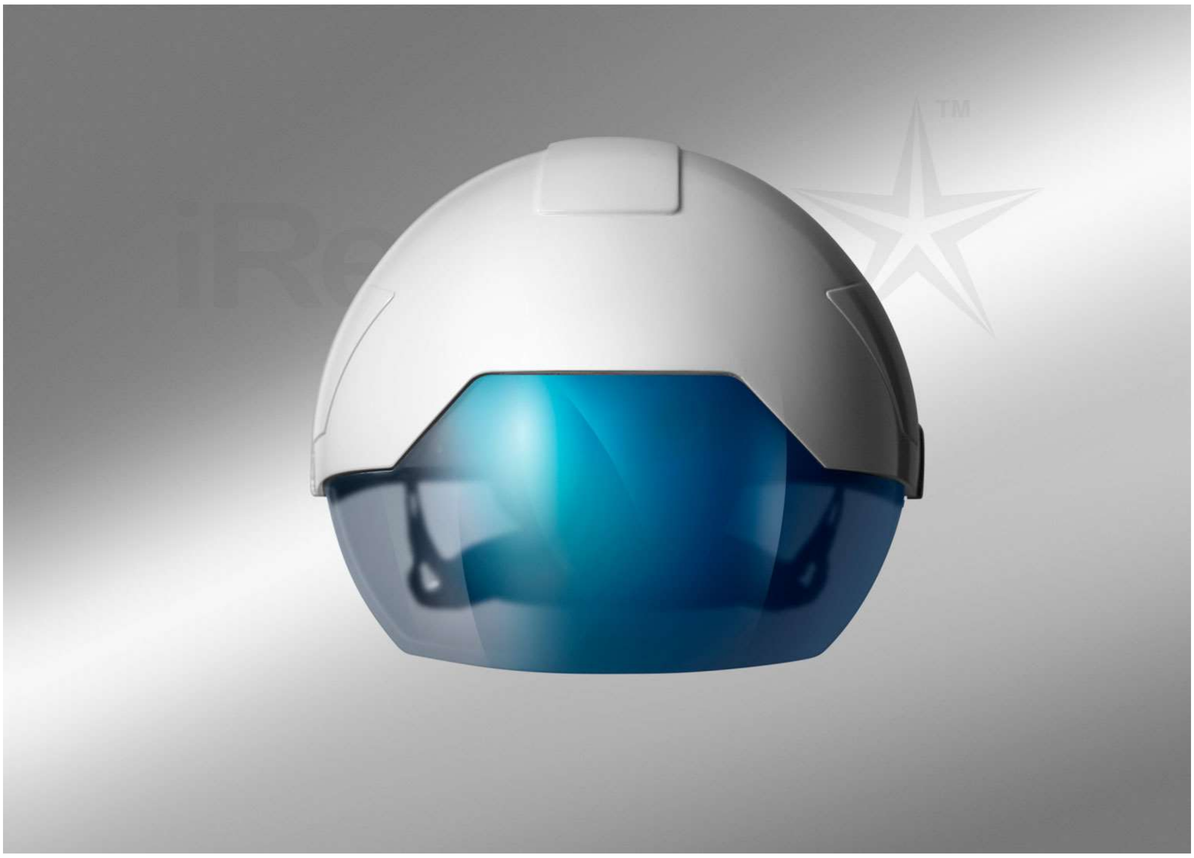

Figure 6: Daqri Smart Helmet[85]

[80] http://donar.messe.de/exhibitor/hannovermesse/2017/U208979/dsh-data-sheet-eng-495327.pdf (2019.03.01)
[81] http://donar.messe.de/exhibitor/hannovermesse/2017/U208979/dsh-data-sheet-eng-495327.pdf (2019.03.01)
[82] https://www.re-flekt.com/blog/why-daqri-smart-glasses-are-an-option-for-augmented-reality (2019.03.01)
[83] https://www.re-flekt.com/blog/why-daqri-smart-glasses-are-an-option-for-augmented-reality (2019.03.01)
[84] https://www.re-flekt.com/blog/why-daqri-smart-glasses-are-an-option-for-augmented-reality (2019.03.01)
[85] https://www.ireviews.com/review/daqri-smart-helmet (2019.03.01)

2.2.5 AR for manufacturing and assembly

It has been well established in the literature that AR application tremendously helps the workers in an assembly to understand the instructions more efficiently and effectively.[86, 87] However, such assumptions are mostly restricted to comparison of using AR with traditional written forms of instructions or 2 dimensional. In this review the focus shall be to consider the comparison where AR is tested compared to more than two forms in instructions in assembly scenarios. This ability of allowing the workers to better understand the assembly and the accomplish the task with least amount of effort mainly emanates from the ability of AR to construct 3D data model overlays onto real vision, such that the parts to be recognized are indicated with precision through tracking and localization algorithms.[88] In a manufacturing assembly such ability allows the workers to understand and distinguish between multiple assembly components instantly without having to switch between instructions and practical implementation. Due to the requirement of customization it is further noted that assembly tasks are much more complex in an industry 4.0 scenario and the task for the workers are not consistent. In such circumstances training for efficiency for each task is not feasible as it can consume tremendous amount of time and to achieve accuracy and efficiency a novice worker requires hours of practice.[89] Such complex operation can be performed seamlessly through the use of AR technology as it can work as extended memory of the worker and can also enhance the hand to eye calibration without requiring them to think for longer periods of time.

Some important issues to consider can be summed as *"important aspect of vision based AR is also the robust tracking and initialization of objects for correct augmentation."* [90]

Richardson conducted a study to test the efficacy and effectiveness of AR tools and systems in an assembly by using tablet-based AR (it shall be noted that HMDs are considered much more efficient than tablet-based methods but usage of HMDs require some time for becoming efficient in interface handling, which at times is not suitable for laboratory environment as the participants used are mainly students.).[91] The researcher used quantitative and qualitative assessment techniques for measuring the amount of impact AR technology can make in an assembly line using three modes of instructions in an assembly line: Model based instructions (MBI) through desktop as traditionally used; MBI using movable hand-held device and AR

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86 Engelke, Webel, & Gavish, 2010
87 Billinghurst, Clark, & Lee, 2015
88 Avila & Bailey, 2016, p. 6
89 Dunleavy, Dede, & Mitchell, 2009
90 Engelke, Webel, & Gavish, 2010, p. 223
91 Richardson, 2016, p. 87

based work instruction on hand held device.[92] The researchers considered the localization of the user through measuring the head movement as a way of understanding the amount of effort a participant had to do while conducting the implementations. The quantitative measure for head movement showed in the results that users equipped with AR based tablets moved least amount of time (33% less time in completing the implementation as compared to traditional method) while achieving the end goal.[93] Which also stated that the users with AR based instruction had to switch their concentration minimum amount of time so had more time in achieving a set task.

Similar results were shown by Werrlich who studied four different forms in instructions two being based on AR technology while two based on simple 2D instructions and models for assembly.[94] They concluded that the efficiency of the AR methods in assembly was much higher than the two traditional methods and furthermore they constructed that HMDs are a better way of using AR as compared to tablet-based solution given that the hands of workers are free to move and they can implement the solutions while at the same time receiving and coordinating the 3D information. These results were further complimented by Chryssolouris who tested the efficacy of AR in terms of assembly completion efficiency in manufacturing and concluded that using AR for instructions at assembly line with or without collaboration of robots reduces the time to task completion and further increases the first-time quality.[95]

Many other such studies exist which point towards the added efficiency and quality of task completion in assembly environment of AR technology in various ways. The results accrued by most of the researchers point out that usage of AR technology for instructions increase the assembly worker efficiency, requires minimum expertise for task completion and adds to lowering the rate of first-time errors.[96,97,98,99,100,101]

The analysis of research pointed out to one important issue that although AR has proven its ability in assembly, but many usability and ergonomic issues hinder the technology for reaching its full potential in assisting assembly workers. Although Werrlich showed that AR technology has many measurable benefits for the assembly

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[92] Richardson, 2016
[93] Richardson, 2016
[94] Werrlich, Nitsche, & Notni, 2017, p. 1098
[95] Chryssolouris, et al., 2009
[96] Blattgerste, Herrema, & Siller, 2017
[97] Lawson, Salanitri, & Waterfield, 2016
[98] Lam, Ferrise, Vlachou, & Re, 2016
[99] Schwald & Laval, 2003
[100] https://www.bcg.com/de-at/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx (11.09.2018)
[101] Rodriguez, Quint, Gorecky, Romero, & Siller, 2015

but at the same time they identified that many usability constraints are persistent throughout the usage of AR technology due to which many potential benefits are not being accrued.[102] Hence, it is also very important to concentrate on identifying such issues such that the usability and functionality of the proposed system can be in a way to achieve maximum benefits for assembly worker guidance. Some identified ergonomic consideration as pointed out in the literature include, wired devices, weight of the headset, the requirement of integration with laptops which can restrict free movement and especially when human have to work in collaboration with robots in industry 4.0 environments.

Work of Dunleavy and Dede points towards the researchers conducted using the HMDs for AR in assembly and stated that the results concluded by such researches lack authenticity for the current scenario as the HMDs used generally had limited graphic processing ability, which hindered the effectiveness considerably.[103] The researchers noted that state of the art HMDs introduced in the recent years are much more proficient and have higher processing abilities as well as graphical clarity such as the Microsoft HoloLens and the Google glasses.[104] Furthermore, they noted that the number of vantage points are considerably decreased when using mounted or non-wearable displays for AR based instructions. The spatially registered instructions were reported to be disconnected form the task space in case for using hand held displays, reducing the usability of the AR technology in real time.[105]

A research based on novice users concluded: *“Comparing printed instructions to augmented instructions the difference was subtle in this simplified example, but all users shared the opinion that it may be useful for more practical assembly tasks (e.g. installing a digital-TV box, putting together furniture etc.). Also the multimodal input interface was favorably judged by the users.”*[106]

Carmigniani showed the efficacy of using HMDs for minimum physical interruption while performing assembly task and showed that ergonomics made a huge difference in the worker efficiency and task understanding.[107] The use of HMDs was observed to change the vantage point of workers and the position where instructions should be placed in the view. Carmigniani extrapolated form the trends in computing technology that in the past two decades the progress has been unprecedented, which can enable wearable devices to have the processing power of huge

[102] Werrlich, Nitsche, & Notni, 2017, p. 1098
[103] Dunleavy & Dede, 2014
[104] Dunleavy & Dede, 2014
[105] Narumi, Nishizaka, Kajinami, Tanikawa, & Hirose, 2011
[106] Sanni Siltanen, 2007, p. 81
[107] Carmigniani, et al., 2011

computers.[108] This is further complemented by the high-resolution display technology which is integrated into the HMDs of the present.

Above stated were the major reasons why any lucrative AR based solution has not been widely accepted by the industry 4.0. Hence, in this thesis this gap in the literature will be fulfilled as a complete comprehensive all-inclusive technology-based state of the art solution for AR in assembly will be tested and analyzed for industry 4.0.

2.3 Software Developing Model

Most modern development processes can be vaguely described as agile. Other methodologies include Waterfall, V-Shaped, Iterative, Spiral.[109] Among those the waterfall model was developed by W. Royce in 1970.[110] The waterfall model is used in this thesis. Because the requirements of the task are very clear, it is appropriate to use a linear model. Its greatest advantage is that it is very logical: think before construction, record it all, implement it according to plan, and keep everything as organized as possible.

2.3.1 Software development and design

In order to realize an efficient architecture and implementation of software proposed for the study, the selection of the management and design model is crucial.[111] However, many formalized and standardized software management models exist. The task here is to analyze the models that are most suitable for augmented reality software and their implementation in a beginner's circuit as users. One essential feature for any software management model is that of defining the requirements of the software starting from usability.[112] In that regard after the selection of the model an overview of the literature is conducted to interpret the most appropriate methodology for usability requirements definition.[113] *"Our highest priority is to satisfy the customer through early and continuous delivery of valuable software."*[114] Hence, in this regard the literature for standard models currently adopted in software industry are analyzed using content analysis approach and depending on the requirements of the worker guidance in assembly system (as established in the previous sections) the most appropriate model is selected.

108 Carmigniani, et al., 2011
109 https://medium.com/existek/sdlc-models-explained-agile-waterfall-v-shaped-iterative-spiral-e3f012f390c5 (15.11.2018)
110 W.Royce, 1970
111 Masoni, et al., 2017, p. 1300
112 Zhou, Duh, & Billinghurst, 2008
113 Fowler & Highsmith, 2001
114 Fowler & Highsmith, 2001, p. 3

There are many standardized ways of conducting the prototyping and software management such as the latest and frequently used early prototyping method presented by Koh.[115] However, for this application it has some drawbacks as testing a prototype in the real-world environment without first finalizing the design is a hefty task and can be very time consuming. Hence, a better choice for Microsoft HoloLens is to base the design choices first based on the state-of-the-art designs in the industries aided with theoretical constructs as stated by Balaji and Murugaiyan[116] in their comparative study of three software models: Waterfall, V-model and Agile. These kinds of processes are explained in this section in detail which further entail that the traditionally used waterfall method is a more lucrative and suitable way of managing the prototype development based on the specifications and the requirement of assembly guidance system proposed for this thesis as stated by Cusumano and Smith.[117]

2.3.2 Waterfall model

The waterfall method follows a systematic and simple approach to design, implementation and optimization of a software and hardware-based product.[118] The efficacy of waterfall model in terms of requirements is summed by the researchers as: *“Requirement given by the client should be clear before we start the next phase of development life cycle because in waterfall model the requirement phase should be freeze before we start the design phase. Further changes in requirement will not be considered.”* [119] Unlike the methods involving implementation for testing the environment and checking the requirements afterwards the waterfall models takes a more formal approach by defining the complete requirements after through research and then going into the implementation phase such that the product can be tested in the real-world environment and the feedback can be based on realistic constraints unlike the testing on hypothetical scenarios.[120] Firstly, the method proposes to the completion of detailed research for extrapolation of trends and analysis of state of art in implementation then the research conducted is aligned with information available at hand from real life where the system is to be implemented. The distilled data is then used for problem demarcation and requirement acquisition for the final product; this is where the stage of definition of architecture, design layouts and coding start.[121] Such approach takes a secure route towards reaching the end goal in minimum amount of time and cost.

[115] Koh, Slingsby, Dykes, & Kam, 2011
[116] Balaji & Murugaiyan, 2012
[117] Cusumano & Smith, 1995
[118] Balaji & Murugaiyan, 2012
[119] Balaji & Murugaiyan, 2012, p. 27
[120] Pan, Polden, Larkin, van Duin, & Norrish, 2010
[121] Balaji & Murugaiyan, 2012

The stages in the waterfall model are to be considered prerequisites of the following stage and none of the stages shall be leap frogged for saving time as it might undermine the whole process. The following flow chart demonstrate the flow of stages that are to be followed:

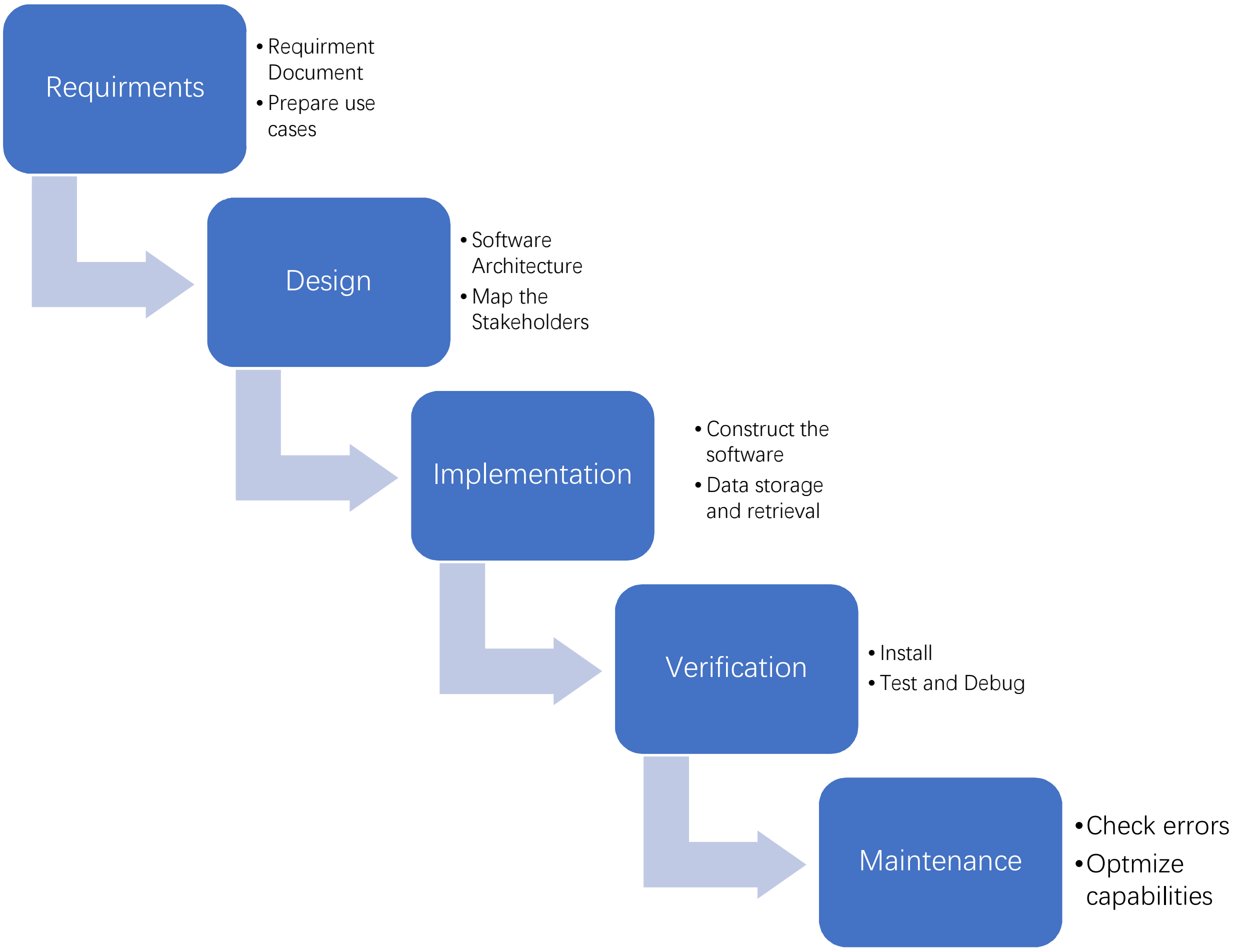

Figure 7: Processes of a waterfall model to be followed for this thesis[122]

Requirements

This stage is focused on extensive research conducted through different resources to benchmark the state-of-the-art systems as well as understand the trends in the technology. Such information is then viewed in the context of the application environment and major components which a system needs to have are demarcated. Here, many different models for requirement analysis can be employed which may include the definition of functional requirements, the usability requirements, and the technical requirements. In this phase multiple use case scenarios are also defined, and system diagrams are constructed to be used in the later stages for clarity. The

[122] http://tonyjustinus.wordpress.com/2007/11/11/w (22.11.2018)

considered elements are then also justified in the light of the literature and state of the art.

Design

This stage focuses on producing a blueprint for the whole process of implementation. Design consideration are done for every component of the application both in hardware and software. The usability issues are discussed, and design solutions are presented to achieve better efficiency and effectives. Here the stakeholders' needs and preferences are considered in terms of aesthetics and technicalities. The system architecture is also designed along with a focus on the user interface. These all consideration are done in the light of literature and state of the art.

Implementation

This phase focuses on the practical implementation part in which the blueprint defined earlier, and the documentation is used to bring the concept into reality. The hardware chosen is integrated for the application and system and the software algorithms to be used are defined. The requirements are fulfilled at this stage for the usability, functionality and technicalities defined earlier. The programming is conducted, and the programmer goes on to build a prototype which is ready for implementation and application in real life environment.

Verification

In this phase of the model the created application implemented based on requirements defined is tested for its efficacy in terms of the check points and the rate of fulfillment of the system. All the functions and use cases defined are tested for their effectiveness and efficiency. The evaluations are conducted in a standardized form in which all the results are sequentially documented, and the failures are noted with their probable causes.

Maintenance

This phase focuses on getting things right based on the feedback produced in the previous stage where all the issues are rectified, and the maintenance checks are conducted to ensure sustainability of the application in the long run. This stage also focuses on fixing the developed system into a real-life context and adjusting the specification to fit perfectly depending on the environment.

The method presents a very easy to understand and clutter free approach to completing the software and hardware implementation process from the very scratch, designed to keep in view every detail in the light of requirements. [123] The

[123] http://tonyjustinus.wordpress.com/2007/11/11/w (22.11.2018)

requirements of the system can be defined to minute details at the beginning so that different teams involved in a project do not face hinderances due to inconsistencies and changes in requirements at later stages.[124] This whole approach makes this model much more economical and efficient as least amount of work is left for experimentation in the later stages which in other models end up in constant rework and losses due to change of requirements at the later stages. Hence for an application such as the one proposes d in this thesis where hardware is to be integrated with the software and changes after prototype are hard and expensive waterfall models presents a suitable approach.

2.3.3 Early prototyping

Pranoto[125]also advocates this process when they were developing an AR prototype and it is a process that involves both experts and potential users. It is an iterative process where the prototype is evaluated several times during the development. Expert in this case refers to the supervisor at the company where this thesis is conducted, and the users are personnel at the same company.[126] By using this process, the prototype will be modified with the help of the feedback from the users and the expert's during the development. This will potentially create the good prototype faster than in a traditional process (e.g. the waterfall model), where a product is designed after predetermined requirements and will not be evaluated until it is fully developed, which in turn creates the possibility of creating the wrong product for the end user. These basic functions were: markers (i.e. an image that marked the position on the beam frame) recognition, the ability to visualize bolts relative to the marker, interaction with the said bolts by tapping on them, a list of markers that is placed on the beam sorted by the order that they appear on the beam, and finally the markers in the list would lit up when a marker of the type has been found.

The approach can be summed up in the quote: *"Using a low level software library and framework like Studiers tube or OsgART provides the maximum flexibility in development of the AR application, but can also be time consuming and requires considerable programming skill. In some cases, it can be helpful to rapidly prototype an idea to show to end users or clients before undertaking a major development exercise."*[127]

The modified version of early prototyping as described by Koh[128] is shown in the following figure:

[124] Pan, Polden, Larkin, van Duin, & Norrish, 2010
[125] Pranoto, et al., 2017
[126] Pranoto, et al., 2017
[127] Billinghurst, Clark, & Lee, 2015, pp. 153-154
[128] Koh, Slingsby, Dykes, & Kam, 2011

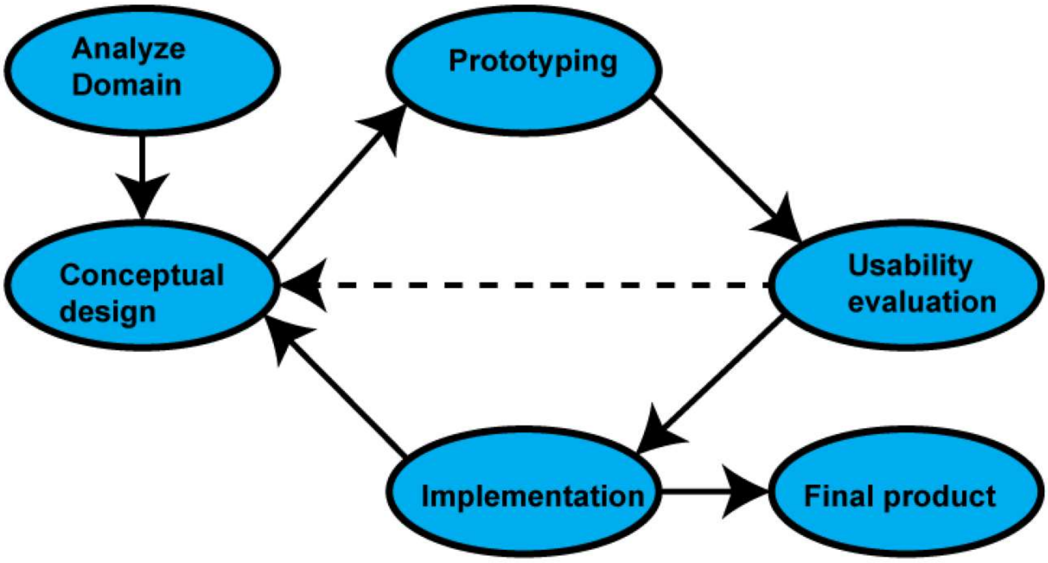

Figure 8: Early prototyping Model (a modified version)[129]

2.3.4 Selection of software developing model

Although many other models exist for the management of software and product design such as AGILE method and V-method etc., but for the current application after analysis of the research the two most appropriate methods were shortlisted: Early prototyping and waterfall model. A final take can be summed from the following conclusions:

"If requirement is clear, larger project then we choose "Waterfall model"

If requirement changes, larger project, proper validation to take place in each phase , tester to be involved in early stages of development, then we can choose "V-Model".

If requirement changes frequently and smaller projects, deliver product in short period time with skilled resources then we can choose "Agile model "."[130]

The process used for shortlisting was based on the results analyzed from various studies and design implementation using AR technology. Furthermore, the major influential factor was the requirement of both software and hardware to be designed in cohesion according to diverse application requirements.

Although the early prototyping method is generally preferred over the waterfall model; however, as this thesis focuses on bridging the gap which was identified in the previous studies that being the inability of the systems being designed for a full

[129] Koh, Slingsby, Dykes, & Kam, 2011
[130] Balaji & Murugaiyan, 2012, p. 29

fledge factory environment using an early prototyping method can be very time consuming. The strategy used for this thesis is based on the water fall model which although have been identified to have drawbacks but suits the purpose of this thesis in the best possible manner.

The requirements can be acquired from the vast amount of literature that is studied for the current study which can then be simply used as a benchmark for designing a system which integrates all essential elements of AR technology for an industry 4.0 assembly. Given that the main identified limitations of the previous studies were due to the inability of the systems proposed to be used in a real factory environment, hence in this thesis the early prototyping stages are leaped over to save time and costs, and a system is designed directly to be practical.

3 State of the Art

This chapter provides an overview of the current trends in the AR application with a focus on assembly guidance and worker training applications. A precedence is constructed for the development and realization of the proof of concept through a working Microsoft HoloLens based assembly worker guidance software. Data is collected from state-of-the-art applications and inferences are made for the design of the system at hand. Given that the field of AR is still growing and gaining momentum, an understanding is developed to reach the best-case approach for the selection of design specifications and requirements based on the current technology and its usability. In that regard this chapter also sheds light on the documented limitations as faced in conducting state of the art application based on AR.

3.1 Recent Trends of AR in Assembly and Manufacturing

As mentioned earlier, the research in AR is a hot topic among major institutions and companies around the world; this has led to a successful application of technology in various domains and subdomains of multiple industries.[131] With the advent of light weight head mounted displays (HMDs) which allow for unhindered intervention of the technology (Google glass, Microsoft HoloLens etc.), the benefits of AR have been shown to be unprecedented in assembly and manufacturing facilities.[132] Hence it is important to extract the benefits which have been accumulated from the application of such tools and technologies within different domains associated with manufacturing of products and their assembly.

Extensive research conducted proclaims: “Augmented reality can help to increase the efficiency and quality of manual assembly training tasks.”[133] AR has been applied at various stages of manufacturing from computer aided designs to the assembly of the product. Hence, to understand the state-of-the-art application for assembly, in this section the latest trends in application of AR at various stages of production in a manufacturing facility shall be captured.

In the next parts of this section the focus is on acquiring detailed specification for the systems and their application in real life scenarios such that information can be gathered for the possibilities of state-of-the-art application of AR in assembly.

[131] Carmigniani, et al., 2011, p. 359
[132] Werrlich, Nitsche, & Notni, 2017, p. 1098
[133] Westerfield, Mitrovic, & Billinghurst, 2015, p. 4

3.1.1 Assembly workers in product maintenance

Maintenance and reconditioning of products require the workers to disassemble complex geometries and then assemble them back after diagnosis and fixing the issues. Such tasks require workers in the assembly line to deal with many kinds of products and given that efficiency is required in assembly, understanding the components and steps to render the work can be hard. At the same time the workers need to recognize the components in the product and use expert knowledge to understand the problem and fix it. As stated by Roy et al.: *“Augmented reality (AR) has the potential to become a major tool for the continuous maintenance, by overlaying and integrating virtual information on physical objects”.* [134] Hence, requirements of maintenance and reconditioning tasks are very similar to those required for assembly in an industrial setting, having similar overall system specification and technical architecture. Hence, the state-of-the-art systems analyzed for maintenance using AR technology provide an accurate precedence for the current study and shall be analyzed in detail. AR technology is being applied to maintenance and repair process for industrial and workshop settings in mainly two forms: to achieve remote collaboration using AR for diagnosis and repair, and to reduce the effort and time required to understand the instructions beforehand. Here, the second form of implementation of AR technology is of special importance for the case of current study given that assembly workers face with similar problems when understanding and utilizing instructions. Predominantly AR has been applied in repair and maintenance industry to increase the efficiency of workers and to reduce the time for problem partition and solution application.[135]

Masoni et al. devised an AR based system for remote maintenance which has the potential of connecting a skilled expert to a novice worker from control room and industrial setting respectively.[136] The system makes use of AR for better definition of instructions from one expert in real time to the novice worker on the assembly line or the workshop. The researchers made use of feedback from the first prototype from the actual users and then modified the AR based system, hence, many important inferences can be made from their work for the current study and they present the state-of-the-art solutions. The researchers depicted the urgency of utilization of the following tools for a real industrial setting which their initial protype and all other systems on the market lacked:[137]

[134] R.Roy, R.Stark, K.Tracht, S.Takata, & M.Mori, 2016, p. 680
[135] Hincapié, Mauricio, Caponio, Rios, & (Eds.), 2011
[136] Masoni, et al., 2017
[137] Masoni, et al., 2017, pp. 1298-1299

- An inspection module: To allow the expert to understand why the problem occurred and what can be the possible cause for such an occurrence such that it can be diagnosed from the very scratch.
- Use of an industrial based universal language for instructions such that the multinational corporations can utilize the system effectively.
- A real time view for the remote person such that the activities can be monitored which are conducted according to the instructions by the novice workers.
- A recorder module of the maintenance steps such that the visual format can be used for better understanding for other workers assigned a similar task.

The figure below demonstrates a basic architecture for instruction using server client/client system.

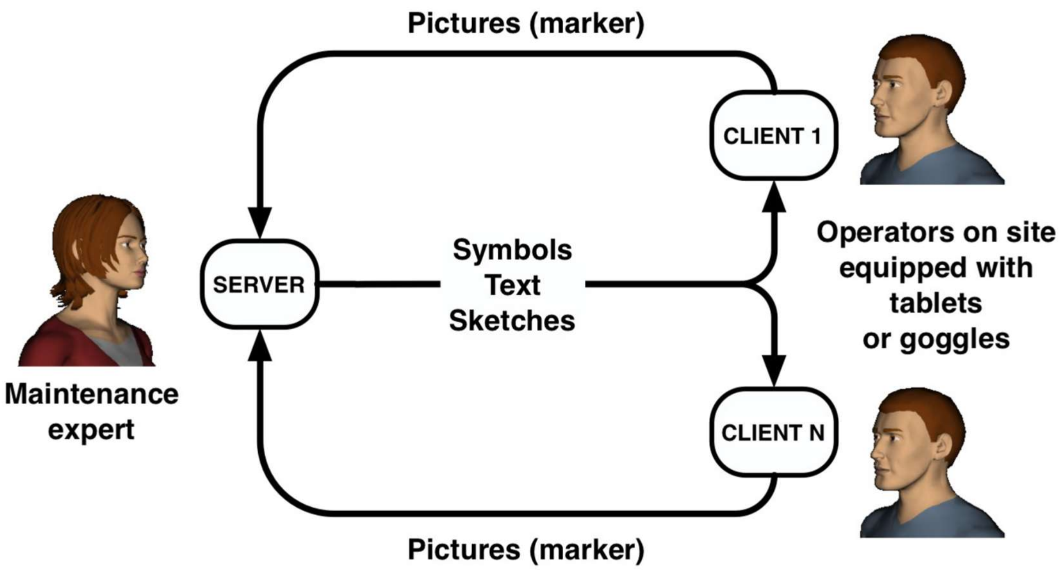

Figure 9: System architecture for information flow between client and server[138]

The modified system from the view of the server being handled by the expert and the visual of the assembly acquired by the novice worker in the workshop is shown for the system devised by Masoni in the figure below.

[138] Masoni, et al., 2017, p. 1300

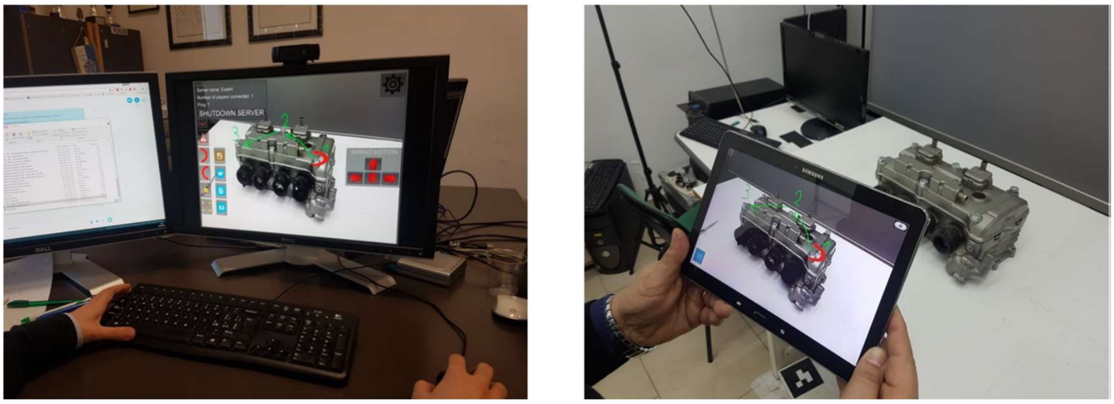

Figure 10: Left (maintenance expert sending the information after analysis); Right (Novice worker receiving the information in 3D spatial form on a tablet which can also be replaced by HMD as proposed by the researchers)[139]

Mourtzis et al. made use of HMD alongside a host PC for the AR implementation in the system which makes it more relevant for the current research.[140] They selected the Vuzix Star 1200XL HMD for AR realization. Furthermore, they made use of two different software packages for the implementation of the system which allowed them to achieve high quality modelling and geometry rendering. They used the Unity 3D which is a cross platform game generation system. The main advantage of the Unity 3D is its flexibility in scripting. Another important fact to consider is the use of C# as scripting language by Mourtzis et al. which is also used for the current system's application.[141] The figures below demonstrate the on-site utilization of AR technology and the architecture for the 3D model generation for the system.

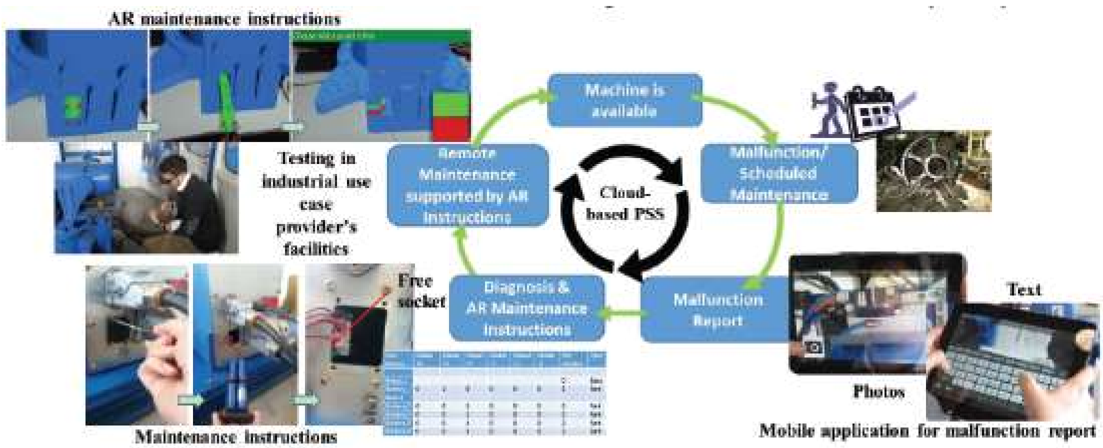

Figure 11: The framework of the sustainable Product Service System based on AR[142]

Erkoyuncu et al. also utilized Unity 3D for the 3D modelling of assembly and geometry. Furthermore, for marker less tracking the researchers utilized Vuforia

[139] Masoni, et al., 2017, p. 1301
[140] Masoni, et al., 2017
[141] Masoni, et al., 2017
[142] Mourtzis, Zogopoulos, & Vlachou, 2017

SDK.[143] SQLite platform is used for the creation of database interface for the authoring platform as described in the figure.

The researchers concluded: “AR offers opportunities for industrial maintenance applications by displaying contextualized information and accessing end-user data. The validation has demonstrated that ARAUM can improve the efficiency in conducting maintenance”.[144]

Zhu et al. devised an AR based context aware system which allows for the authorization of devices and components of an assembly such that the images could be shared remotely with an expert and while at the same time instructions can be generated for real time collaboration.[145] Zhu et al. used the latest HMDs for maximum usability and increased efficiency for collaboration and solution implementation.[146] The figure below demonstrates a use case for the application of AR:

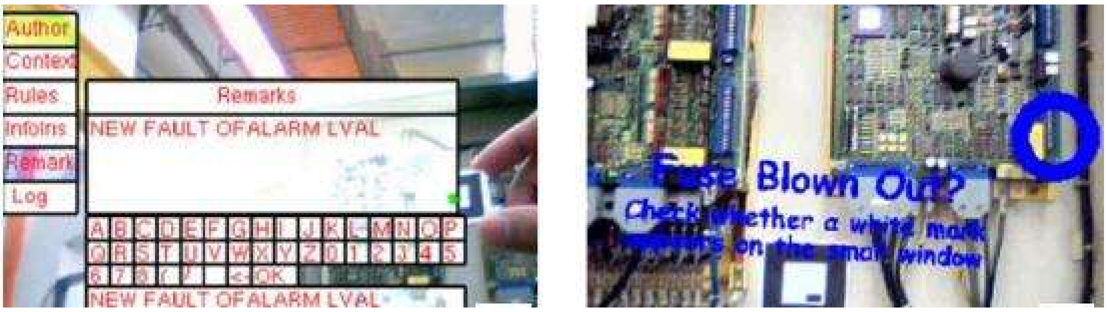

Figure 12: A context aware and authorable AR maintenance system for real time collaboration and implementation;[147] Left (worker sends a message to the expert); Right (through real time context awareness of the assembly, the expert provides a real time instruction for the worker).[148]

In order to quantify the effectiveness of AR as an aid for realistic maintenance sequences for technicians working with sets of instruction Henderson and Feiner designed tests based on efficiency and quality of performance.[149] Their AR based maintenance system used the state-of-the-art HMDs which were integrated with data based on instructions for maintenance sequences alongside context awareness and image recognition algorithms. The implemented tests in real life scenarios using comparisons of AR technology with traditional sets of instructions concluded that the use of AR technology for maintenance sequence radically increased the efficiency and quality of performance of the technicians.

[143] Erkoyuncu, del Amo, Dalle Mura, Roy, & Dini, 2017
[144] Erkoyuncu, del Amo, Dalle Mura, Roy, & Dini, 2017, p. 468
[145] Zhu, Ong, & Nee, 2013
[146] Zhu, Ong, & Nee, 2013
[147] Zhu, Ong, & Nee, 2013, p. 1711
[148] Zhu, Ong, & Nee, 2013, p. 1711
[149] Henderson & Feiner, 2009

A highly usable car maintenance system for road side problem demarcation and solution implementation is designed by Lee and Rhee, using AR technology for a novice driver to be directly instructed by an expert mechanic in real time.[150] The system uses context awareness and image recognition as well with a real time connectivity to the internet for collaboration with the expert. However, their system did not materialize the use of HMDs and instead utilized the power of simple imaging and data integration in spatial 3D. The figure below demonstrates a real-life example of the system:

Figure 13: An AR based ubiquitous car service system[151]

Zhu et al. designed a state of the art Authorable Context-Aware AR Maintenance System (ACARS) which allows the expert and developers of technology to collaborate in real time for generation of context-relevant information of the assembly which is authorized in real time by the technical expert working on-site.[152]

3.1.2 Product manufacturing in industry 4.0 environment

Manufacturing processes are implemented general in industry 4.0 facilities through computer simulated scenarios and computer aided design for maximum manufacturability. The product assembly has to be visualized and the analysis of each component is obtained in real time such that design choices can be made. Understanding the state of art in this domain can allow us to ad value for the assembly line application. AR technology can enhance the ability of the workers, engineers and designers to collaborate for on-site tasks through context awareness and delivery of instructions in real time.[153]

In this context a hybrid facility layout planning approach based on AR technology is proposed by Jiang et al.,[154] which allows for geometry information acquisition through an interactive modelling method; such approach allows for seamless integration of real and virtual content which in turn enables real time interactions. The flexibility of

[150] Lee & Rhee, 2008
[151] Lee & Rhee, 2008, p. 440
[152] Zhu, Ong, & Nee, 2013
[153] Mourtzis, Zogopoulos, & Vlachou, 2017
[154] Jiang, Ong, & Nee, 2014

the system enables for the definition of multiple criterions in accordance with the layout planning tasks of the facility. Figure below demonstrates the layout planning in action.

Figure 14: Layout planning for manufacturing facility to assist the on-site workers using AR.[155]

AR technology is also widely being used in the instructions provided for the on-site workers for CNC machining process and their simulation for better efficiency and quality of performance. ARCNC system developed by Zhang provides a good example of use of AR technology in for machining operations. The system can assist operations for 3-axis CNC machines, which provides a challenge otherwise for the operators and highly qualified individual can only handle them through conventional instructions. Three main units are integrated in the ARCNC system: AR-assisted human machine interface, display device, and a fully automated CNC machine. The system has the flexibility of making use of both HMDs or screens for display of information and image recognition.

Product designing in industry 4.0 context has also been radicalized as due to flexibility and customization for the customers there is a need for design generation and prototyping in least amount of time. AR technology has come to aid for such process in a manufacturing facility setting as well. Many such implementation distills the accurate utilization of AR based tools and techniques which may be employed in the current study.

The use of computer aided design is a norm in the manufacturing facilities in that regard Ng et al. devised a state-of-the-art system which has the capability of producing 3D models of objects in AR environments to support the interaction and provide instructions for design to a novice worker. The researchers devised a prototype of the ARCADE (AR Computer-Aided Design Environment) system for use in real industrial settings. The system allows the direct consumer to fiddle with the designs of the product and then bring them into realization in a 3D AR based environment.[156] The instructions of the new designs are then passed to the designers at the assembly which can bring the concept into realization. Hence, a user is given

[155] Jiang, Ong, & Nee, 2014, p. 465
[156] Ng, Chong, & Chemmangattuvalappil, 2015

direct control and can use virtual and real objects through AR technology to transform the product and experience full customization. Such AR based system also allows the designers and engineers to fully understand the user requirements by first allowing the users to customize the products in virtual environments while in the concept generation and design phase of the product. In this regard a multi-level function behavior structure framework is proposed by Ng et al. which allows for testing the functionality and consistency of the design through reasoning and evaluation in virtual space and by using AR technology. The ARCADE system provides the virtual facility for the designers as well as the specification providers for instant prototyping which allows for the distillation of usability issues in a product and can provide a use case scenario. The ARCADE system in its essence provides an instruction provision, authorizing and context awareness system using AR technology which is an essential component of the worker guidance system proposed in the current study.[157]

3.1.3 A review of current researches

The following table shows an analysis of the current application of manufacturing and maintenance domains of AR technologies. The features for all related systems are acquired for use in the system proposed for the current study and their limitations are also identified so that the compromise can be realized.

Institution	Scope of Work	Features	Limitations
School of Industrial and Information Engineering University of Patras[158, 159]	Maintenance, manufacturing	Assembly Planning and simulation by AR: feature design for assembly, handing of component contacts based on defined constraints Design integration and assembly through collaboration at different stages and skilled and unskilled workers.	The prototype contains primitive design of the features in applications. The systems require an already built CAD models with accurate assembly parts designed to scale.
German Research Center for Artificial Intelligence (DFKI)[160]	Assembly, training	Monitoring of work flow by recognition of current activities using data being acquired from sensor mesh. Context dependent authorization for automated creation of instructions by segmenting videos based on on-site segments of tasks.	The real time feedback cannot be provided which can considerably reduce the percentage of error and assembly time.

[157] Ng, Chong, & Chemmangattuvalappil, 2015, p. 2
[158] Masoni, et al., 2017
[159] Mourtzis, Zogopoulos, & Vlachou, 2017
[160] Gorecky, Mura, & Arlt, 2013

University of Skövde[161]	Assembly	AR assembly system-based content creation process through authoring of steps and components AR technology based industrial application for the assembly line workers.	The scene and user interaction are very limited. The researchers deployed time consuming and complex authoring process.
Fraunhofer IGD[162]	Assembly, manufacturing	Interdisciplinary information integration for maximum advantage in a single industrial application Assembly training-based criteria for AR technology through the consideration of human cognition and movements in the assembly line.	The feedback provided is haptic only There is no surety of optimal visualization and the tools used for it such as the HMDs
Human Interface Technology Laboratory New Zealand[163, 164]	Assembly	AR graphics backed adaptive guidance for novice workers. Utilization of force feedback through cubical user interface and mobile phone applications	The assembly operations for which the system designed are very limited and basic such as screw driving Occlusion is not handled very well Limited accuracy due to marker-based tracking.
Curtin University[165, 166]	AR assembly system evaluation	Experimental frameworks for cognitive workload evaluation for the use of AR in assembly tasks. Research studies based on human learning curve integrated with cognitive workload and motivation of the workers.	LEGO assembly used as an experiment and are limited to a laboratory. The tested system was mainly on students and a limited number of trainees which is not the case in global organization
Columbia University[167, 168]	Maintenance, assembly and construction	Information management system for the assembly Guidance system based on AR for the assembly line workers Analysis of the routine tasks and acquisition of assembly equipment for context evaluations	Low adaptability for diversity The hardware used is not portable

Table 3: A review of AR assembly guidance and manufacturing research

[161] Syberfeldt, Danielsson, Holm, & Wang, 2015
[162] Webel, et al., 2013
[163] Westerfield, Mitrovic, & Billinghurst, 2015
[164] Zhu, Ong, & Nee, 2013
[165] Hou & Wang, 2013
[166] Hou, Wang, & Truijens, 2013
[167] Henderson & Feiner, 2009
[168] Feiner, Henderson, & Salonen, 2008

3.2 AR Application across Industries

In order to get a hands-on view of the application of AR technology across various fields different state of the art applications are analyzed. The aim in this section is to distill all the optimum approaches for the application of AR for worker guidance such that the most suited techniques can be employed for the system proposed in the current study. Recent trends show that AR technology has been widely embraced as an influential tool for many fields and their sub domains.[169] Although in the past decades AR usage in real life was a far-fetched concept due to the limitations the technology had but in the recent years a more serious approach is being taken by industry experts to use AR for better efficiency and effectiveness in task handling and problem solving.[170] AR has been most applicable in the subdomains of mechanical engineering. The manufacturing, maintenance and repair industry were covered thoroughly in the earlier section, in this section the focus is shifted towards the state of art in other related fields: both mechanical and non-mechanical.

3.2.1 Aerospace

In the global aircraft manufacturer market, AR is gaining momentum and is radically deployed in various phases of aircraft design and manufacturing.[171] It was concluded by the researchers that *“the implementation of AR generates gains of labor qualification hiring less qualified worker because their training for these specific tasks are easier whereas they also become easier to perform. Taking into regard that learning time is also extremely faster than the conventional way, it is also possible to compute gains with training costs reduction”.*[172] Boeing (an important player in air craft manufacturing) partnered with the Iowa State University and conducted a detailed study on utilizing mixed reality training related sensory and self-reported data for evaluating methods of instructions delivery at the assembly stages.[173]The researchers evaluated three different work instruction delivery methods. The research study in actual environment concluded that the use of AR in instructions for aircraft manufacturing processes can increase the quality first time while at the same time increasing task efficiency. The research further indicated that the use of AR helped in enhancing worker concentration towards tasks at hand and the workers were shown to be more involved with higher levels of focus into accomplishing tasks at hand.[174] Furthermore, it was found that use of tablets and smartphone increased

[169] Billinghurst, Clark, & Lee, 2015, p. 236
[170] Erkoyuncu, del Amo, Dalle Mura, Roy, & Dini, 2017, p. 465
[171] Frigo, da Silva, & Barbosa, 2016
[172] Frigo, da Silva, & Barbosa, 2016, p. 129
[173] Re, Oliver, & Bordegoni, 2016
[174] Billinghurst, Clark, & Lee, 2015

the time of understanding of instructions and the workers were much less focused on achieving the goals defined. Re et al. (2016) further demonstrated that specific task in the air craft assembly were more inclined for the benefits from the use of AR technology as compared to other; such were the complex tasks which required too much information to be processed by the workers.[175]

Figure 15: Adamjanin demonstrates Boeing's prototype wire bundle assembly application[176]

3.2.2 Education

The introduction of AR technology in teaching is a revolution in education. AR technology can make the students' attention and energy more focused on the learning process and make the course more attractive. Today, 94% of students want to use their cell phones in class for academic purposes.[177] Unlike texts and pictures in past books, AR technology can be presented to students visually in a 3D model, visualizing abstract parts, and helping students to understand courses more deeply.

[175] Re, Oliver, & Bordegoni, 2016
[176] Azuma, 1997, p. 358
[177] https://campustechnology.com/articles/2017/12/12/students-want-to-use-their-cell-phones-in-class.aspx (26.11.2018)

AR also allows students to interact with 3D models. AR course materials allow students to understand topics in depth. Teachers can ask students online and see their answers directly. Students can participate in learning groups to complete assignments remotely. The teacher can see which students did not join in, thereby giving further attention. Chemical experiment classes do not have to worry about the dangers that chemicals may pose. Different from traditional textbooks, on the virtual screen, pop-up numbers can be seen, links to related information, definitions of vocabulary etc., to acquire knowledge in a digital way. AR technology has slowly entered the classroom, allowing the combination of visual and learning, allowing the integration of virtual animation and real space, allowing students to learn happily.

3.2.3 Medical treatment training

In medicine, doctors can use AR to diagnose, treat and even perform surgery. Immersive system are more and more used for training and educating doctors. AccuVein is an application that projects the circulatory system onto the patient's body to make it easier for the nurse to draw blood.[178] AR can also be used for plastic surgery, and patients can have an intuitive reconstruction result.[179]

Doctors can use AR technology to visualize the operation and training of surgical operations. Using a surface sensor, the patient's three-dimensional data information is collected in real time, and the corresponding image is drawn in real time, and is integrated into the patient's observation.[180] This is very useful for surgery. AR technology can make doctors need to be small, even without any surgical incision, to clearly see the patient's internal "anatomical view."

A research team scans the abdomen of pregnant women with an ultrasonic sensor and draws a three-dimensional image of the fetus at the corresponding part of the abdomen.[181] The doctor can then see the status of the fetus in the mother.[182]

3.2.4 Industry

AR technology is widely used in industry. A system interface is provided in modern cars for the diagnosis of problems and the analysis of the performance of different components of the engine. Although the manufacturers provide a connection for scanner with the car for in detail review of the engine status and other mechanical

[178] Khor, et al., 2016, p. 454
[179] Amin, 2011
[180] State, et al., 1994
[181] State, et al., 1994
[182] State, et al., 1994

parts, but the solution of problems must be carried using written instructions.[183] This problem demarcation and solution technique is experiencing a radical change using AR technology. AR technology allows a novice worker to understand the assembly of the engine and if a problem arises an inexperienced person can attempt to easily solve softcore issue using 3D models captured through a shared database.[184] AR has further the potential to show the results of the diagnosis integrated with the different engine components. The figure below demonstrates an AR based application for diagnosis of problem in an automobile.

Figure 16: Engine maintenance by placing the marker on the U-shaped object and place it near the engine[185]

A similar tracking and authoring AR-based system for Mercedes Benz is being implemented by Singh using a marker-based approach to user tracking and orientation. The marker was attached to an object that is U-shaped within the engine of the car so that the placement of the 3D model can be calibrated.[186] This technique is also useful when applying AR in the assembly because a single shape that is uniquely defined in an assembly can be used as a reference point over which all other parts can be traced. Singh used multiple markers to improve tracking

[183] Gabbard, Fitch, & Kim, 2014
[184] Lawson, Salanitri, & Waterfield, 2016
[185] Regenbrecht, Baratoff, & Wilke, 2005, p. 3
[186] Singh & Student, 2016

accuracy.[187] The system has been implemented by HMD and has been shown to improve the understanding of engine mounting and problem definition for inexperienced users without technical knowledge of the vehicle engine.

3.3 Instruction Techniques for AR in Assembly

As the main aim of the current research is to effectively enable the assembly worker to perform their tasks by following instructions in the form of 3D data models, analysis of the state of the art of instruction techniques through the use of AR is instrumental as well. *"A non-representative preliminary study comparing all instruction techniques suggested that our in-situ implementation worked better (i.e. more stable) on the HoloLens than on the Moverio BT-200."*[188] This conclusion is from a study conducted by Blattgerste et al. who compared four different techniques of presenting the instructions for assembly worker guidance.[189] The research study provides a good precedence for the current proposed system as the researchers not only compared the instructions provided in 3D format through Microsoft HoloLens in an assembly setting to the traditional paper instructions. But also compared them with provision of instructions through handheld device (smartphone) and a competitor of HoloLens (Epson Moverio BT-200).[190]Hence, their research tested instruction implementation in two formats: in-view implementation and in-situ implementation. In-view implementation is the one in which instructions are presented to worker through a handheld object in two-dimensional pictorial form; however, in-situ instructions are presented to the workers as 3D models displayed through HMDs. The researchers tested the implementation on Lego models which represented components to be handled in the assembly lines by the workers. According to Blattgerste et al. firstly concluded that for in-situ instruction for the assembly worker Microsoft HoloLens is the most appropriate choice depending on its usability and the response from the experimenters as compared to the Moverio BT-200.[191] The two figures below show a comparison of usage of In-situ instructions (through Microsoft HoloLens) and instructions through smartphone.

[187] Singh & Student, 2016
[188] Blattgerste, Herrema, & Siller, 2017, p. 3
[189] Blattgerste, Herrema, & Siller, 2017
[190] Phipps, da Silva, Cho, & Coppens, 2016
[191] Blattgerste, Herrema, & Siller, 2017

Figure 17: Left (Instructions provided through Microsoft HoloLens); Right (Instructions provided through smartphone).[192]

Blattgerste et al. compared the ways of instructions using three main criteria: Completion times, Errors registered, and cognitive load experienced by the user.[193] In addition, the results were measured through a qualitative approach as well. The researchers concluded after detailed quantitative and qualitative testing in control environments that Microsoft HoloLens present an option for the use of AR which considerably reduces the number of errors by the assembly worker when following the in-situ instruction provided.[194] The results for error reduction were statistically significant. However, the researchers concluded that use of Microsoft HoloLens did not considerably reduced time of instruction implementation when compared with 2D models.[195] The researchers concluded that for the optimum achievement of efficiency and effectiveness in providing guiding worker in assembly, the approach should be to use in-situ feedback for part demarcation and pictorial feedback to understand the complete assembly.[196]

Similarly, in their research Tang demonstrated that the use of HMDs considerably reduces the head movement and reduces the distances eyes must capture while performing an assembly task, hence this reduces the hinderances in the performance for the assembly workers. Furthermore, their research demonstrated that AR based instruction systems considerably reduce cognitive load and the probability of error in assembly tasks; as stated in conclusion: *“This study provides evidence to support the proposition that AR systems improve task performance and can relieve mental workload on assembly tasks.”*[197]

The use of AR as a benchmark for assembly work management is done by Funk. The researchers systematically evaluated various forms of instructions using AR technology. Thus, the most appropriate form and layout of instructions can be represented among many different data interpretation and 3D space modeling

[192] Blattgerste, Herrema, & Siller, 2017
[193] Blattgerste, Herrema, & Siller, 2017
[194] Blattgerste, Herrema, & Siller, 2017
[195] Blattgerste, Herrema, & Siller, 2017
[196] Blattgerste, Herrema, & Siller, 2017
[197] Tang, Herrema, & Romero, 2003, p. 7

techniques. The work of Funk et al. is of importance for the current study. [198] The researchers used a methodology from the General Assembly Task Model (GATM), which subdivided the task presented to the worker into assembly into four distinct phases: two task-dependent and two task-independent. The researchers also measured the cognitive load of the task using the National Aeronautics and Space Administration (NASA) Task Load Questionnaire. In addition, researchers compared different forms of instruction systems: traditional paper instructions, data model instructions on tablets, HMD-based view projection, and in situ projection.[199] The in-situ method projected the instructions interactively in real time, for comparison purposes the other three methods used similar pictorial forms of instructions. According to Funk et al. is the most suitable method for assemblers' guidance on HMD-based in situ projection.[200]

Similarly, Tang et al. have shown that the use of HMDs significantly reduces head movement and reduces the distances that the eyes must capture when performing an assembly task, thus reducing the obstacles to assembly worker performance.[201] In addition, their research has shown that AR-based education systems significantly reduce the cognitive burden and the probability of error in assembly tasks.

Sand et al. tested novices in the assembly to understand the task without prior knowledge. [202] They found that the inherent problems of cognitive burden, as experienced by workers when first using HMD, can be reduced if the instructions and models are projected directly onto the work area. Their work has been motivated by the predicament of using early-stage HMDs that were not stable when creating virtual data models. A similar instruction technique has also been reported by Rodriguez et al. Proposed, in which instead of using HMD, the command was projected directly onto a physical workspace for clarity. It should be noted, however, that the researchers in these two studies do not use advanced HMDs as a point of reference but base their claims from previous studies on the inefficiency of HMDs and AR for providing guidance. In addition, some studies have focused on the effects of changes in the models of models used for teaching in basic AR technologies and HMDs. Re et al. tested various ways to provide indicators in the implementation of AR statements, and they concluded that the most appropriate and efficient way to guide workers in assembly is the user's gaze to get feedback; However, such an implementation requires a prior training of the workers and there is a learning curve associated with controlling their view of accuracy in AR.[203]

[198] Funk, Dalle Mura, Caponio, & Salanitri, 2016
[199] Funk, Dalle Mura, Caponio, & Salanitri, 2016
[200] Funk, Dalle Mura, Caponio, & Salanitri, 2016
[201] Tang, Herrema, & Romero, 2003
[202] Sand, Engelke, Quint, & Adamovich, 2016
[203] Re, Oliver, & Bordegoni, 2016

3.4 Conclusion

Although in the last decade tremendous amount of research has been conducted in the application of AR in various domains, but the conducted studies were limited to the experimenter's laboratory and were not specifically designed keeping in view the requirements and dynamic of a real industrial setting. The research specific issues and the limitations of previously conducted studies are given in detail in the summary table, in this section shall focus on the generic issues in the state of the art which makes the current study viable. It can be extrapolated from the studies analyzed that the focus of the most appropriate assembly worker guidance system was on the usage of tablets for AR. Furthermore, given that the technology in AR, specially the tools such as the HMDs are still evolving, it was noticed in the previous studies that the capabilities of HMDs were not utilized to the fullest. A thorough study of the application of AR in assembly for worker guidance demonstrates that none of the systems proposed all in one integration of the data modeling tools, the in-situ projection and the collaborative server-based systems at the same time in a single application. Although Microsoft HoloLens was used for implementation of AR systems in the previous works but the database and server at the backhand specially designed for Microsoft HoloLens was not brought into use.

As demonstrated in this section the use of technology for achieving full potential of an AR based data centered system is limited and researchers focused on just making incremental changes such that they can achieve better results as compared to traditional methods of instructions and assembly handling tasks. The maximum capability and usability of HMDs is not tested. Furthermore, researcher made use of early stages of HMD prototypes and they did not focus on deciphering the limitations of such HMDs for their potential for making the job stress full due to their unconventional build.

It can further be distilled from the analysis of state of the art that no single system for worker guidance in assembly exists which integrates the state-of-the-art techniques in all components of the system from instruction presentation techniques to use of collaboration, context awareness of the workers, tracking and authoring etc. Such processes require higher computing power and HMDs with built-in Digital Signal Processors, Visual processing units and Application Specific Built Integrated Circuits. Hence, the latest tools for AR implementation are the need of the hour for assembly worker guidance as a lot of information is to be gathered, processed, and then communicated through 3D spatial overlays in real time; in the previous researchers analyzed the used techniques and tools by the researchers had considerable limitations which rendered them inefficient for assembly lines.

The major issue with the experiments conducted in the past is their inability to be replicated in a real industry 4.0 environment as most of them are tested using students as a sample. This issue can be further established through the research conducted by Webel as they showed that in performing industry task many skills are to be used in parallel such as the motor skills, and procedural memory which cannot be replicated in a laboratory as the stakes for the participants for error avoidance is not high.[204] Such skills as defined by the researchers can only be acquired through vast assembly experiences. In a real assembly environment, the workers deployed are much experienced in using such skills hence extrapolating results based on experiments conducted by students cannot stand true for real assembly workers. Such limitations point towards the subjectivity of the recent research studies analyzed.

As it can be seen from the table with research summary most of the experiments were limited to laboratory and most assembly-based systems were tested over LEGO assembly. Such environments have completed different sets of issues associated with implementation. According to the state-of-the-art application through the HMDs it was analyzed that the technology of HMD had considerable limitation before. However, with the Microsoft HoloLens these limitations can be subsided as the technology has further enhanced. Previously the activation of HMDs was voice dependent which was not feasible for a factory environment given that the factory environments are very noisy. Hence, previous researcher did not consider the problem that not much of voice commands can be employed for assembly.

The fact that the cognitive stress of the workload and the tool management plays an important role in diffusing the energy of the workers, restricting research to just time measurement for deciphering efficiency is not a good strategy. It can be concluded from the analyzed research that most of the assessment principles are driven by achieving lower times to assembly and none of the research seem to take a more long-term approach for efficiency and effectiveness for AR systems.

Furthermore, the previously used tools for AR are not very suitable for assembly environment as workers must work very fast alongside robots and they must have a clear vision with minimum hindrances in sight. Hence, enabling wider field of view presents a challenge which has not be addressed in the previous researches. A good approach shall be for this thesis to consider the line of sight of the workers using the HMDs and enable them to have wider angle view. As the tools are required to be used as wearable and for longer periods of time in the assembly line, one important factor to consider is to ensure the comfort of the workers in their gear. Although previous studies considered the cognitive impact using tools for AR created on novice workers but not many researchers concentrated on the general eye and head tiredness that might result from extended use of the gear.

In previously implemented systems for assembly it was analyzed that most of them made use of a reference point which is usually a shape identified in the assembly.

[204] Webel, et al., 2013

The resistance to occlusion was also limited in many researches. However, such approach limits the flexibility of use of the tools as in industry 4.0 environment constant customization results in variability in the assembly which might not provide a reference point with every operation. This problem has been solved in the application of AR in other fields such as entertainment as seen in the previous section. Hence, a more enhanced approach shall be to deploy the hands of the worker as reference point and use algorithms (used in application of AR for other industries but not manufacturing and assembly) to identify the shape and state of the assembly.

It was further noticed that not much focus was given to the user experiences for the tools integrated in the assembly line. Due to requirement of greater efficiency and quality in the assembly lines the user interface shall be considered for all sorts of impact such that minimum stress can be experienced by the workers and they can have access to information instantly and accurately. It was analyzed in the state-of-the-art implementations that the studies which concentrated on the technology aspect of the AR tools and techniques somewhat restricted their approach for enabling better user interface simultaneously. This is the major reason why a standalone and dependable AR implementation system does not exist in the market for assembly workers with the state-of-the-art functionality in all domains.

4 Concept

Software system development is completed in stages. According to Section 1.1, software development can be mainly divided into the following stages:

• Study the relevant literature on worker guidance and AR as well as the state-of-the-art research on existing solutions

• Derive the requirements

• Develop the general and fine concept

• Develop / program the AR worker guidance

• Document the process

Following on from the advantages and disadvantages of the analysis in Chapter 3, the development concept of Microsoft HoloLens is outlined in this chapter. At this stage, the software design requirements are determined, the programming language selected, and the software development process and steps determined. In this section, the technical specifications for functionality implementation are determined.

It is necessary to clarify the purpose of the system, which is to assist workers in installing 3D printers using the AR- assembly worker guidance system provided by Microsoft HoloLens. Having analyzed the literature, the status of AR discovery and the development status of AR- assembly worker guidance system can be understood. The software development results are expected to provide a new AR- assembly worker guidance system unlike traditional media, thus helping workers to obtain better information.

The system design can be divided into two stages: general and fine.

In the general design, it is necessary to divide the system into modules, determine the function of each module, outline the user interface, state the data inputs and outputs, assess the connection between these data, process the analysis, determine the database table logic and identify the hardware and software development platform.

At this stage of the detailed design, each module can be assigned to different people for parallel design. In the detailed design phase, the designer's work object is a module. Moreover, the designer designs and expresses the module's algorithm, process, state transition and other content according to the local task and external interface provided by the summary design. It should be noted that, when structural adjustments are necessary (such as submodule decomposition), one must return to the outline design stage and adjust the summary design document, rather than solely solving them locally. The most important components of the detailed design document are the flow chart, state diagram, local variables and corresponding text descriptions of the module.

4.1 Hardware and Software Development Platform

Unity3D software: Visual models are created with Unity3D and the multi-platform development tools to produce interactive content. The program written can publish games to the Windows UWP platform.

Server: A stable web server is implemented via Raspberry Pi to provide a foundation for data transfer.

4.2 System Structure

The developed assembly aid system allows Microsoft HoloLens to read assembly information (pictures, text, 3D models etc.) via WLAN communication and display them in the glasses. Figure 1 outlines the relationship between these components.

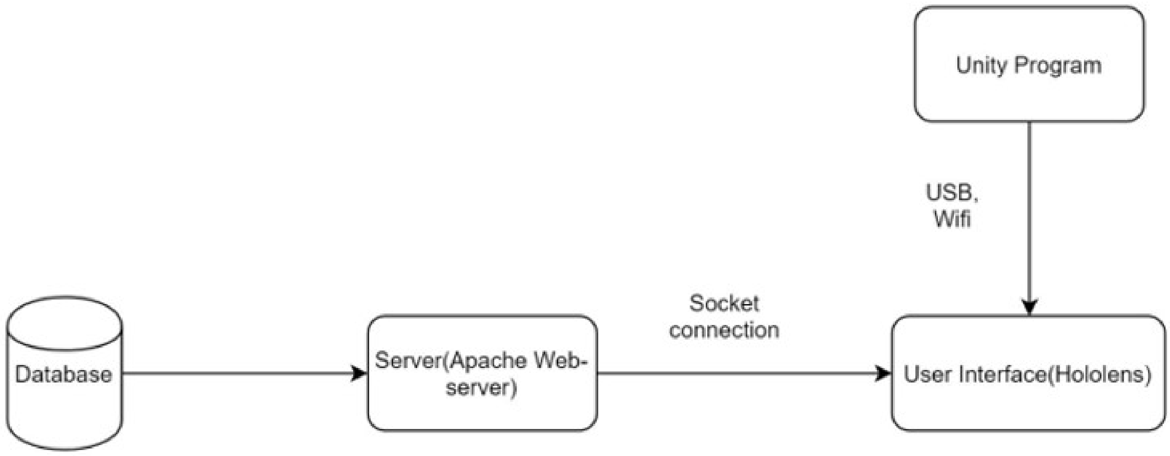

Figure 18: Overview of the assembly worker guidance system

4.3 System Function

As described in Chapter 2.2.4, Microsoft HoloLens is essentially a holographic computer built into a headset that lets user see, hear, and interact with holograms within an environment such as a living room or an office space.[205] The development of the worker guidance system needs to take full advantage of the existing features

[205] https://www. Committedreviews.com/opinion/hololens-release-date-news-and-price-2922378 (22.02.2019)

of Microsoft HoloLens. Therefore, there should be functions allowing workers to get visually Information, such as text, images and 3D models), Text-to-speech (TTS) and interactions with holograms (such as voice commands and gestures) to obtain the required information in different ways. As described in Chapter 2.2.5, this various way of providing information can let the workers better understand the assembly and the accomplishment of the task with the least amount of effort. Although Microsoft HoloLens was used for implementation of AR systems in the previous works but the database and server at the backhand specially designed for Microsoft HoloLens was not brought into use.[206] This thesis is to fill this gap, so related functions have been developed to allow workers to capture relevant information through the database to solve related problems. This database is similar to the study done by Erkoyuncu et al.,[207] however this thesis uses phpMyAdmin as the database platform.

Hence, this system must possess the following functions:

Voice command input

Voice commands include all commands that workers need to interact with Microsoft HoloLens when installing the printer, such as the next step, the previous step, repeating current steps and selecting different assembly methods, all of which require corresponding voice commands.

Gesture input

Gesture operations function identically to voice command operations. All workers can interact with Microsoft HoloLens and must be able to do so using only gestures. Thus, workers can access information in any environment (such as noisy environments) using gestures alone.

Various forms of assembly instructions for text, images, 3D models and voices

One benefit of AR-assembly worker guidance systems compared to traditional manuals or flat-panel assembly instructions is that AR can provide workers with a full range of 3D information displays. Hence, the software should make full use of the advantages of AR by providing information to workers through various mediums, such as text boxes, pictures, real 3D models and AR-based assembly instructions to help workers to understand the assembly more comprehensively. Consequently, worker's operational efficiency can be improved and the turnover rate reduced.

[206] See Chapter 3.4
[207] Erkoyuncu, del Amo, Dalle Mura, Roy, & Dini, 2017

Real-time retrieval database

The advantage of real-time network database retrieval is that the program itself can be separated from the database so that the database can be changed at any time without updating the program. Thus, program size is reduced and database flexibility enhanced.

Other useful features

Workers can implement moving text boxes or 3D models using voice command or gesture operation. Moreover, it must be possible to change the server IP address where the database is stored at any time. If the server IP address changes, workers only need to change the corresponding IP. Changing the entire program is not necessary.

In order to understand the current development environment and conditions, the theoretical basis of software development must be determined based on the literature and the development environment and conditions currently available in 3D printers must be understood.

In addition, product functions must consider practical problems by being able to achieve their own technical capabilities. From the perspective of economic efficiency, these functions should be practical. These functions are consistent with the development of AR- assembly worker guidance system.

4.4 System Inputs and Outputs

Section 4.3 briefly described several major functions of the system that implements the inputs and outputs. The relationship between them is shown below:

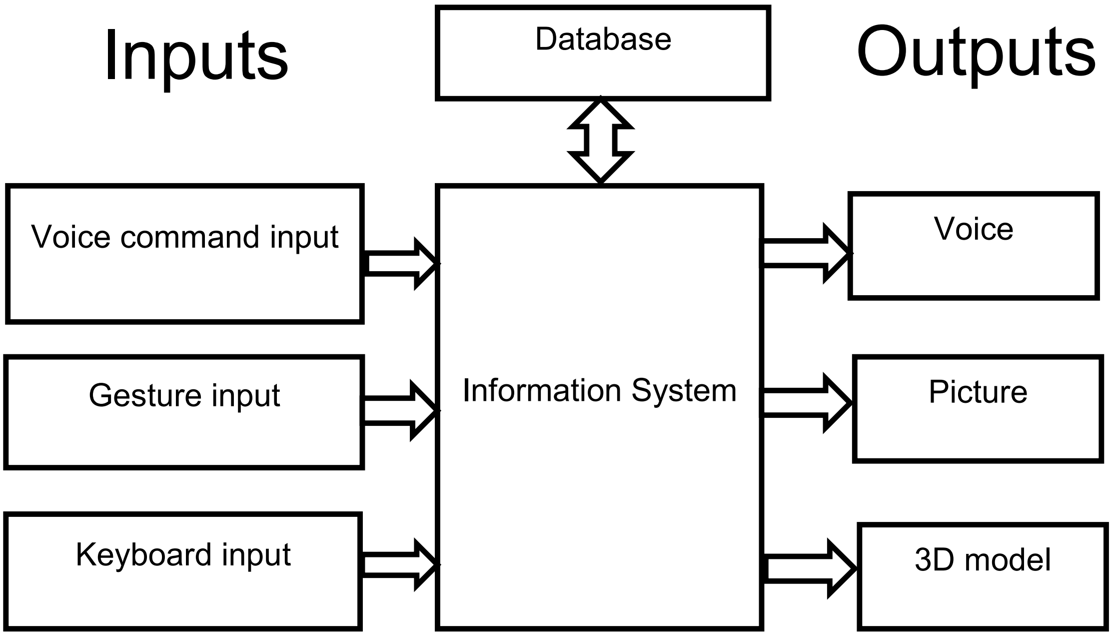

Figure 19: System inputs and outputs

4.5 User Interface

The Microsoft HoloLens features sensors, 3D optical head-mounted full-angle lens displays and surround sound, thereby allowing interaction with the user through the eyes, voice and gestures in AR. The user interface must include the text information (topic specific and assembly instructions) for installing the 3D printer, pictures for each step and the 3D model. In addition, there are function menus, which can be hidden and accessed at will.

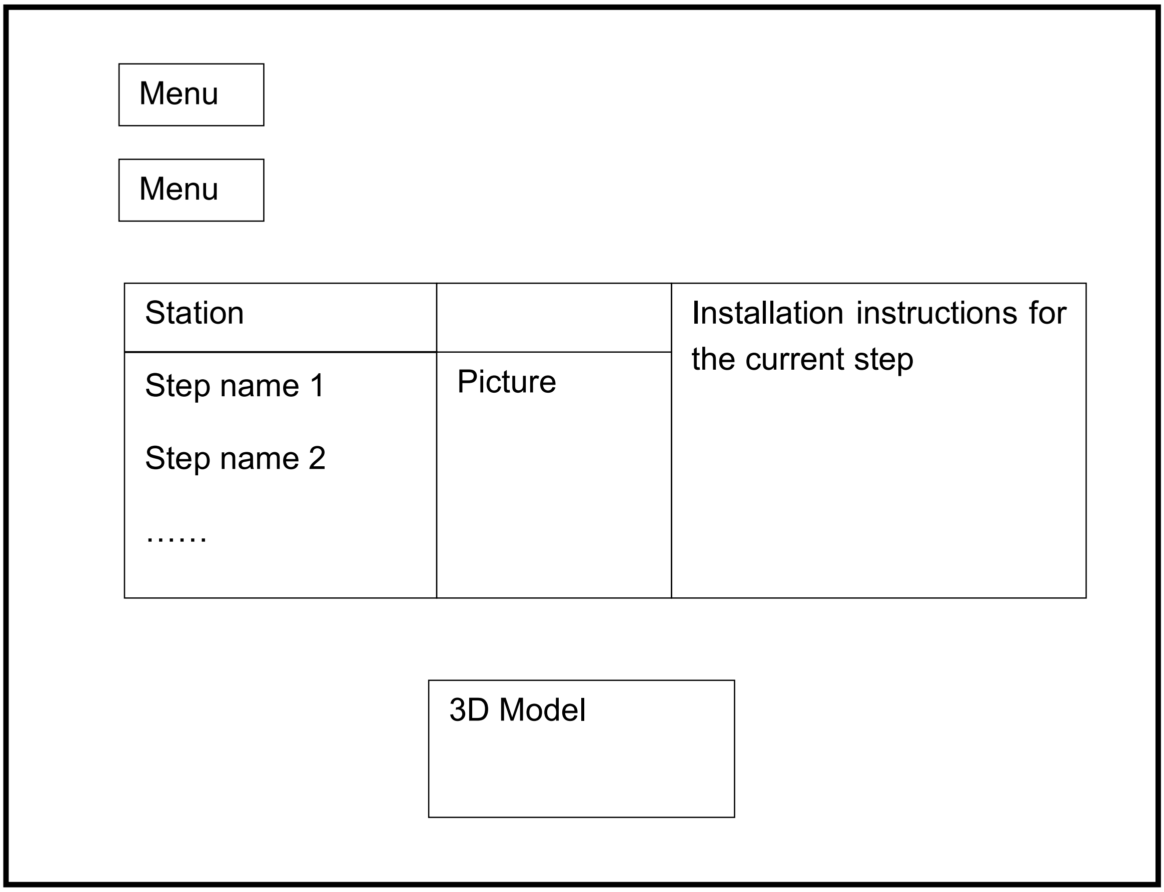

Figure 20: Microsoft HoloLens user interface layout

As shown in the figure above, the top left corner of the interface consists of a list of two menus, which can be opened and closed. The first menu list contains features for selecting related methods and general setup features. The second menu list includes specific features displayed in the assembly instructions. This interface module can be adjusted at any time according to user needs. Hence, it is convenient for the user.

4.6 Process Analysis of Voice Command

The following figure shows the approximate flow of the voice command program:

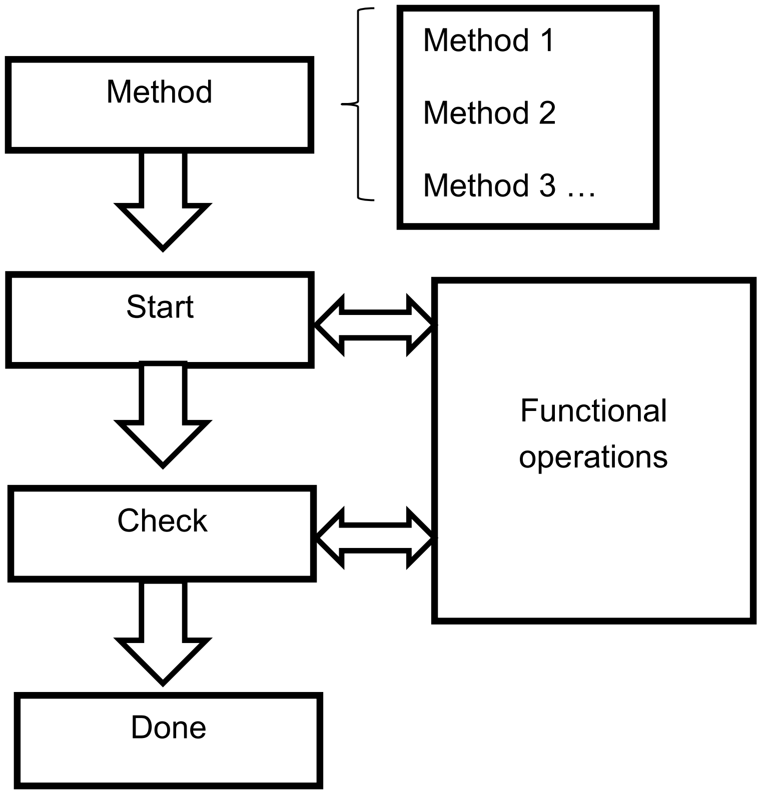

Figure 21: Approximate flow of the voice command program

The above diagram shows the basic flow of voice commands. First, the user must select the correct assembly method for the 3D printer. Then, Microsoft HoloLens reads the data for the corresponding assembly method in the Raspberry pi database through the network. The data includes a zip file containing all the 3D models of the assembly steps, pictures and texts for the steps and the title information. Dynamic pictures are displayed during the reading process to inform the user that the file is being read and to proceed to the next step after reading.

After the file is read, the user can initialize the program using voice command, activate the initialization settings for various commands and access the information, including the first step assembly. For example, the model movement command is set to "immovable".

Whenever the user completes a step, they can use the voice command "check" to proceed to the next step. At this point, all assembly information is updated to contain the information in the next step. These commands, including model movement, are also automatically set to the initial value "immovable".

When the user enters the last step, the system prompts the user to complete the operation.

The whole process should be flexible so that the user can freely jump from the current step to the first step regardless of the step. In other words, the assembly method selects this step. In addition, the user should be able to perform all the settings allowed under the current step, as well as the overall settings (such as changing the database IP address), regardless of the current step.

Since the gesture command flow and voice command flow are the same, the gesture command program flow is not repeated.

4.7 Program Module Design

The program module includes the following aspects:

UI design

The unity's GUI is used to produce designs according to the interface layout in Section 4.5.

Data reading

Control data is transferred over the network from the Raspberry Pi to the Microsoft HoloLens.

Voice command control

Various voices can be used to achieve the corresponding functions.

Feature design

Various functions are achieved.

4.8 Logical Design of Files and Database Tables

The assembly assistance system data consist of three different types - step, procedure and product.

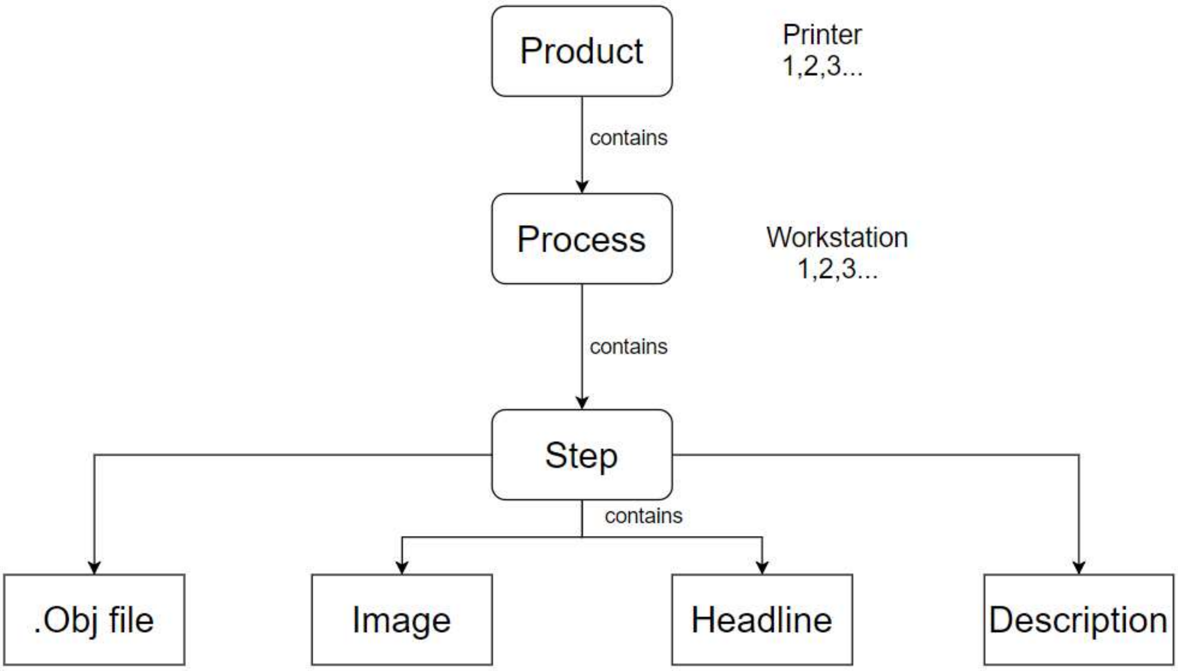

Figure 22: Data structure concept

Product

The product constitutes a different type of 3D printer. Different products have different assembly methods. The product contains the following information:

- Printer ID

The Printer ID is the only differentiated authentication that can identify the 3D printer. Arabic numerals are used, starting from 1 and descending according to the smoothness of the added printer.

- Printer name

The printer name is the name of the 3D printer itself. Since each 3D printer model is slightly different, each 3D printer has its own unique name.

- Model ID

Since each printer uses a different assembly method, each printer follows a different model which contains all the parts in the 3D display and is stored in the database as a zip file. The same model can be applied to different printers.

- Date of last update

The date the printer was last changed.

- Date created

The date the new printer was created.

- Status

Status 'A' stands for active printer or active record, while status 'I' stands for inactive printer.

Model

The model contains the following information:

- Model ID

The model ID is the only differentiated authentication that can identify the model. Arabic numerals are used, starting from 1 and descending according to the smoothness of the added model.

- Model name

The model name is the name of the model itself.

- Date of last update

The date the model was last changed.

- Date created

The date the new model was created.

- Status

Status 'A' stands for active model or active record, while status 'I' stands for inactive model.

Step

During assembly, the workpiece can occupy different positions for continuous processing, with the part of each position completed. The steps cover each single step and are the smallest of the three data types. Step contains the following information:

- Step ID

The step ID is the only differentiated authentication that can identify the step. Arabic numerals are used, starting from 1 and descending according to the smoothness of the added step.

- Step name

Step name is the name of the step itself, which describes the assembly work that needs to be done in this step.

- Step image

Step image stores the images that need to be displayed in this step.

- Step obj

Step obj stores the 3D model that needs to be displayed in this step. Since the 3D model stores the 3D model of each step in a zip file, all the step obj's of a printer are the same. The program automatically reads the step obj of each step-in order.

- Step mtl

Step mtl is generally empty. The material-related settings are already completed in Unity unless special materials are required.

- Step description

Step description specifies the assembly method of the current step.

- Step headline

Step headline is the headline displayed in the current step. In general, the headline displayed at each step is the same.

- Printer ID

The Printer ID shows the printer ID of the current step.

- Date of last update

The date the step was last changed.

- Date created

The date the new step was created.

- Status

Status 'A' stands for active step or active record, while status 'I' stands for inactive step.

5 Practical Implementation

In this thesis, a detailed plan must first be developed and then each step carefully studied and designed before the final product is completed. Moreover, all details are documented as much as possible.

The first step is to determine the software development engine. In the first step, the Unity engine is used to develop Software for Microsoft HoloLens glasses. PHP and MySQL are used to create and manage databases. The waterfall model is used in the development framework. In the waterfall model, software development activities are performed linearly. Hence, the current activity must accept the results of the previous activity and then execute the following activity. The current activity's results need to be verified. If verification is successful, the results are used as the input for the next step. Otherwise, the final change step should be completed. This section leads to the implementation of the 3D printer component assist system, which is then evaluated in the "Printer Components" section of the next section and evaluated against the user questionnaire.

5.1 Software Development Schedule

As described in the previous section "software developing model", this thesis uses the waterfall model. The following is a combination of the waterfall model and the actual thesis situation, which depicts the thesis development process in detail.

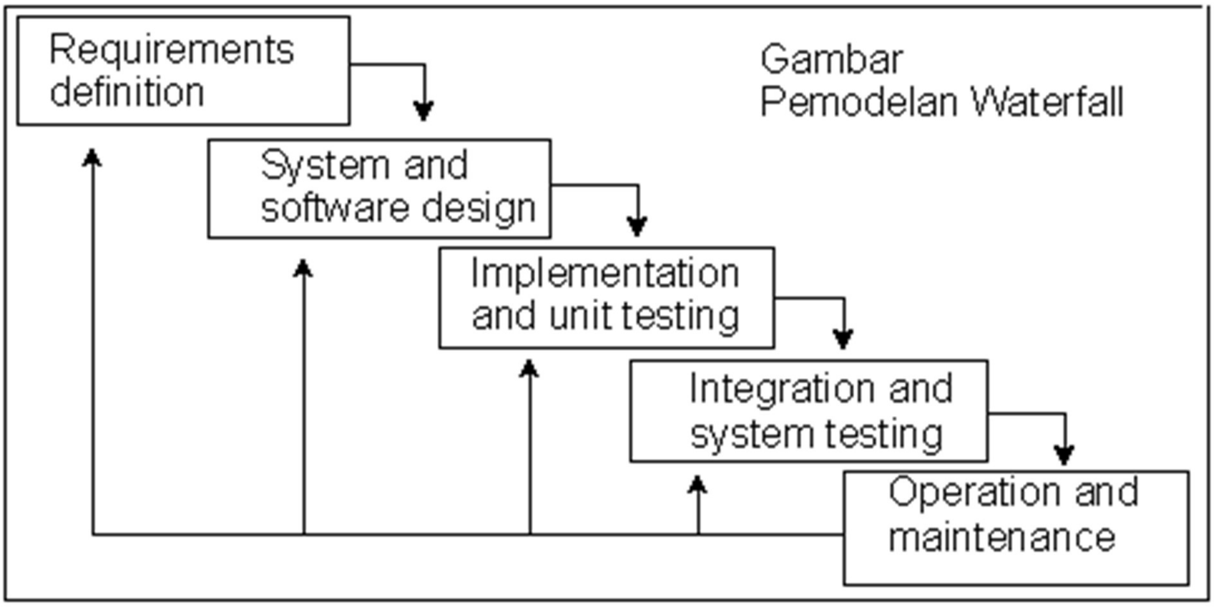

Figure 23: Processes of the waterfall model to be followed in this thesis[208]

[208] http://tonyjustinus.wordpress.com/2007/11/11/ (21.12.2018)

5.2 Interface Function

3D Printer assembly is achieved by running the application on the Microsoft HoloLens. The application was developed on a unified platform and can be run on a UWP platform (such as the HoloLens x86 emulator). Then, it was compiled with Visual Studio and finally installed on Microsoft HoloLens. The program can interact with staff, including gestures and sounds, in order to help workers to perform AR-assembly worker guidance system on 3D printers. Once the appropriate application has been run, it can be launched in Microsoft HoloLens.

The application has two main functions: voice command control and gesture control (interactive panel). Voice command control is generally used because it is convenient and fast. In special circumstances, such as when ambient noise is relatively large, voice control cannot achieve good interaction and so gesture control should be used instead.

5.2.1 Voice control

Using voice control allows workers to easily interact with Microsoft HoloLens in order to retrieve the desired information.

The voice control flow is as follows:

In the program, there is only one Space anchor before the user's eye. The worker says, "method x[209]", and the program retrieves the corresponding contents from the Raspberry Pi database via wireless network. Figure below shows the interface for the assembly method selection:

[209] x can be 1, 2, 3, 4, which respectively means method 1, method 2, method 3 and method 4.

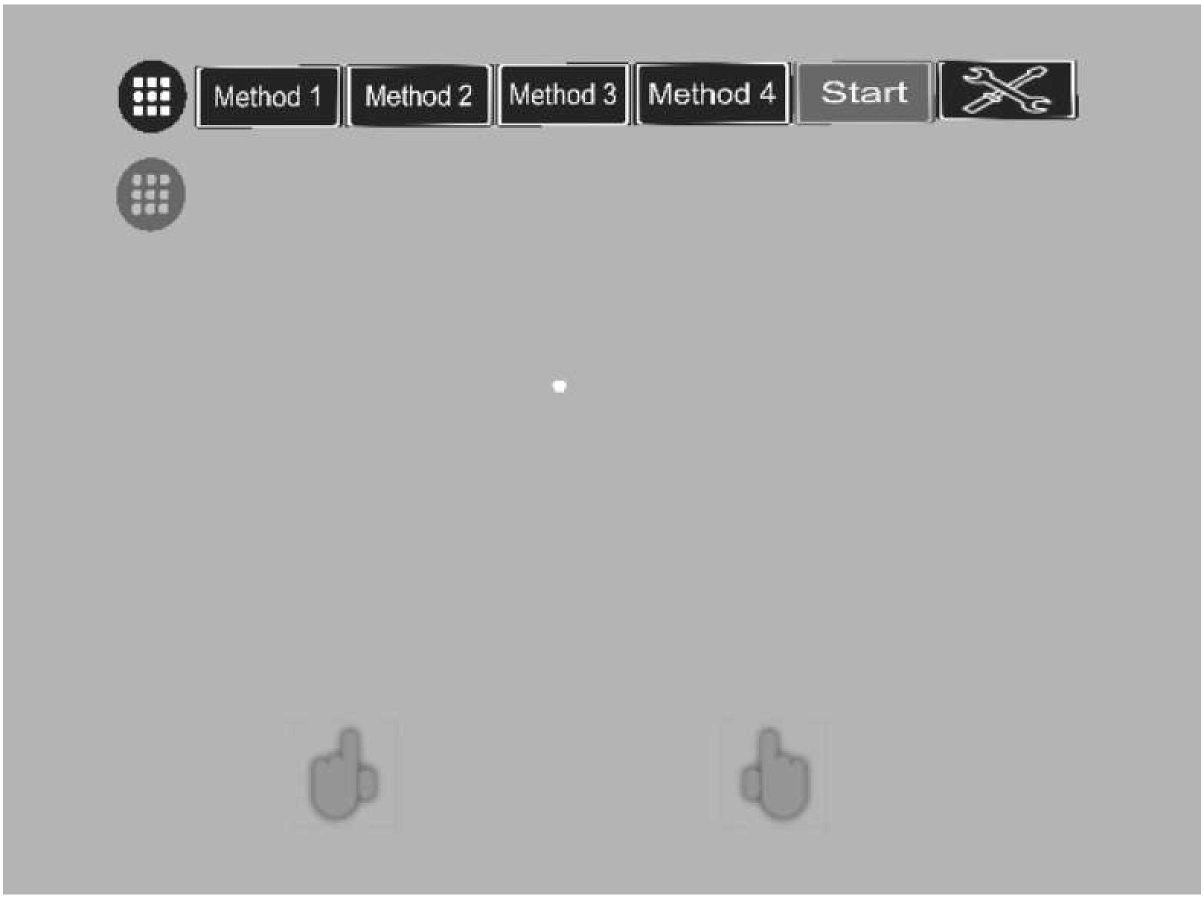

Figure 24: assembly method selection interface on Unity emulator[210]

The code for method 1[211] is shown below:

[210] The background should be black in Microsoft HoloLens, in this case the background is set to gray for clarity.
[211] Due to the time limitation, only method 1 to method 4 are programmed in script, if there are more assembly methods in the future, more methods should be added.

```
        switch (voice)
        {
            case "method one":
                {
                    GameController.instance.OnClickMEthodButton();
                    commandCube.SetActive(false);
                    commandCube.transform.localScale = Vector3.zero;
                    for (int i = 0; i < NewPrint3DObj.transform.childCount; i++)
                    {
                        NewPrint3DObj.transform.GetChild(i).gameObject.SetActive(false);
                    }
                    settingButton.GetComponent<UIController>().isOpen = false;
                    ClearData();

                    APIController.instance.ApiCall(1);
                    for (int i = 0; i < commandText.Length; i++)
                    {
                        if (i == 0)
                        {
                            commandText[i].GetComponent<TextMesh>().color = Color.white;
                        }
                        else
                            commandText[i].GetComponent<TextMesh>().color = new Color32(111,
                                111,111, 255);
                    }
                    PrinterState = 0;
                    GameController.instance.gameOverText.SetActive(false);
                    GameController.instance.loadingImage.SetActive(true);
                    break;
                }
```

Figure 25: Voice control code: install method call

After Microsoft HoloLens hears the voice command "Method 1", execute the following command:

- The “start” function and “start” button of the first function menu is set to "Activated", so that the next voice command "start" can be performed for initialization.
- The second function menu is set to "inactive".[212] The forward, backward, repeat, move, go and other commands in the function menu are not available.
- Download the text, images, and 3D models required for "Method 1" from the server, but the display of these messages is set to "not displayed".
- The first description text is white, and the rest of the them are gray.
- Set "The work is done" message to “not displayed”.

After selecting the assembly method, the assembly interface should be initialized. Use the voice command "start" to make the text description and "3D model" that were previously set to "not displayed" displayed in the user interface. At the same time, all functions of the second menu are activated.

[212] The default is not activated, just to ensure that these functions cannot be activated in current step.

In this instance, the text in the language command box is shown as white text and the title ("PFSeqenzen station 1"). Hence, this is station 1 in the assembly working process. The first step ("Frame below") is highlighted in white. At the same time, a text box with specific instructions for the first step "Frame below" pops up, in this case is " Place 4x lower frame parts (items 1, 2, 3) in the device as shown and align", and the corresponding picture (in this case it is 1010.png) from the database is displayed. The content is as shown in Figure below. Similarly, the printer part as 3D model is also displayed in red as shown in Figure:

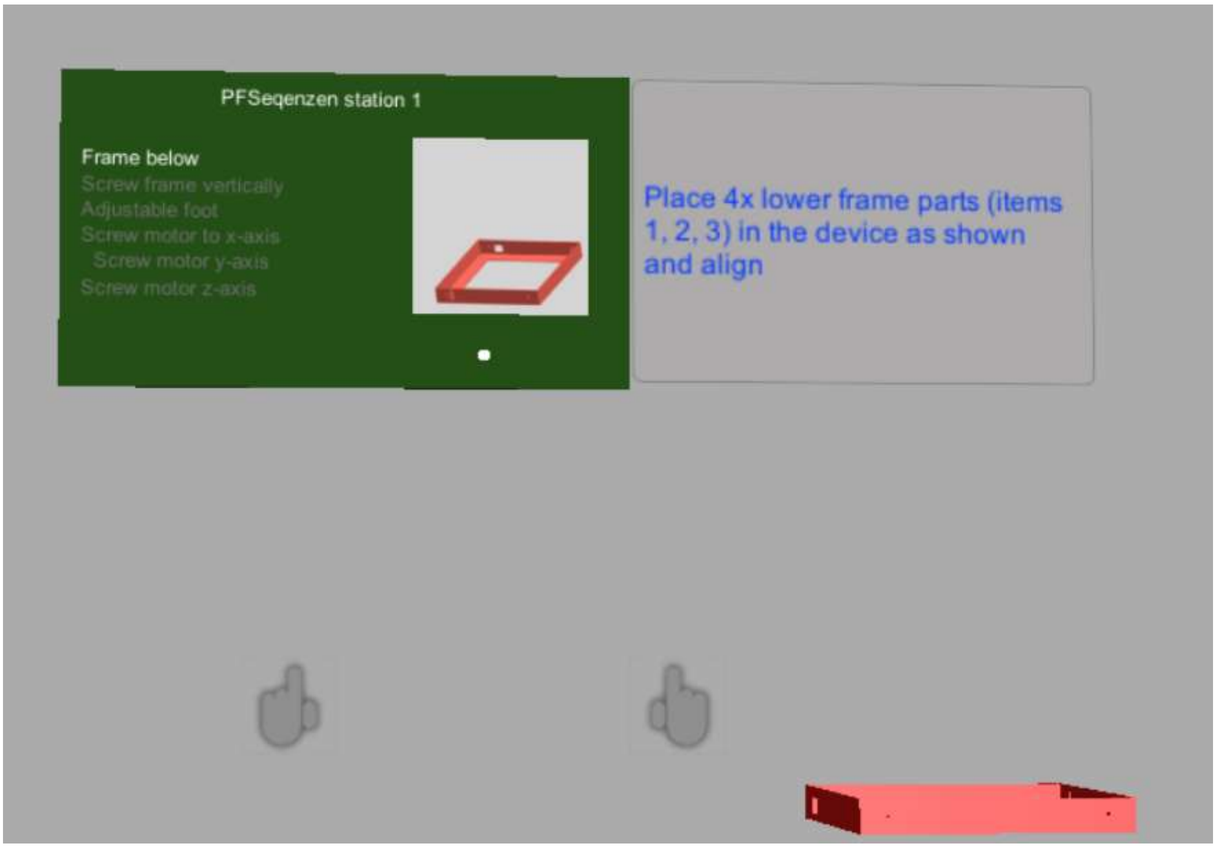

Figure 26: User's interface of station 1 on Unity emulator

By saying “check”, the Microsoft HoloLens knows that the previous step has been completed. At this time, the first operation instruction "Frame below" in the command prompt box becomes dark, while the second step instruction ("Screw frame vertically") becomes white. Furthermore, the text for the first step-by-step operation description ("Place 4x lower frame parts (items 1, 2, 3) in the device as shown and align" disappears, while the text box for the second detailed operation description appears " Place the 4x vertical frame (item 4) and screw it together with the lower frame members (2x M6x8 flat head screw) ", as does the corresponding picture for this step (1030.png) At the same time, the red pedestal prompt box disappears and the second step user's interface appears as shown in Figure:

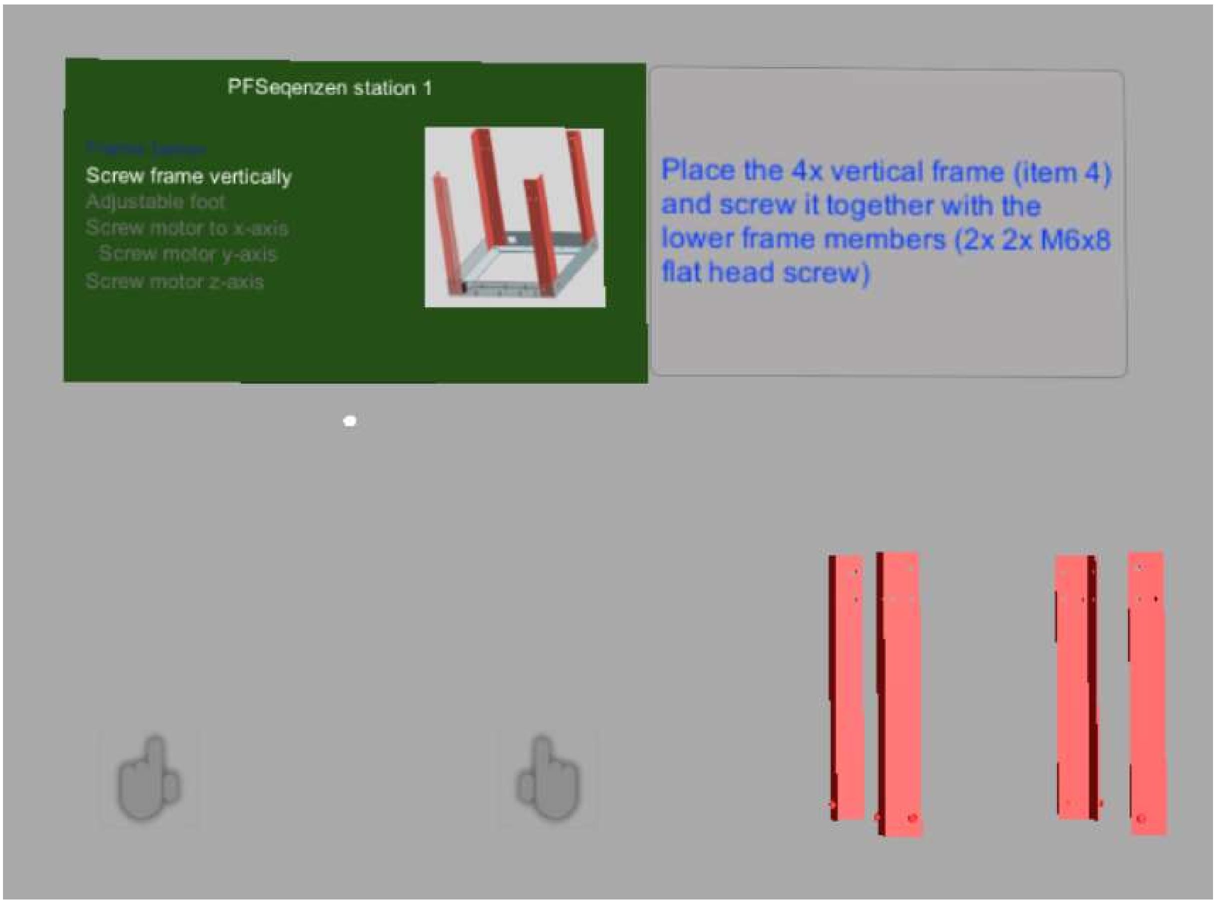

Figure 27: User's interface of station 2 on Unity emulator

Each conversion step requires programming in the check voice command. Only the code from the first step to the second step check command is shown here.

```
case "check":
  {
    {
     if (sType == stateType.ready)
      {
            TitleObj.GetComponent<TextMesh>().text =
            gameController.instance.printerData[PrinterState].headings[1];

     if (commandText[0].GetComponent<TextMesh>() == null)
            commandText[0].AddComponent<TextMesh>();
            commandText[0].GetComponent<TextMesh>().color = new Color32(23, 54, 129, 255);
     if (commandText[1].GetComponent<TextMesh>() == null)
            commandText[1].AddComponent<TextMesh>();
            commandText[1].GetComponent<TextMesh>().color = new Color32(255, 255, 255, 255);
            NewPrint3DObj.GetChild(1).gameObject.SetActive(true);
            ChangeColors(NewPrint3DObj.GetChild(0), WatMat);
            ChangeColors(NewPrint3DObj.GetChild(1), RedMat);
            sType = stateType.firstOver;
            ShowTexObj.GetComponent<MeshRenderer>().material.mainTexture =
            GameController.instance.printerData[PrinterState].imageTexture[1];
            ShowMessageObj.GetComponent<UnityEngine.UI.Text>().text =
            GameController.instance.printerData[PrinterState].descriptionText[1];
           StartCoroutine(TexttoSpeech(1, 0.5f));
     }
```

Figure 28: Voice control code: check command

From the above figure, the following command was executed after using the voice command "check":

- The current text description turns dark blue and the next text description becomes white.
- The current picture and 3D model are no longer displayed, showing the next 3D model.
- Start the next step of Text to Speech.
- The printer assembly state is updated to the next step of the printer assembly.

The subsequent assembly steps are followed by the same steps as before, until the assembly step in station 1 has been completed. The text description "The work is done" appears, prompting the assembly to terminate.

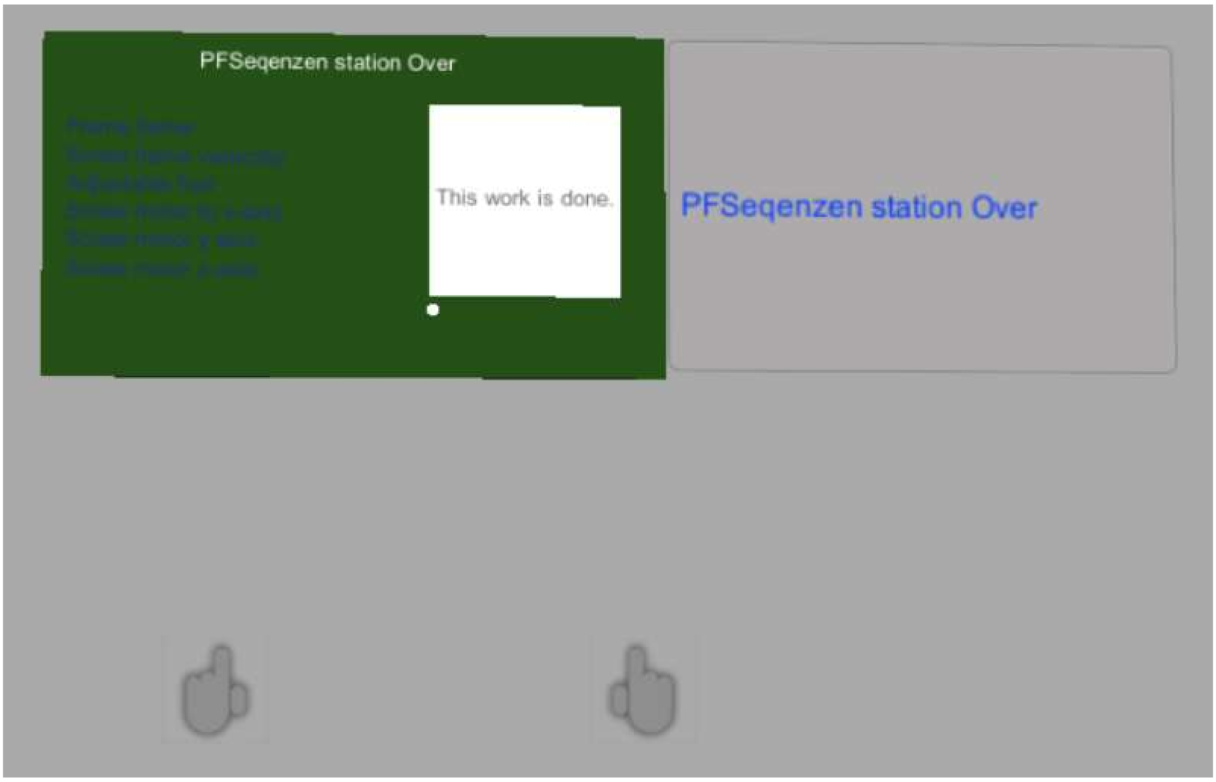

Figure 29: User's interface if work is done on Unity emulator

5.2.2 Gesture control

All voice controls can be replaced with gesture controls in order to prevent workers from using voice control and the Microsoft HoloLens from interacting in special situations. There are two gesture control panels which control the call assembly method and assembly flow control. Gesture control uses the control panel shown in Figure:

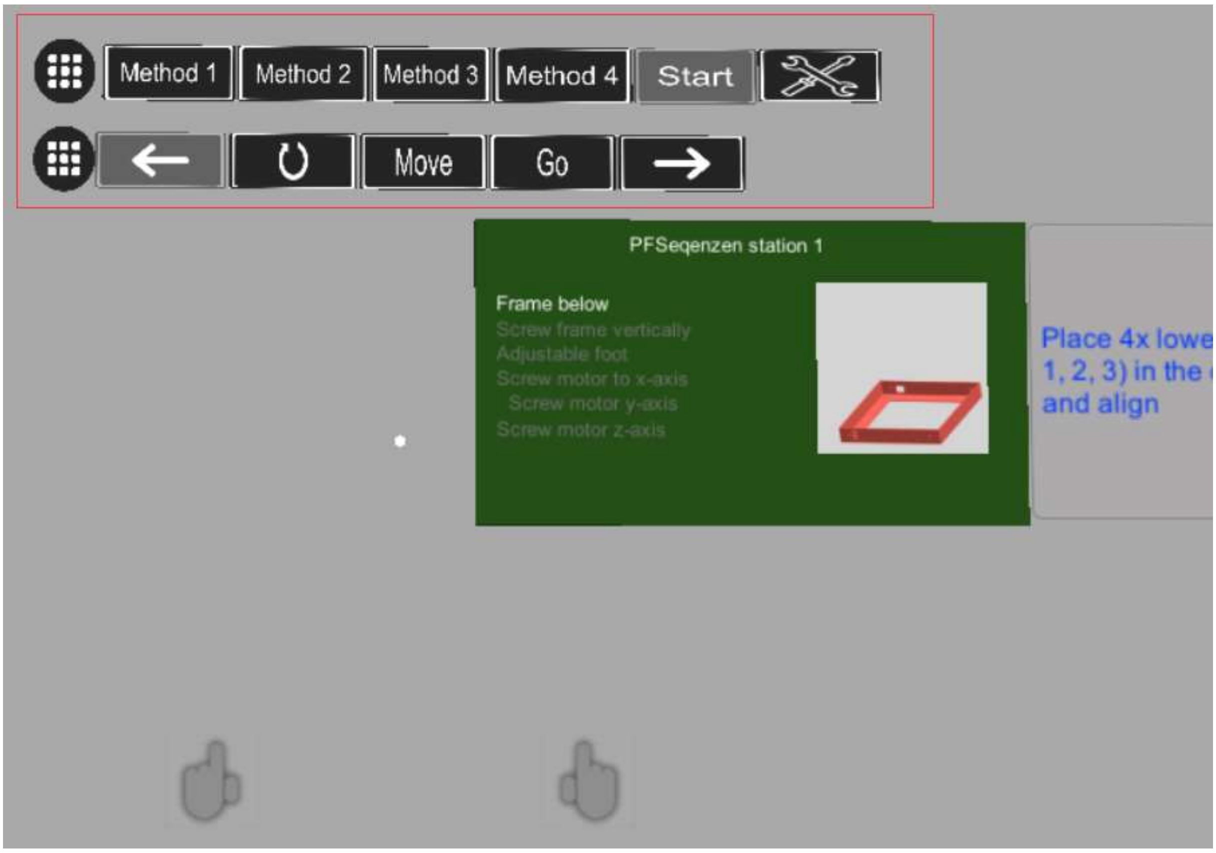

Figure 30: Gesture Control Panel on Unity simulator

The first row of panels is the control call method and initialization. In the current version, Method 1, Method 2, Method 3 and Method 4 can be called separately. After calling one of the assembly methods, one can click "start" to initialize this assembly method.

Panel control has the following features:

• Back function: The user can return to the previous step.

• Repeat function: The user can re-listen to the voice description of the current step.

• Settings: The user can set the access IP address of the web server.

• Move: Users can move the assembly instructions at will.

• Go: Users are free to move 3D printer parts.

Back function

```
case "checkwithbackwarddir":
  {
    if (sType == stateType.finish)
     {
       TitleObj.GetComponent<TextMesh>().text =
GameController.instance.printerData[PrinterState].headings[6];
    if (commandText[5].GetComponent<TextMesh>() == null)
        commandText[5].AddComponent<TextMesh>();
        commandText[5].GetComponent<TextMesh>().color = new Color32(23, 54, 129, 255);
        if (commandText[6].GetComponent<TextMesh>() == null)
            commandText[6].AddComponent<TextMesh>();
            commandText[6].GetComponent<TextMesh>().color = new Color32(255, 255, 255, 255);
            NewPrint3DObj.GetChild(6).gameObject.SetActive(true);
            ChangeColors(NewPrint3DObj.GetChild(5), WatMat);
            ChangeColors(NewPrint3DObj.GetChild(6), RedMat);
            GameController.instance.gameOverText.SetActive(false);
            sType = stateType.SixthOver;
             ShowTexObj.GetComponent<MeshRenderer>().material.mainTexture =
             GameController.instance.printerData[PrinterState].imageTexture[6];
              ShowMessageObj.GetComponent<UnityEngine.UI.Text>().text =
              GameController.instance.printerData[PrinterState].descriptionText[6];
              StartCoroutine(TexttoSpeech(6, 0.5f));
       }
```

Figure 31: Voice control code: Backward command[213]

The back function and check function are the opposite (check is for the next step, back is for the previous step). From the above figure, the following command is executed after using the "back" button:

- The current text description turns dark blue and the text description of the previous step turns white.
- The current picture and 3D model are no longer displayed, showing the previous 3D model.
- Start the previous step of Text to Speech.
- The printer assembly state is updated to the previous step of the printer assembly.

Repeat function

When the repeat function(or restart function) is executed, the program will determine the status of the current printer assembly step. If the assembly status is "has not started yet", the program will not execute any commands.

If the assembly status is "Installing", the program repeats the voice command of the current step.

[213] Only the code from the last step to its previous step is shown here.

If the assembly status is "Assembly Complete", the program repeats the voice command "PFSeqenzen station Over".

In other cases (if there are special circumstances), the program returns to the previous assembly state, and then executes the check command (that means, to the next step).

Settings

Currently there is only one function: change the ip address of the server. In addition, the setting button is always activated, preventing workers from re-entering after incorrectly setting the wrong IP.

Move and go

The Move and Go buttons can be either active or inactive. In the active state, the button's outer frame is displayed in red, allowing the move operation to be performed. When the instruction information interface appears, the voice command "move" is available in order to move the command prompt box. When the 3D Printer Model part appears, the voice command “go” is available in order to move the 3D printer prompt box. When the command prompt box does not appear, the voice input "move" does not respond. Moreover, when the 3D printer prompt box does not appear, the voice input "go" does not respond. The code is shown below:

```
case "move":
                {
                    if (sType != stateType.non && sType != stateType.apiRequest)
                    {
                        if (moveActive)
                            disableMove();
                        else
                            enableMove();
                    }
                    break;
                }

            case "go":
                {
                    if (sType != stateType.non && sType != stateType.apiRequest)
                    {
                        if (goActive)
                            disableGo();
                        else
                            enableGo();
                    }
                    break;
                }
```

Figure 32: Gesture control code: Move command and go command

5.2.3 Other functions

In the development process of App, according to the feedback from the user, some special functions have been developed to make the user be more convenient to operate this App.

Center

Sometimes the user interface is not displayed directly in front of the user. Using the move and go commands is too cumbersome, so a special command has been developed to put the user interface directly in front of the user.[214]

```
case "center":
  {
      print("center");
      center.transform.position = center2.transform.position + new Vector3 (1,1,4);
      center.transform.rotation = center2.transform.rotation;
      break;
  }
```

Figure 33: Voice control code: “center”

“Sahra”

When the worker says the app's name "Sahra", the user receives audio feedback to confirm that the program is ready to run. The code is shown below:

```
case "sahra":
            {
                musicObj.GetComponent<AudioSource>().Play();
                break;
            }
```

Figure 34: Voice control code: “Sahra”

After using the "move" or/and "go" commands to adjust the text description or the 3D model, sometimes the user needs to use a convenient and simple voice command to disable these two functions. So the ‘’stay” command was developed. The code is shown below:

[214] And then user can use “move” or “go” function to do fine-tune.

```
case "stay":
                {
                    {
                        print("stay");

                        disableMove();
                        disableGo();
                    }
                    break;
                }
```

Figure 35: Voice control code: “stay”

5.3 Web Server

The data in Microsoft HoloLens is mainly read and transferred from the Web Server via WLAN. This has the following advantages over traditional Microsoft HoloLens Apps that put all data in the App.

Reduce the size of the App

Since the assembly method of each printer is different, in the process of assembling many assembly methods are used. If the data required for each assembly method is placed in the unity program, it is obvious that It is very unrealistic. Because doing so will make the program very redundant. Using web server can only retrieve the required data packets, which is very convenient and fast.

Data and procedures are independent of each other

Putting the data into Web Server realizes that the logical structure of the database and the application are independent of each other. If user need to change the database, user do not need to change the program but database. Moreover, the use of the database can also be used to conveniently control and manage the data.

Improve the security of user’s data

The data is placed in the web server, and the web server can only be accessed by username and password, which can prevent data loss, incorrect updates, and unauthorized use by users. In future versions, different databases of different users can also be established, which prevents mutual interference of data between different users.

When choosing web server, cost is the main factor, so the low-cost web server should be the first choice. Raspberry Pi is a great tool for setting up a web server because it is inexpensive and practical.

Raspberry Pi is a mini computer integrated into a single board. Currently, there are two new models.

- Raspberry Pi 3 Generation B+ type

Figure 36: Raspberry Pi 3 Generation B+ type[215]

- Raspberry Pi A type

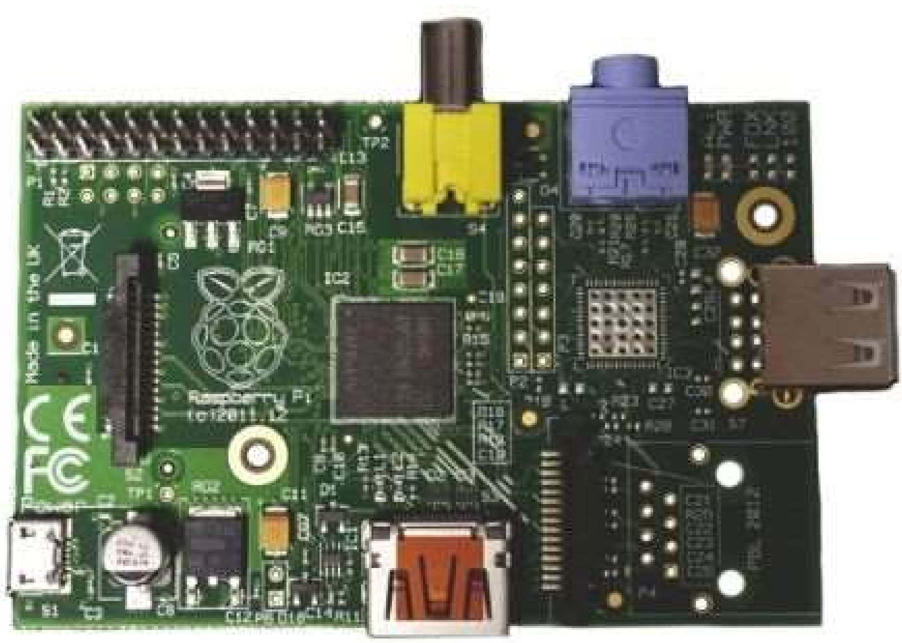

Figure 37: Raspberry Pi A[216]

[215] https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/ (22.12.2018)
[216] https://in.rsdelivers.com/product/raspberry-pi/raspberry-pi-type-a/raspberry-pi-type-a/7568317 (22.12.2018)

Although the latter is cheaper, it has fewer interfaces (including only one USB port), lower CPU, lower memory and fewer accessories. Hence, the third generation B+ is used. The B+ has four USB ports and 512M of memory. The CPU is upgraded to a 4-core primary frequency of 1G, which is six times faster than the previous A-type. The following are for this model, although most features are also available for the Raspberry Pi A.

5.3.1 Apache webserver

The data must be placed in the server, with the relevant data read by the Unity program. Here, Raspberry Pi is used as a temporary server, for which it is necessary to install Apache and PHP on the Raspberry Pi via web search. There is index.html under /var/www, which is the default home page. Then, the corresponding data is put onto the Raspberry Pi. Finally, the Raspberry Pi IP address is entered and the following interface appears:

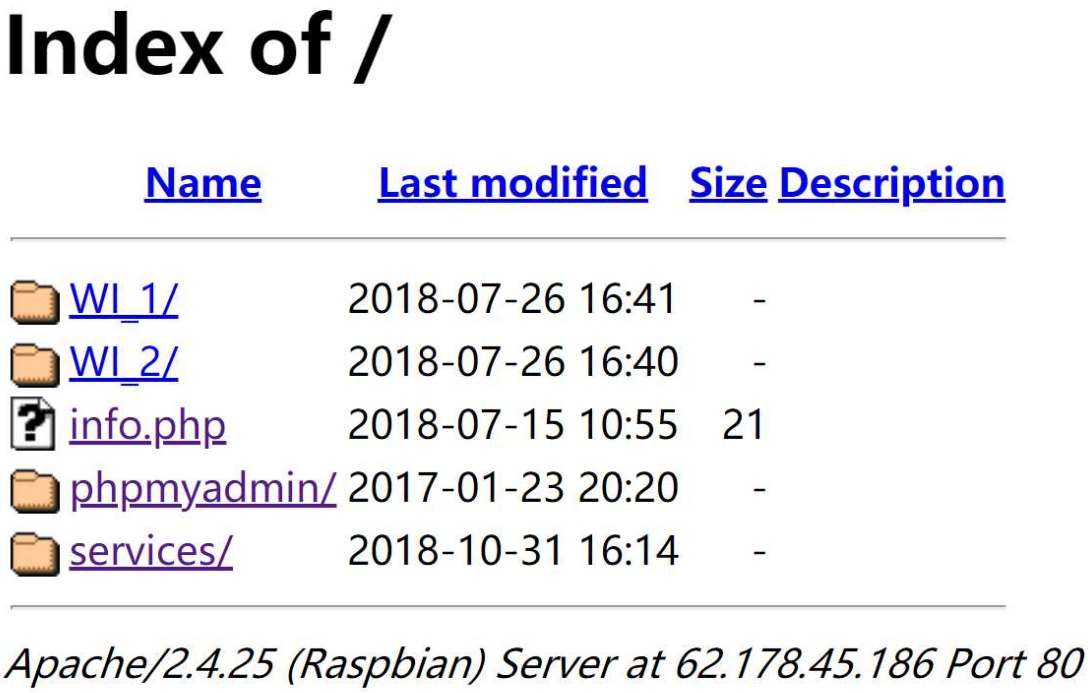

Figure 38: Raspberry Pi home page interface

5.3.2 Data storage

The database contains 3 types of data: .txt file, .png file and part drawing .obj file. The database is established by installing Myphp. With phpMyAdmin used as the database. After assembly, the following interface appears. The database is shown in Figure 13:

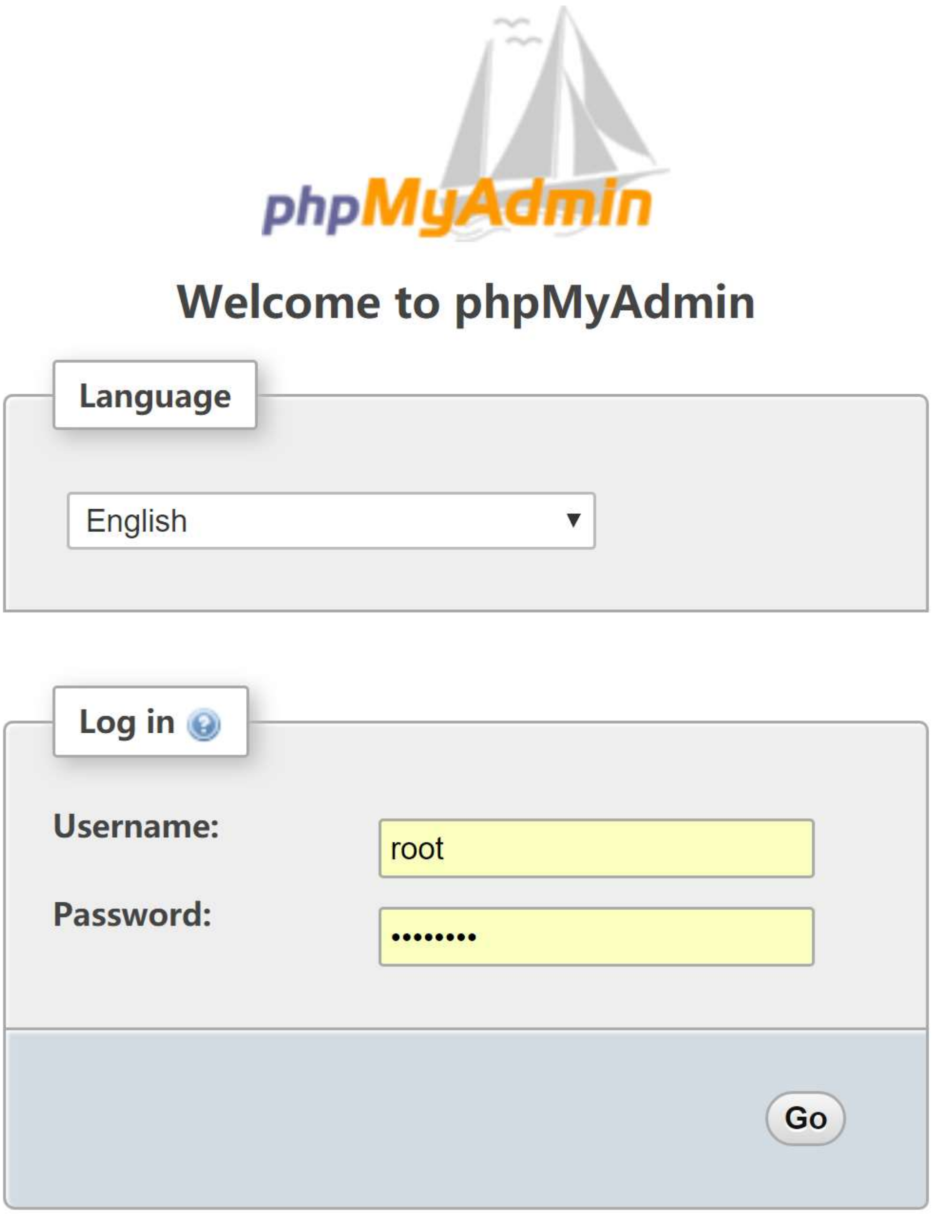

Figure 39: Myphp Database

Once entered, the corresponding database can be created.

The database is divided into the following sections:

- Printer

Printer ID: Each different printer has a unique ID number which is used to distinguish between different printer models.

Printer Creation Time: The time the printer was added to the database is recorded.

Printers Update Time: The last time the printer updated the database is recorded.

- Assembly Information:

Title: The title of each station.

Description: Detailed assembly instructions for each station.

Image: Image assembly instructions for each station.

Model: 3D model of each station.

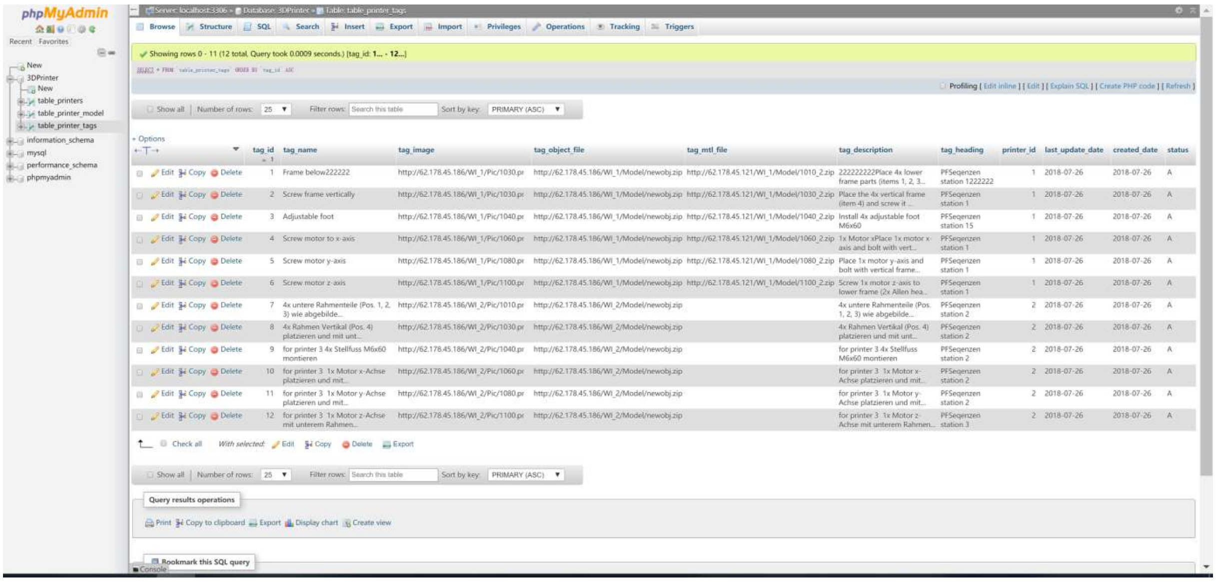

Figure 40: Database structure: printer part

5.4 Evaluation using Questionaires

After the Microsoft HoloLens App has been developed, the App needs to be evaluated. By using the questionnaire to understand the current problems of the App, SWOT-Analysis can be better performed in the next chapter.

According to ISO 9241-110:2006 (E), a questionnaire survey[217] was designed with a total of five participants. They completed the questionnaire after using the app. SWOT-analysis was performed based on the questionnaire. The areas of analysis include the following aspects:

- Basic information

By understanding the background information of user[218], the relationship between user’s basic situation and the App proficiency and preferences can be analyzed. By analyzing the user's background information, it is also possible to find out which kind of user is best suited to use this app.

[217] See Chapter 7 Appendix
[218] Such as occupation, age, education, experience in using AR equipment etc.

- Suitability for the task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

- Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

- Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

- Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

- Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

- Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

- Suitability for learning

The dialogue should support and guide the user in learning to use the system.

- Overall Evaluation

Overall Evaluation includes the user's overall satisfaction with the app, as well as comments and suggestions for the app.

5.5 Evaluation using SWOT-analysis

Strengths, weaknesses, opportunities and threats analysis (SWOT- analysis) is a foundational assessment model that measures an organization’s capabilities, limitations, potential opportunities and threats.[219] Advantages are aspects that they themselves own and that others cannot surpass in a short period of time. The so-

[219] https://www.investopedia.com/terms/s/swot.asp (28.01.2019)

called advantage is not possessed by others. The opposite is weaknesses, which are difficult to overcome in a short period. Advantages and disadvantages can also be understood as opportunities and threats. Opportunity refers to the ability to turn disadvantages into advantages and enhance current advantages. Some opportunities are based on innovation. Threats not only refer to one's own disadvantages but also potential competition to current advantages. The purpose of SWOT analysis is to achieve stable development in the long run.

The results of the SWOT analysis can be translated into action plans, whereby advantages and disadvantages are combined with opportunities and threats to produce four development areas. According to these four situations, the corresponding strategic countermeasures are given.

- SO strategy

Enterprises can use their own advantages to maximize the use of external opportunities and adopt an offensive strategy.

- WO strategy

Enterprises can tailor a disadvantage to capture external opportunities and adopt a counter strategy or innovative strategy.

- ST strategy

Enterprises can capitalize on their own advantages to take up a challenge, deal with external threats and adopt a proactive defensive strategy.

- WT strategy

The threats faced by enterprises are the disadvantages of enterprises. Consequently, enterprises should adopt a more conservative defense strategy, while making up for their shortcomings and seeking solutions to external threats.

Figure 41: SWOT Analysis converted into TOWS (SO, ST, WO and WT Strategies)[220]

SWOT-analysis is not perfect. For instance, it lacks priorities and instead merely provides an analysis without solutions or alternative decisions. This analysis can produce a lot of ideas but it cannot help to choose which method is the best. Extensive information is generated but not all information is useful.

Nonetheless, SWOT-analysis is suitable for this thesis. By using SWOT-analysis, the weaknesses of the App can be understood and subsequently resolved. Moreover, potential threats can be analyzed and prevented, while opportunities can be exploited and strengths enhanced for the purpose of specifying the strategy to achieve the goal.

For this App, SWOT analysis involves listing the internal advantages and disadvantages as well as the external opportunities and threats related to the software through questionnaires and analysis. Then, the information can be arranged in a matrix form and the various system elements matched. After analysis, conclusions are drawn.

Strengths

- The app contains all the information needed for the assembly and no useless information.
- There is no unnecessary interaction between the user and Microsoft HoloLens.
- The assembly-related functions are relatively complete and there is no need to “walk the curve” in order to implement certain functions during assembly.
- The software icons are vivid and easy to understand.

[220] https://www.business-to-you.com/swot-analysis/ (28.01.2019)

- When the system status changes (such as during data retrieval or work completion), the user can clearly see said change through the interface.
- When the user makes a mistake, they can easily go back to the previous step.
- The assembly operation is smooth and waiting time is generally suitable.
- Users can choose the 3D printer assembly method at will.
- The text assembly instructions in the App, the 3D model and picture descriptions are all relatively easy to understand. The assembly instructions are consistent with the user's reading habits and do not conflict with the user's cultural background.
- Users can utilize different command methods to complete tasks, including voice commands (quick and convenient) and only gestures in noisy environments. Assembly instructions can be adjusted at any time for easy reading.

Weaknesses

- The assembly information interface occasionally changes based on the user's location and viewing direction, forcing the user to repeat voice commands.
- The lack of software manuals means some features are unknown to the user. There are so many gestures and voice operations that users cannot remember them all in a short time.
- In certain cases, such as disconnected network connections, it is not possible to switch the assembly method as the Microsoft HoloLens can only retrieve one assembly method at a time.
- When using Microsoft HoloLens for the first time, the user must follow the assistance even if they have already completed the software-related operations multiple times.
- The App's speech recognition has two major problems: First, in noisy environments, sometimes the Microsoft HoloLens does not respond to the user’s voice commands. Second, Microsoft HoloLens interprets other speech (such as the user talking to themselves or others) as a voice command, resulting in an incorrect command.
- The lack of animated demos can cause boredom as animated presentations are more vivid than simple 3D models.

Opportunities

- With the development of Industry 4.0, AR- assembly worker guidance system will become increasingly popular.
- The popularity of product customization will increase the need for an assembly aid system similar to this App.
- Microsoft HoloLens is constantly being updated, which is good for the App.

Threats

- Many users are not used to wearing Microsoft HoloLens during assembly work. Some find it uncomfortable to wear myopia glasses and then wear the Microsoft

HoloLens. Some testers required help holding the Microsoft HoloLens to keep it stable, while others had to remove the Microsoft HoloLens during assembly. Consequently, assembly is made more difficult.

- The software's Text-to-speech (TTS) function is limited to English and has an obvious English accent when reading German.
- There may be a better hardware carrier than Microsoft HoloLens in the future, which would require the App to be redeveloped.
- Microsoft HoloLens is expensive, limiting application in the industrial sector.
- Few users can accept new technologies as users generally do not want to change their information retrieval habits.

SO

- Existing software development architectures could be leveraged and similar AR-assembly worker guidance system developed in order to help workers to install mechanical devices other than 3D printers, thereby promoting the comprehensive industrialization of factories.
- At any time, according to the continuous development of Microsoft HoloLens equipment, new features can be added in order to better meet user needs.
- The database system is continuously improved based on customized user needs, thereby establishing a huge database of assembly information for products.

WO

- App functionality can be improved based on feedback from user surveys.
- User instructions can be added so as to enhance the user experience, thereby encouraging even more people to try the App.
- Video can be added to the mobile phone to explain App operations.
- An animated demo of the assembly could be added to the App.

ST

- It is important to remain abreast of trends in AR hardware and look forward to potential changes to the App.
- User experience feedback should be regularly collected and newer versions released based on the market and user needs.
- The benefits of AR- assembly worker guidance system should be highlighted and barriers to users accepting new technologies reduced.

WT

- Face up to the shortcomings of the App. Update App regularly to solve the shortcomings of the App.
- Communicate with users frequently, find App's problems in time, solve these problems and gain the trust of users.
- Keep up with the hardware technology updates and update the software accordingly.

- Pay attention to changes in users' needs and market demands, and update software in a timely manner.

6 Conclusio

The purpose of this thesis is to develop a Microsoft HoloLens App for TU Wien Pilot Factory Industry 4.0 using an immersive system which can assist workers in installing different 3D printer models. The use of AR assist systems provides new solutions to problems in the industrial sector. Assembly worker guidance system provides another means of solving the problem.

In this chapter, development limitations are first discussed, then directions for app improvement are proposed. Finally, an overview is provided based on the development direction of AR technology under Industry 4.0.

6.1 Critical Appreciation of the Work

The current app is based on Microsoft HoloLens, a assembly worker guidance system that meets the identified needs of workers during 3D printer assembly. The app can provide workers with clear instructions for assembly steps in the form of 3D models, pictures and texts, which can be clearly, intuitively and comprehensive displayed to workers. In addition, the operation panel function has been added, which is practical and easy to understand. The program is modularized and is relatively simple to modify. Because the app can realize the retrieval, recall and storage of the database using Microsoft HoloLens over the wireless network, the app is also relatively flexible.

Despite these advantages, the app requires improvement in the following areas.

- Due to time constraints, the currently developed version contains only the first 6 steps of the printer assembly. Since installing a 3D printer requires several assembly steps, the database requires extension.
- In voice commands, due to the limitations of the program itself, it is impossible to automatically program the voice commands of each printer. It is only possible to manually input the initial call voice of each printer (for example, Method 1, Method 2, Method 3 etc.) This could cause the program to be constantly updated as the number of printers increases. Moreover, it is also possible to pre-program a sufficient number of printer voice call commands, such that 1000 printers would have 1000 voice calls. The resulting operational efficiency problems and other unknown problems require verification.
- When the worker's line of sight shifts, the assembly instructions stay in place, meaning no issues arise. The program does not use the Vuforia function but instead uses the camera coordinates and assembly information in the program. Fixing the fixed value is awkward and inflexible.

- The program is not highly flexible. Different users have different requirements for the program. At present, this app lacks customizability.
- The convenience of program migration must be verified. The app can only be used on the current version of Microsoft HoloLens, as well as future versions. Even if it can be used on other displays, or the program amount can be modified, verification is nonetheless required.
- Currently developed apps are only available in English, which requires workers to be proficient in reading and understanding English. Failure to do so may result in reduced assembly efficiency or even errors.
- A software usage instruction should be added into the “setting” area, in order to help workers who are not familiar with Microsoft HoloLens usage or who are not familiar with voice commands can easily access and get information about related functions. Even if some functions do not cause workers to forget or be unfamiliar for a long time, they can be checked at any time.

6.2 Outlook

6.2.1 Mobile device use

Currently, AR devices are predominantly head-mounted displays, such as the Microsoft HoloLens. The disadvantage of wearing such a sealed helmet is that it is very cumbersome, increasing workers' fatigue and decreasing working efficiency. Moreover, it is currently sold at a relatively high price, making the initial investment cost of AR- assembly worker guidance system relatively large. Hence, some factories may be unwilling to take the risk of investing. At the same time, head-mounted displays do not match with workers' habits. Workers are more accustomed to looking at flat-panel electronic displays, such as on cell phones. If a program is ported from the clumsy Microsoft HoloLens to a flexible and convenient mobile phone, the pressure on workers would be reduced, as would their resistance to the new equipment as well as the investment needed. This is because using mobile phones avoids the investment that would be incurred if hardware equipment were bought. In addition, it is also possible to expand the population of AR use, as mobile AR devices are already available. In most cases, consumers using AR mobile devices are enough to satisfy demand.

6.2.2 Animation demonstration

In the current app, Catia's 3D model is used to show the parts or components that need to be installed. Hence, the static 3D model is much more vivid than the text description. However, if animation were used, the assembly process would be even more vivid. Hence, workers can understand the assembly steps more succinctly, reducing error rates.

6.2.3 Multi-language version

Multilingual versions are divided into two components: text and speech. The text component needs to be manually entered in the database. There may be some languages (such as Latin letters or small language letters) that are not correctly recognized by the Unity program. The voice component requires Microsoft's speech recognition system. At present, there are more than 20 languages available in speech recognition. How best to transplant languages to the unity program is a problem that needs to be studied and discussed.

6.3 Future Developments

6.3.1 AR Kit

Unlike head-mounted displays such as the bulky Microsoft HoloLens, AR Kit is a mobile-based AR platform with an AR app for use on the iOS platform. AR Kit provides a simple API with a simple interface, which will be available to millions of iOS devices without the need to purchase a separate AR display device. In order to realize full AR Kit functionality, A9 and above are required,[221] which most devices running iOS 11 possess, including the iPhone 6S.

Features

AR Kit has three main functions, the first of which is tracking. Tracking is a core feature of AR Kit which can track devices in real time.

World tracking

The relative position of the device in the physical environment can be provided.

With the Visual Inertial Odometry (VIO), an accurate view of the device location and orientation is provided. The visual inertia odometer uses camera images and motion data from the device.

More importantly, no peripherals are needed. Moreover, it is not necessary to know the environment in advance or to have additional sensors.

[221] https://www.apple.com/at/ios/augmented-reality/ (19.12.2018)

Scene Understanding

Tracking the upper layer constitutes a type of scene understanding that determines the attributes or characteristics of the environment surrounding the device. This provides certain functions, such as plane detection.

The second function is room plane detection and scene understanding. Plane detection determines the surface or plane in a physical environment, such as a floor or a table. In order to place virtual objects, Apple provides hit testing capabilities, capturing points of intersection with real-world topologies in order to place virtual objects in the physical world. Scene understanding allows for light estimation, which ensures the virtual geometry is properly illuminated in order to match the physical world.

Combined with the above features, virtual content can be seamlessly integrated into the physical environment.

The third function of AR Kit is rendering. Apple allows any rendering program to be easily integrated. The continuous camera image stream, tracking information and scene understanding can be imported into any rendering program. For those using Scene Kit or Sprite Kit, Apple provides a custom AR view that completes most of the rendering for the wearer. Therefore, compared with traditional AR equipment, getting started is easier. Apple also provides a metal template via XCode that integrates AR Kit into a custom renderer. Unity and UNREAL [222] currently support full AR Kit functionality.

[222] Unreal is also a game engine like Unity.

Figure 42: A LEGO app using Apple's new ARKit features.[223]

6.3.2 World lenses

Snapchat has launched an AR camera app. A Snapchat update on iOS and Android introduced World Lenses, changing the way users view their surroundings. For example, by pointing the camera at the sky, a cloud, rain or a rainbow can be added. In addition, some World Lenses can also animate faces and, depending on whether the front camera or rear camera is used, different effects can be produced. The new World Lenses is equipped with a Selfie Lenses so that one can easily slide between the two. According to Snapchat, "World Lenses will help Snap chatters decorate the world around them in even more fun and creative ways"[224] The company has announced a "Go Vote" feature, and is currently adding flash, whitening, live wallpaper and other lenses. In addition, World Lenses will add color to what is captured.

Snapchat is preparing for the release of spectacles for sunglasses. There is now an option on Snapchat to pair the app with the user's glasses (Spectacles). This can be done by pressing the button on the glasses and pointing them to a specific QR Snap code in the app.

[223] https://arstechnica.com/gadgets/2018/06/arkit-2-why-apple-keeps-pushing-ar-and-how-it-works-in-ios-12/ (08.04.2019)
[224] https://www.techadvisor.co.uk/how-to/social-networks/how-use-snapchat-world-lenses-3659049/ (19.12.2018)

Now there is a feature which allows users to send a friend's story or Live Story as a snapshot to others so that any given users can feature in each other's' stories. Hence, stories can be discovered and shared with others.

Figure 43: World lenses[225]

225 https://www.techadvisor.co.uk/how-to/social-networks/how-use-snapchat-world-lenses-3659049/ (19.12.2018)

7 Appendix

This section shows the results of the user survey. Five testers were found to come to TU Wien Pilot Factory Industry 4.0 to participate in the test. These testers have different ages, occupations, and educational backgrounds. Some of them have used Microsoft HoloLens before, but some have not. Some understand the assembly of 3D printers before, and some know nothing about how to install a 3D printer. At first, they briefly understood how to use the app, and then independently installed the 3D printer using Microsoft HoloLens without help. Finally, the questionnaire was filled out.

This chapter mainly contains the following parts:

- Original user survey
- The first user survey results
- The second user survey results
- The third user survey results
- The fourth user survey results
- The fifth user's survey results

7.1 User Survey Sample

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 years old

○ 18 years old to 25 years old

○ 26 years old to 35 years old

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your education

Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

○ Students

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ Used both AR and VR devices

○ Only used VR equipment

○ Only used with AR equipment

○ Never used both devices

□I think this is annoying

4. Your previous experience in installing 3D printer

○ Have installed 3D printer before

○ First time install 3D printer

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   ____

   ____

   ____

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

   ____

   ____

   ____

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

____

____

____

4. Do you find that the effort required for the task result is suitability?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

____

____

____

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

____

____

____

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

____

____

____

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

____

____

____

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe which situation you can't go back.

____

____

____

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe how do you want to change the way you are prompted?

____

____

____

4. You often have to consult colleagues or a manual in order to continue to work?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in what situation do you need help?

____

____

____

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   ____

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you can’t get backward.

4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe the situation which you have to wait.

5. Can you choose the installation method you need?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you cannot choose the installation method.

____

____

____

Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which menu items or features does not match your thoughts?

____

____

____

2. Are you sometimes surprised at how the program responds to your input?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation you feel that the App's response does not meet your expectations?

____

____

____

3. Do you think the vocabulary in the App is easier to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which words are difficult to understand?

4. Do you think that the information structures fit your reading habits?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which information structures do not meet your reading habits?

5. Does the content match your cultural conventions?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

____

____

____

Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   ____

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe what how do I want to interact with HoloLens?

   ____

   ____

   ____

2. Can you adjust Information window on the computer to make reading and working easier?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe under what situation can't I adjust the window?

   ____

   ____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which learning information needs to be added to the App?

   ____

   ____

   ____

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

   ____

   ____

   ____

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

____

____

____

Overall Evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   ○Quite satisfied

   ○Not so satisfied

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   ○No

   ○Hard to say

3. Is this App easy to use?

   ○Yes

   ○No

   ○Hard to say

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   ○This is not a good way to install it.

   ○Hard to say

5. What was your impression of using this App for the first time?

____

6. What suggestions and comments do you have for this App?

7.2 Tester No. 1

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 years old

○ 18 years old to 25 years old

○ 26 years old to 35 years old

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your career

○ Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

○ Students

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ Used both AR and VR devices

○ Only used VR equipment

○ Only used with AR equipment

<u>○ Never used both devices</u>

□I think this is annoying

4. Your previous experience in installing 3D printer

○ Have installed 3D printer before

<u>○ First time install 3D printer</u>

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   ____

   ____

   ____

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

   ____

   ____

   ____

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

   ○ Yes

   <u>○ No</u>

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

   ____

   ____

   ____

4. Do you find that the effort required for the task result is suitability?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

   ____

   ____

   ____

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

Wenn man den Drucker einrichtet, bewegt sich die Bilder immer schief. Dann muss man jedes mal wieder „center“ sagen.

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

____

____

____

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

   ○ <u>Yes</u>
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

   ____

   ____

   ____

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

   ○ Yes
   ○ <u>No</u>
   □ I am not sure
   □ I am not satisfied with this

   If "Yes" was selected, please describe which situation you can't go back.

   ____

   ____

   ____

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe how do you want to change the way you are prompted?

____

____

____

4. You often have to consult colleagues or a manual in order to continue to work?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in what situation do you need help?

Have to click the button, what is the voice input.

____

____

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   <u>It heard something wrong, then switched from method 1 to methode2.</u> ________

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you can't get backward.

____

____

____

4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe the situation which you have to wait.

____

____

____

5. Can you choose the installation method you need?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you cannot choose the installation method.

____

____

____

Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which menu items or features does not match your thoughts?

____

____

____

2. Are you sometimes surprised at how the program responds to your input?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation you feel that the App's response does not meet your expectations?

With „methode1"it didn't start immediately, I must say "start". ________________

____

____

3. Do you think the vocabulary in the App is easier to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which words are difficult to understand?

___

___

___

4. Do you think that the information structures fit your reading habits?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which information structures do not meet your reading habits?

___

___

___

5. Does the content match your cultural conventions?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

____

____

____

Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   ____

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe what how do I want to interact with HoloLens?

   ____

   ____

   ____

2. Can you adjust Information window on the computer to make reading and working easier?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe under situation can't I adjust the info window?

   Step description by method 2 is too long, but the words can’t switch to the next line.____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which learning information needs to be added to the App?

   ____

   ____

   ____

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

   ____

   ____

   ____

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

____

____

____

Overall Evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   <u>○Quite satisfied</u>

   ○Not so satisfied

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   <u>○No</u>

   ○Hard to say

3. Is this App easy to use?

   ○Yes

   ○No

   <u>○Hard to say</u>

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   ○This is not a good way to install it.

   <u>○Hard to say</u>

5. What was your impression of using this App for the first time?

   It's new and modern. Its voice in a laud environment is not clear enough.

6. What suggestions and comments do you have for this App?

   A moving animation with voice instruction is better to understand than the pictures with words.

7.3 Tester No. 2

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 years old

<u>○ 18 years old to 25 years old</u>

○ 26 years old to 35 years old

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your career

Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

<u>○ Students</u>

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ Used both AR and VR devices

○ Only used VR equipment

○ Only used with AR equipment

<u>○ Never used both devices</u>

□I think this is annoying

4. Your previous experience in installing 3D printer

○ Have installed 3D printer before

<u>○ First time install 3D printer</u>

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   As a woman , I don't know how each part looks lke, I need to know their exact look to know that to grab.

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

4. Do you find that the effort required for the task result is suitability?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

   ____

   ____

   ____

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

   ____

   ____

   ____

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

____

____

____

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

   ____
   ____
   ____

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "Yes" was selected, please describe which situation you can't go back.

   ____
   ____
   ____

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe how do you want to change the way you are prompted?

4. You often have to consult colleagues or a manual in order to continue to work?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in what situation do you need help?

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   ____

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the situation which you can’t get backward.

   ____

   ____

   ____

4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation which you have to wait.

   ____

   ____

   ____

5. Can you choose the installation method you need?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you cannot choose the installation method.

___

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___

Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which menu items or features does not match your thoughts?

   ____

   ____

   ____

2. Are you sometimes surprised at how the program responds to your input?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation you feel that the App's response does not meet your expectations?

   ____

   ____

   ____

3. Do you think the vocabulary in the App is easier to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which words are difficult to understand?

4. Do you think that the information structures fit your reading habits?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which information structures do not meet your reading habits?

5. Does the content match your cultural conventions?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

____

____

____

Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   <u>□ I am not sure</u>

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   <u>□ I am not sure</u>

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   ____

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe what how do I want to interact with HoloLens?

   ____

   ____

   ____

2. Can you adjust Information window on the computer to make reading and working easier?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe under situation can't I adjust the info window?

   ____

   ____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which learning information needs to be added to the App?

   ____

   ____

   ____

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

   ____

   ____

   ____

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

____

____

____

Overall Evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   ○Quite satisfied

   <u>○Not so satisfied</u>

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   ○No

   <u>○Hard to say</u>

3. Is this App easy to use?

   <u>○Yes</u>

   ○No

   ○Hard to say

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   ○This is not a good way to install it.

   <u>○Hard to say</u>

5. What was your impression of using this App for the first time?

   The glass doesn‘t fit my head shape, it keeps dropping off and I have to stabllize it in order for it to sit, which makes the installation quite difficult.

6. What suggestions and comments do you have for this App?

   It would be better if the images for each part can be move “real”, so that the user can find the corresponding part more efficient.

7.4 Tester No. 3

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 years old

○ 18 years old to 25 years old

○ 26 years old to 35 years old

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your career

Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

○ Students

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ Used both AR and VR devices

○ Only used VR equipment

○ Only used with AR equipment

<u>○ Never used both devices</u>

□I think this is annoying

4. Your previous experience in installing 3D printer

○ Have installed 3D printer before

<u>○ First time install 3D printer</u>

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   ____

   ____

   ____

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

   ____

   ____

   ____

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

○ Yes

<u>○ No</u>

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

---

4. Do you find that the effort required for the task result is suitability?

<u>○ Yes</u>

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

---

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

____

____

____

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

____

____

____

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

   ____

   ____

   ____

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "Yes" was selected, please describe which situation you can't go back.

   ____

   ____

   ____

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe how do you want to change the way you are prompted?

____

____

____

4. You often have to consult colleagues or a manual in order to continue to work?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in what situation do you need help?

____

____

____

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   ____

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the situation which you can't get backward.

   ____

   ____

   ____

4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation which you have to wait.

   ____

   ____

   ____

5. Can you choose the installation method you need?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the situation which you cannot choose the installation method.

   ____

   ____

   ____

Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which menu items or features does not match your thoughts?

   ____

   ____

   ____

2. Are you sometimes surprised at how the program responds to your input?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation you feel that the App's response does not meet your expectations?

   ____

   ____

   ____

3. Do you think the vocabulary in the App is easier to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which words are difficult to understand?

____

____

____

4. Do you think that the information structures fit your reading habits?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which information structures do not meet your reading habits?

____

____

____

5. Does the content match your cultural conventions?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

____

____

____

Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   ____

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe what how do I want to interact with HoloLens?

____

____

____

2. Can you adjust Information window on the computer to make reading and working easier?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe under situation can't I adjust the info window?

____

____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which learning information needs to be added to the App?

   ____

   ____

   ____

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

   ____

   ____

   ____

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

___

___

___

Overall Evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   ○Quite satisfied

   ○Not so satisfied

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   ○No

   ○Hard to say

3. Is this App easy to use?

   ○Yes

   ○No

   ○Hard to say

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   ○This is not a good way to install it.

   ○Hard to say

5. What was your impression of using this App for the first time?

For short sighted people, this AR glass is not very fit to short sighted glass.

6. What suggestions and comments do you have for this App?

The gesture identification is not good as voice control. The screen is not vertical sometimes. But, in general, it can be a good instruction for people who do not well know how to install structures.

7.5 Tester No. 4

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 years old

○ 18 years old to 25 years old

<u>○ 26 years old to 35 years old</u>

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your career

Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

<u>○ Students</u>

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ Used both AR and VR devices

○ Only used VR equipment

○ Only used with AR equipment

○ Never used both devices

□I think this is annoying

4. Your previous experience in installing 3D printer

○ Have installed 3D printer before

○ First time install 3D printer

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   ____

   ____

   ____

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   <u>□ I am not sure</u>

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

   ____

   ____

   ____

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

   ○ Yes

   <u>○ No</u>

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

   ____

   ____

   ____

4. Do you find that the effort required for the task result is suitability?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

   ____

   ____

   ____

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

○ Yes

<u>○ No</u>

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

____

____

____

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

○ Yes

○ No

<u>□ I am not sure</u>

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

____

____

____

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

   ○ Yes
   ○ <u>No</u>
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

   ____
   ____
   ____

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

   ○ <u>Yes</u>
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "Yes" was selected, please describe which situation you can't go back.

   <u>Connection lost, no voice command to go back.</u>______________________
   ____
   ____

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe how do you want to change the way you are prompted?

   ____

   ____

   ____

4. You often have to consult colleagues or a manual in order to continue to work?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in what situation do you need help?

   ____

   ____

   ____

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   Bad connection, screen offset after installation steps, white datissue.__________

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you can’t get backward.

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4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe the situation which you have to wait.

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5. Can you choose the installation method you need?

<u>○ Yes</u>

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you cannot choose the installation method.

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Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which menu items or features does not match your thoughts?

   ____

   ____

   ____

2. Are you sometimes surprised at how the program responds to your input?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation you feel that the App’s response does not meet your expectations?

   When using „center“ or „move” command.______________

   ____

   ____

3. Do you think the vocabulary in the App is easier to understand?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which words are difficult to understand?

   ____

   ____

   ____

4. Do you think that the information structures fit your reading habits?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which information structures do not meet your reading habits?

   ____

   ____

   ____

5. Does the content match your cultural conventions?

○ <u>Yes</u>

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

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Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   Random crashes due to connection issues.____________________________

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe what how do I want to interact with HoloLens?

   ____

   ____

   ____

2. Can you adjust Information window on the computer to make reading and working easier?

   ○ Yes

   <u>○ No</u>

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe under situation can't I adjust the info window?

   ____

   ____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which learning information needs to be added to the App?

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____

____

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

„Center" and „move closer".
____

____

____

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

____

____

____

Overall Evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   ○Quite satisfied

   ○Not so satisfied

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   ○No

   ○Hard to say

3. Is this App easy to use?

   ○Yes

   ○No

   ○Hard to say

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   ○This is not a good way to install it.

   ○Hard to say

5. What was your impression of using this App for the first time?

   Little bit hard without studying the voice commands at the very beginning.

6. What suggestions and comments do you have for this App?

   Display the red 3D modell really close to the real model.

7.6 Tester No. 5

User survey

“HoloLens App”

Dear user,

You are welcome to participate in the “Experience of 3D Printer Assembly by using Microsoft HoloLens” questionnaire. This questionnaire is designed to understand whether using this Microsoft HoloLens App is a good solution for assisting workers in 3D printer assembly. This survey uses dialogue principle according to ISO 9241-110:2006(E). The answers in this questionnaire are not simply right or wrong, so you can fill in according to your most real situation and opinions. The questionnaire is recorded in an anonymous manner and is for research analysis only, which will not be used for other purposes. Please feel free to these answers. The opinions you provide are invaluable to this research. Without your help, researchers will have difficulty completing the intended research goals. We sincerely thank you for your support!

How to Fill:

- If you are not sure about the answer, then Select “I am not sure”. In the process of filling out, you can point out the shortcomings of this App. If you feel that there are some big shortcomings in this App which makes you very uncomfortable, please select “I am not satisfied with this”.
- Please fill in the truth according to your actual situation, do not discuss with others.
- Questions have only one option and fill it in parentheses.
- The questionnaire needs to be recovered after use. Please do not make any mark on the questionnaire.

Basic Information

By understanding your basic information, we can analyze the relationship between your basic situation and the App proficiency and preferences. If you feel that some information is not convenient, you can choose "I think this is annoying".

1. Your age-group

○ Under 18 yearsold

○ 18 years old to 25 years old

<u>○ 26 years old to 35 years old</u>

○ 36 to 45 years old

○ 45 years old or older

□I think this is annoying

2. Your career

Teachers, scientific research, civil servants and other institutions

○ Finance, banking practitioners

○ White collar or technician

○ Service industry personnel

<u>○ Students</u>

○ Freelance

○ Retirees

○ other

□I think this is annoying

3. Your VR or AR experience

○ <u>Used both AR and VR devices</u>

○ Only used VR equipment

○ Only used with AR equipment

○ Never used both devices

□I think this is annoying

4. Your previous experience in installing 3D printer

○ <u>Have installed 3D printer before</u>

○ First time install 3D printer

□I think this is annoying

Suitability for the Task

The HoloLens App needs to be appropriate to assist the user to complete the task. The dialogue should present the user all related information.

1. Does this App contain all the information you need to install a 3D printer?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please name some information that you would like to add in the App.

   ____

   ____

   ____

2. Is there any useless information in the App's interface?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation have you ever thought:" I don't need this information."

   ____

   ____

   ____

3. Are there any interaction steps in the App that are unnecessary during the interaction process?

   ○ Yes

   <u>○ No</u>

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which step have you ever thought:" This step is completely unnecessary".

   ____

   ____

   ____

4. Do you find that the effort required for the task result is suitability?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe in which situation have you ever thought: "I could do that with less effort."

   ____

   ____

   ____

5. Do you think there are functions in the App that you need to repeat settings or gestures that you need to repeat, but they are unnecessary?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "Oh, why should I repeat this action again?"

____

____

____

6. Do you need to get around with detours or tricks to achieve results as you would like them to be?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in which situation have you ever thought: "I can't implement this task through App functions, but I can find other ways to achieve it."

____

____

____

7. Do you think the App's function icons are easy to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which icons have you made you confused.

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____

Self-descriptiveness

At any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed.

1. When working with the HoloLens, do you know what input (gesture, voice) is expected of you as for the next step?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "No" was selected, please describe which situation do you think you don't know how to proceed with the next installation.

   Using/ Seeing this interface for the first time without knowing anything about it or how it works seemed to be a bit confusing.

2. Have you ever encountered a situation where you can't go back if you mishandled the App without an error message?

   ○ Yes
   ○ No
   □ I am not sure
   □ I am not satisfied with this

   If "Yes" was selected, please describe which situation you can't go back.

3. Do you think the App's prompts are obvious when the system status changes (such as reading data, network problems etc.)?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe how do you want to change the way you are prompted?

____

____

____

4. You often have to consult colleagues or a manual in order to continue to work?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe in what situation do you need help?

Sometimes the picture was missing or it was to small, so I had no concrete idea of what to do.

____

Controllability

A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.

1. Can you do the task in the order that makes the most sense to you?

   <u>○ Yes</u>

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe the order that works best for you.

   ____

   ____

   ____

2. Does the program sometimes do something without you want at some time?

   ○ Yes

   <u>○ No</u>

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe the situation.

   ____

   ____

   ____

3. Can you get backward for your work step if it is appropriate for your task execution?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you can’t get backward.

Several times I had to repeat what I wanted.

4. Do you feel slowed down by the program in your work speed, e.g. through a very long waiting time?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "Yes" was selected, please describe the situation which you have to wait.

Loading time was quite long but maybe are to a slow internet connection.

5. Can you choose the installation method you need?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe the situation which you cannot choose the installation method.

____

____

____

Conformity with user expectations

A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions.

1. Do you find any menu items or features where you think they should be?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which menu items or features does not match your thoughts?

   ____

   ____

   ____

2. Are you sometimes surprised at how the program responds to your input?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe in which situation you feel that the App's response does not meet your expectations?

   ____

   ____

   ____

3. Do you think the vocabulary in the App is easier to understand?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which words are difficult to understand?

But „easier“? Compared to what? ________________________________

____

____

4. Do you think that the information structures fit your reading habits?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which information structures do not meet your reading habits?

____

____

____

5. Does the content match your cultural conventions?

<u>○ Yes</u>

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe which content do not match your cultural conventions?

____

____

____

Error tolerance

A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management.

1. Can you fix the consequences of incorrect input with little effort?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which misuse caused you a lot of time?

   ____

   ____

   ____

2. Is the program always stable and reliable while you using this App?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe when is this App not stable?

   Didn't react my voice.______________________________

   ____

   ____

Suitability for individualization

A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs.

1. Can you use different forms of representation to complete your work (e.g. gesture, voice command)?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe what how do I want to interact with HoloLens?

   ____

   ____

   ____

2. Can you adjust Information window on the computer to make reading and working easier?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe under situation can't I adjust the info window?

   ____

   ____

Suitability for learning

The dialogue should support and guide the user in learning to use the system.

1. Are useful Rules and underlying concepts of the App available for you to learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "No" was selected, please describe which learning information needs to be added to the App?

   ___

   ___

   ___

2. Do you think there are any voice commands or rules that need to be designed to re-learn?

   ○ Yes

   ○ No

   □ I am not sure

   □ I am not satisfied with this

   If "Yes" was selected, please describe which voice commands or rules that need to be designed to re-learn?

   ___

   ___

   ___

3. Are the usage instructions helpful in understanding the use of this App?

○ Yes

○ No

□ I am not sure

□ I am not satisfied with this

If "No" was selected, please describe Which instructions need to be added?

___

___

___

Overall evaluation

1. What is your evaluation of this App?

   ○Very satisfied

   ○Quite satisfied

   <u>○Not so satisfied</u>

   ○Very unsatisfied

2. If you need to install a 3D printer yourself, would you like to continue using this App to assist with the installation?

   ○Yes

   <u>○No</u>

   ○Hard to say

3. Is this App easy to use?

   <u>○Yes</u>

   ○No

   ○Hard to say

4. How much do you think this App will help you install 3D printers? Compared to other instructions, such as instructions, or using a tablet device for installation demonstrations.

   ○This is the best way to assist with installation.

   <u>○This is not a good way to install it.</u>

   ○Hard to say

5. What was your impression of using this App for the first time?

It was quite interesting as I never installed a 3D-printer this way before, but the app had some problems and without help I would not have known what to do. __

6. What suggestions and comments do you have for this App?

Instead of pictures use a video and maybe it would be nice to be able to move the red 3D-modell! Also the spoken German turned out to be English actually.

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9 List of Figures

10 List of Tables

11 Abbreviation

e.g.	Exempli gratia
i.e.	Idest
AR	Augmented reality
App	Application
ICT	Information and communication technology
WLAN	Wireless local area network
IP	Internet Protocol
WIMP	Windows, icons, menus, pointer
CPS	Cyberphysical system
VR	Virtual reality
SLAM	Simultaneous localization and mapping
DOF	Degrees of Freedom
FOV	Field of View
3D	Three-dimensional
ICT	Information and communications technology
PLM	Product Lifecycle Management
API	Application Programming Interface
CAD	Computer Aided Design
GIS	Geographic Information Science
MES	Manufacturing Execution System
QR code	Quick Response Code
BIDI code	Bi-directional language
UI	User Interface
HMD	Head-Mounted Display
MBI	Model based instructions
ACARS	Authorable Context-Aware AR Maintenance System
CNC	Computer numerical control
NASA	National Aeronautics and Space Administration
PHP	Hypertext Preprocessor
VOI	Visual Inertial Odometry