



Augmented Reality for Maintenance Help of Optometry Equipment

Master degree in Direct Digital Manufacturing Engineering

Fernando Sismeiro de Sousa Pinção

Leiria, march of 2025



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Project Report under the supervision of Professor Anabela Gonçalves Rodrigues Marto,
and Professor Henrique de Amorim Almeida

Leiria, march of 2025

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Dedication

I would like to dedicate this document to my mother Martinha and to my father Nuno, as well as to my sister Luísa and my dog Eevee.

This dedication is also to all my classmates and professors, whose supported the last six years of my bachelor's and master's degrees.

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Abstract

As in other areas of medicine and industry, optometry makes use of a vast array of equipment, which professionals are able to operate. The equipment used in this research needs maintenance and calibration during time, which could require the assistance of professionals in the area. In this scope, the present document was developed in way to evaluate the applicability of Augmented Reality tools as an assistant to optometry professionals to reduce the difficulty of calibration. The objective was based on previous works by other researchers, as well as essays carried out directly with the equipment properly said.

During the investigation, there were performed two cases of study using Augmented Reality applications. On the first case of study, the use of paper manual was compared to the technology with and without overlapping for the identification of parts in the equipment. In the second case of study, however, both instruction systems were evaluated in terms of efficiency for assembly instructions and memory. The essays, performed by participants of ages from 17 to 70 years old, revealed that Augmented Reality presents an improvement in parts recognition, assembly and tasks memorization.

Keywords: Augmented Reality, Optometry, Assembly, Maintenance, Calibration

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List of Abbreviations and Acronyms

ABS	Acrylonitrile Butadiene Styrene (material)
AR	Augmented Reality
CAD	Computer-Aided Design
GPS	Global Positioning System
HMD	Head-Mounted Display
IoT	Internet of Things
LCD	Liquid Crystal Display
PDM	Product Data Management
SDK	Software Development Kit
VR	Virtual Reality

1. Introduction

Maintenance procedures are involved in the majority of industries. As a process has equipment applied, it is almost required to calibrate or change parts and consumables during time. This step could be performed in some cases by the operator, which normally is a person specialized in using; however, some processes are not trivial, even to the operator, which could imply the assistance of another entity, obliging them to travel undetermined distances, depending on the geographic position of the equipment and the assistant, as well as other associated costs.

Since the beginning of the millennium, Augmented Reality (AR) called the attention of industries to use as visual tools on different tasks. In this scope, researchers have explored the applicability of AR to aid people's jobs, as well as their reactions to the introduction of a new learning method.

2. State of Art

Augmented Reality makes use of a vast set of knowledge to reach different solutions. Depending on the needs of the applications, there are divergent decisions to take in terms of development, usage, applicability, evaluation and so on. The user is another variable to consider, once he is given responsibility for the decisions taken using the application and how he interacts with the virtual environment.

In this chapter it is presented the search and evaluation of existent knowledge used before the production of the AR application and the cases studies developed in the real environment.

2.1. Distinction of errors

Based on assembly tasks, as a crucial part of the maintenance and repair operations, failures during the process need to be considered to optimize the instructions and associate the external cause that led to the error. By the meaning, error can be defined as all the occasions in which a planned sequence of physical or mental activities fails to achieve its intended outcome. Nevertheless, these failures cannot be attributed to the intervention of some change agency (Reason, 1990). As a possible distinction between errors in industrial installation, it was proposed by a combination of Reason and Rasmussen's studies (Rasmussen, 1982) a classification between real errors and violation practices:

- Real errors were determined as involuntary actions that affect the operator's task. Normally they are associated with generic psychological mechanisms and limitations, so the error can be skill-based, rule-based or knowledge-based, with the last two being related as mistakes. Skill-based errors happen when the operator fails to execute the planned action, due to not having the necessary competences, and mistakes are caused by failure in planning the task, in particular missed information (knowledge-based) or not following the pre-established regulation (rule-based).
- Violation is a voluntary act, which could consist in the break of a rule, procedure, or norm. It can be routine violation, where the operator is exposed to multiple similar variables, becoming part of is routine, situation violation,

caused by the operating conditions, and exceptional violation, normally extreme violation, associated with non-negligible consequences (Mura et al., 2016).

Beside this distinction, errors in maintenance and assembly can also be characterized in different ways, based in the result that the operator confronts (Kim & Park, 2012):

- Wrong object: the object does not match the task.
- Omission: one, more or part of the actions were not performed manually
- To little: not enough force applied during the action.
- Wrong action: The action was performed in a different way from what was planned.

2.2.Methods to reduce the error

There are different possible causes of maintenance and assembly errors during the operation, whether from the working conditions or even from the operator's physical and mental factors. These features are defined as Performance Shaping Factors (PSFs) (Blackman et al., 2008), which can influence the operator's performance in different tasks and some of these can be quantified as well:

- Assembly and maintenance system factors: The whole system conditions, including the workspace, resources, and work plan, could have deficiencies, such as poor ergonomics, repetitiveness of tasks and noises, causing mental and physical stress in the operator.
- Product factors: Related to properties, such as the similarity between different parts or the variety of distinct products, which can increase the complexity of the tasks by overloading operator's memory.
- Operator factors: Properties related to the operator, such as memory, mental and physical abilities, skills, training level and experience can determine the probability of errors to occur.

The main method defined from the beginning of the project to study and develop was the augmented reality instructions. However, it is essential to review other methodologies used in the same scope, identify the potential between them and justify the choice of using AR.

Training in personnel consists of different approaches to on-the-job training (OJB), face-to-face (FFT) and computer-based training (CBT). The advantages of these approaches are

that there is no need for special devices and promotes a higher responsibility of the workers, although, depending on the operation and the skill/training level of the forming, could influence distraction errors, some of them unidentifiable. Also, these methods require the approach of other skilled operators to guide and supervisor the trainees (Mura et al., 2016).

Focused on the design, Poka-Yoke is a method that prevents physical errors by suggesting the correct action and impeding wrong alternatives that could not work or even cause damage to the equipment and the operator. This philosophy is very simple and easy to apply in project, however poka-yoke does not cover and detect all the errors.

Sensors are well known for industry applications. They can be wearable, implemented in multiple places, whether on the tool or the operator, or even remote in the environment, converting kinematic and dynamic quantities into electrical signals (Hartmann, 2011; Hartmann et al., 2009; Koskimaki et al., 2009). The main reason to use sensors is to quantify, almost precisely, different variables, so it is possible to compare results and identify possible errors, although this installation implies additional costs and needs to be well planned to implement. In addition, not all errors can be quantified, and this comparison of results requires a posterior database.

In alternative to traditional 2D drawing, the use of 3D CAD models to give instructions for the work allows the operator to graphically view the process and introduce him to a better understanding of the representation. In addition, the use of 3D models confers the capability to present detailed technical information that was not possible in traditional 2D drawing. Besides, the introduction to a different form of instruction presentation can cause distraction (Olwal et al., 2008; Zaeh et al., 2009).

Augmented reality could increase the human sensory capabilities with virtual content in the real environment and can be extended with the previous methods mentioned. Developing an AR tool is accessible and provides easy interpretation and immersive experience for the user. On the other hand, some devices could be less comfortable and the introduction to a new virtual environment could induce the worker to distraction (Fraga-Lamas et al., 2018; Mourtzis et al., 2022).

2.3. Augmented reality

Augmented reality (AR) is defined, according to Milgram and Kishino (Milgram et al., 1995), as the technique to “augment” the real world with virtual models. The concept was vulgarly introduced in 1994, although, in 1997, Azuma (R. T. Azuma, 1997), established a set of essential properties for an AR system, such as the need of combining virtual objects in the real world, supporting the interaction of the user during work, and conferring the geometric alignment between the real world and the virtual world (Berryman, 2012).

Nowadays it is applied in different areas, including tourism (Cranmer et al., 2023), cultural heritage (Marto et al., 2022), entertainment (Hung et al., 2021), videogames (Qin, 2021), marketing (Rauschnabel et al., 2019), medicine (Zoabi et al., 2023), logistics (Lagorio et al., 2022), manufacturing (Mourtzis et al., 2022), and others. The maintenance case applied to augmented reality gives advantages improving the man-machine interface, due to the real time visualization, which allows to input information about the objects presented on screen, as well as communicate information about the components or even the auxiliary tools.

The main motivation to use augmented reality in maintenance and assembly lies in amplifying the user’s precision in certain actions that imply precision and complexity, obliterating the need to divert focus from the working station to look at the instructions. Also, in situations of disparity between the present model and the instruction model, the implementation of a database which counts with different possible cases allows the adaptation of the same instruction model to other equipment (Henderson & Feiner, 2011).

2.3.1. Types of augmented reality

There are different ways of categorizing augmented reality. Some authors defend that AR could be differentiated between marker-based and markerless-based (Boonbrahm et al., 2020), and other six main types of augmented reality, which in turn can be divided in two groups, the triggered AR and the viewed-based AR (Edwards-Stewart et al., 2021). The triggered AR contains a stimulus that initiates the augmentation process, being this stimulus one of following four types of triggers: 1) markers (paper or objects); 2) a GPS (Global Positioning System) location; 3) dynamic augmentation; or 4) a combination of the last two, classified as complex augmentation. On the other hand, viewed-based AR could be 5) indirect augmentation; or 6) non-specific digitalized augmentation.

Marker-based AR uses markers in the real world as a trigger to display digital content in the virtual environment. Once the function is recognizing the spatial position, both distance and orientation, of an entity in relation to the used device, markers could be pictures and patterns, as shown in Figure 1, or even, as presented in Figure 2, objects with volume (Boonbrahm et al., 2020). AR with GPS location, also known as geographic-based AR, does not involve image markers, but instead dynamic geographic spots as triggers to display virtual content, according to Figure 3. It is considered as a form of markerless augmented reality. Dynamic augmentation is a marker-based augmentation form, although the marker is not restricted to one alternative. Different from the techniques above, dynamic augmentation begins by recognizing the object characteristics and then adapting the virtual content to fit these characteristics. This AR technique is mainly used to fit human features, as shown in Figure 4, such as face recognition or body part adaptation. As a combination of the techniques presented, complex augmentation can take advantage of the marker-based, geographic-based, and dynamic-based augmentation as a way of complementing each other.

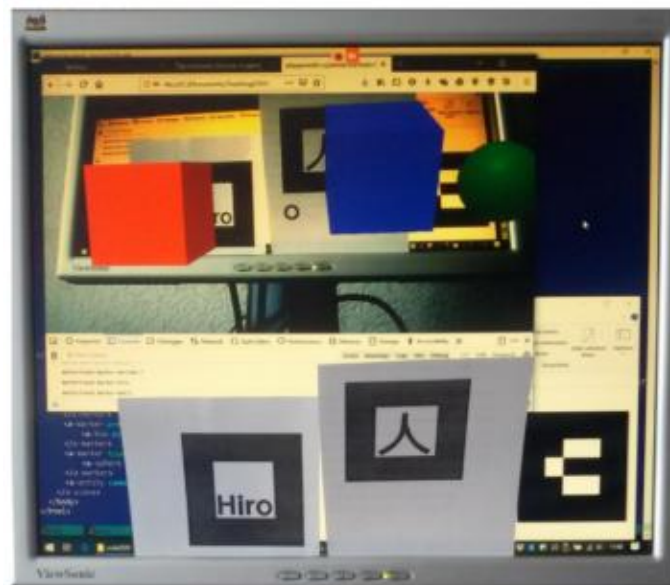


Figure 1 - Augmented reality markers (Edwards-Stewart et al., 2021)

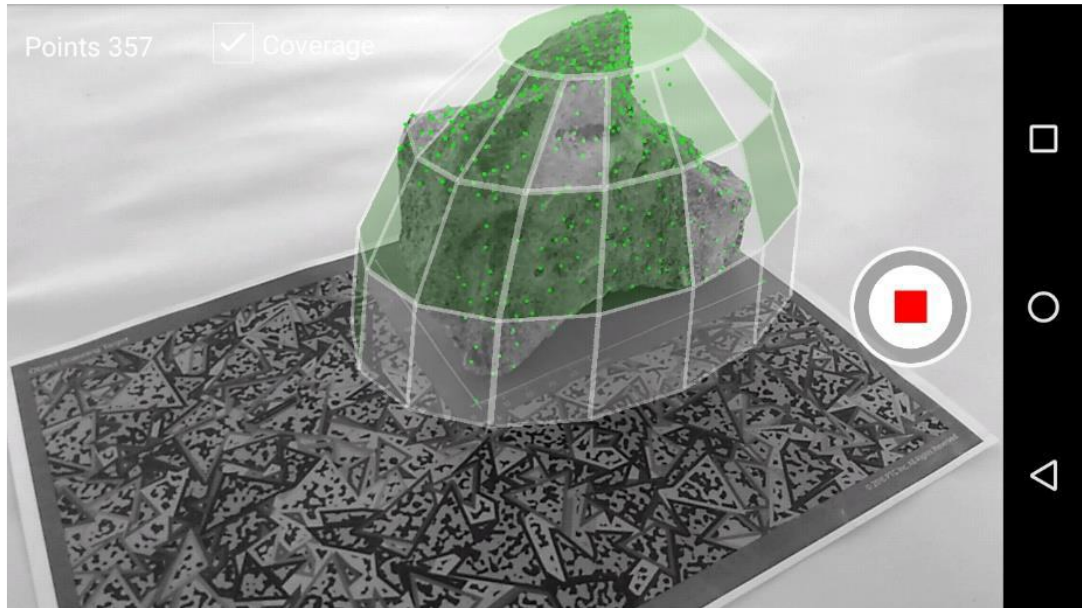


Figure 2 - Scan of a stone using Vuforia Object Scanner in way to use as an augmented reality marker (Marto et al., 2022)



Figure 3 - Illustrative representation of wikitude, an AR method based on GPS coordinates (Vakaliuk & Pochtoviuk, 2021)

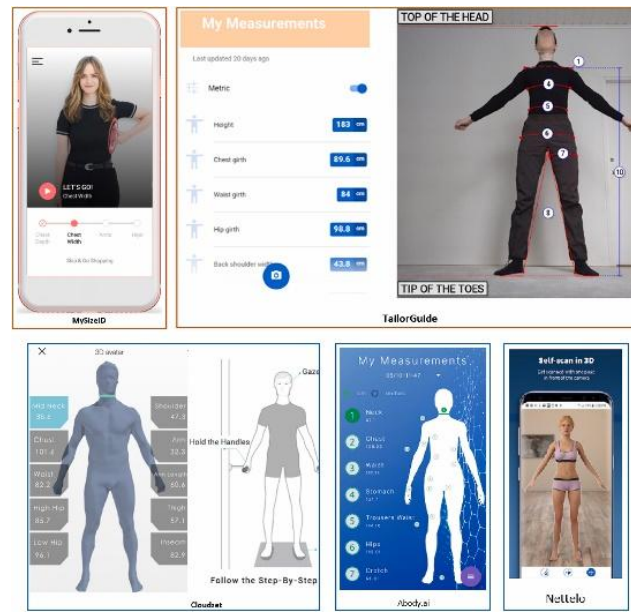


Figure 4 - AR dynamic body features recognition (Karadayi-Usta, 2024)

Indirect and non-specific digital augmentation are methods that do not need to be triggered the same way as the mentioned before. Indirect augmentation starts with a static image, using a picture instead of a real time camera, and augments the established entities. This method is commonly used to scan and edit images with a camera, since the projection identified can be converted to a flat picture. The last method is non-specific digital augmentation, and the technique is based on a dynamic view of the real world without specific references or markers, such as a flat ground or wall to place virtual content. This method works by using stereoscopic cameras (Edwards-Stewart et al., 2021).

2.3.2. Concept of mixed reality

Mixed reality was defined as a concept on the final of 1990's decade; however, it was not a concrete idea. Due to the vast range of distinct applications to this method, it exists multiple definitions for "mixed reality" to the date, based on the application area (Rokhsaritalemi et al., 2020).

The initial definition of "mixed reality" was introduced as an interface of reality-virtuality, where the virtual models are represented on real world scale from computational techniques. Based on this concept, from the point of view of the user, there is a physical environment observed, as well as a simultaneous virtual environment overlapped, where virtual and real objects coexist. In general, mixed reality is an environment diffused between augmented reality and augmented virtuality, as presented in Figure 5.

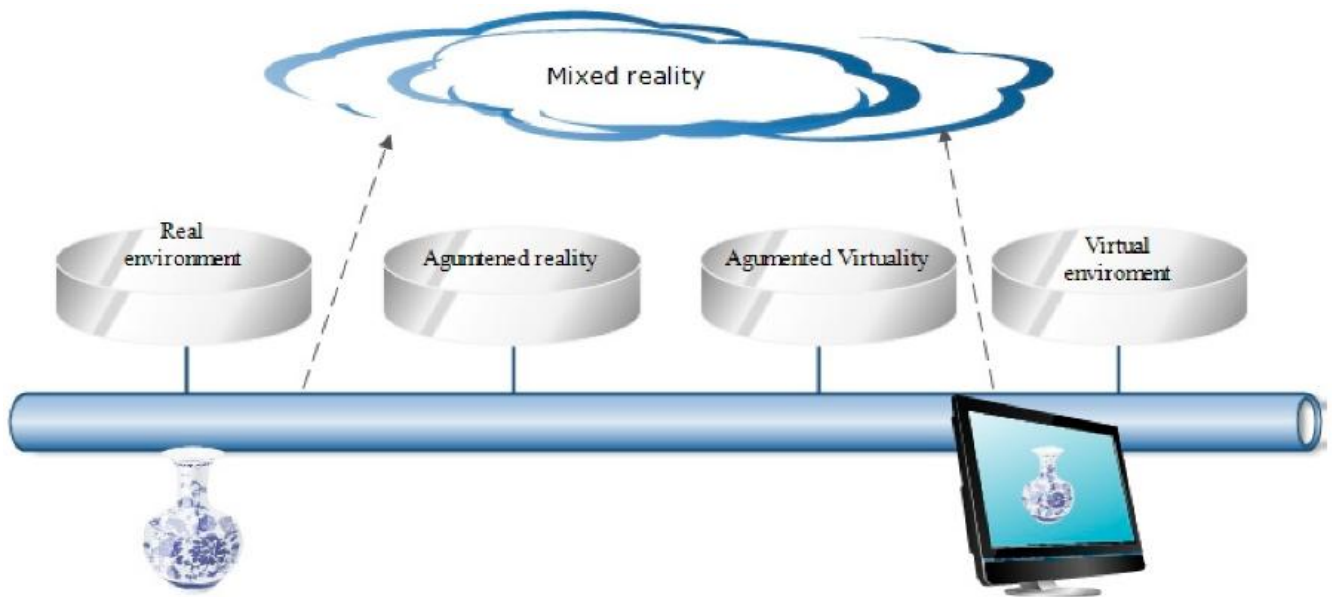


Figure 5 - Framework of mixed reality between real and virtual environments (Rokhsaritalemi et al., 2020)

In the face of the mixed reality concept uncertainty, Speicher et al. (Speicher et al., 2019) have debated in conference about the common characteristics between different authors, in order to reach a consensus about possible definitions of this technique:

- Number of environments. Associated to the total of necessary environments for a specific type of system, be they physical or virtual.
- Number of users. It refers to an obligatory number of users who need to be associated with a system, both simultaneously and asynchronously.
- Immersivity level. There is no specific method to clearly quantify, once it is directly associated with the user feeling of immersivity, however it is based on the digital content, such as interactive inputs. It is worth noting that this is not a factor that varies linearly with the virtual objects' quantity on user view field.
- Virtuality level. To separate virtual reality and mixed reality, the virtuality level refers to the quantity of digital content appearing on the user view field, on relation with the quantity of real environment presented. In this way, virtual reality is defined with a virtuality level of 100%.

- Degrees of interaction. The interaction could be implicit or explicit, given that implicit interaction is associated with not changing the environment, such as visualizing a three-dimensional model from different angles, while explicit interaction implies the change of the environment.
- Inputs. The type of physical inputs could define a mixed reality system, such as moving, geographic location or even tracking sensors.
- Outputs. All outputs of a mixed reality system are virtual type, given that could be image and audio, or in more advanced cases, haptic, taste and smell.

2.3.3. Advantages of augmented reality

Distinct methods could be implemented in different areas as a solution to reduce the error, as seen before. In maintenance and assembly, augmented reality is applied with the main purpose of helping the operator with additional information (Fraga-Lamas et al., 2018).

Augmented reality integrates the digital assembly instructions with the physical tasks, which expands the capability of explaining the process in the environment with digital information (R. Azuma et al., 2001, p. 201). The visual experience is extended with additional helping (Henderson & Feiner, 2011), as well as the possibility to interact at the same time with objects in the cyber-physical space (Syberfeldt et al., 2015), depending on the usability and reliability of the process (Westerfield et al., 2015). In addition, AR could be used as a way of integrating the user into a virtual environment, enriching the real world experience (Fiorentino et al., 2009) in a not expensive and easy way to develop and implement (Yuan et al., 2008). The instructions in AR, as well as the traditional system, follows-up the user cognition, developing a better understanding of the assembly system (X. Wang et al., 2016; Z. Wang et al., 2021), even though some instruction resources are maintained, such as manuals, videos or animations that simulate the processes and allows the user to preview the necessary steps. This integration decreases the time-consuming by increasing cognitive efficiency, resulting in faster and better manual productivity (Büttner et al., 2017; Yuan et al., 2008). And most importantly, AR instructions compared to traditional 2D drawings and schemes, are more natural, intuitive, and upgrades performance by the allowing the interaction only with bare hands (Ong & Wang, 2011).

This interaction man-machine provides the user with a confidence and security feeling about the work, which results in better performance and quality of the results.

2.3.4. Types of visual representation

When developing an augmented reality tool, it is important to consider the best visual representation to fit the instruction model and the tasks to realize. Part of this choice follows the user cognitive rules, to a better understanding of manual assembly efficiency. Even though the understanding of the task cannot be directly correlated with the assembly efficiency, once this parameter parts mainly from the operator's experience. Also, the accuracy of interpretation is dependent on the user's cognition of visual representation (Z. Wang et al., 2022).

The representation in two dimensions is the most common in traditional instructions, as a homologated and practice solution. For the same reasons, this implementation, similar to the case presented in Figure 6, in AR instruction systems is the most frequent even nowadays. In addition to the representation of technical drawings schemes, the implementation of dynamic forms of media, such as animations and presentations as mentioned before, is available. The only limitation of this representation is not being suitable for more complex and physical tasks (Fiorentino et al., 2009; Mizell, 2001).



Figure 6 - Example of 2D instructions based on an AR application (Mura & Dini, 2021)

Three-dimensional representation is considered a generalization of two-dimensional representation, once it was the natural tendency of evolution (Feiner et al., 1993;

Optronique et al., 2003). The main reason to use three-dimensional models instead of the traditional two-dimensional draws persists in transmitting a strong and natural perception of the task (J. Huang et al., 2017; Uva et al., 2010). However, some of the instructions could be complex and hard to interpret by the operator, which require higher levels of cognition to analyze.

Moreover, dynamic 3D representation increments the three-dimensional representation by converting into animations in cyber-physical space, as exemplified on Figure 7. This solution turns it possible to add color patterns, movement and different appearances to guide the operator, depending on the task and reducing the need of precious experience in certain situations (Billingham et al., 2008; Hou et al., 2013). The issue in this representation is the high tendency of distractions. The overuse of different characteristics, such as movements and colors, could make it harder to maintain the focus of the operator, so it is important to balance these features.

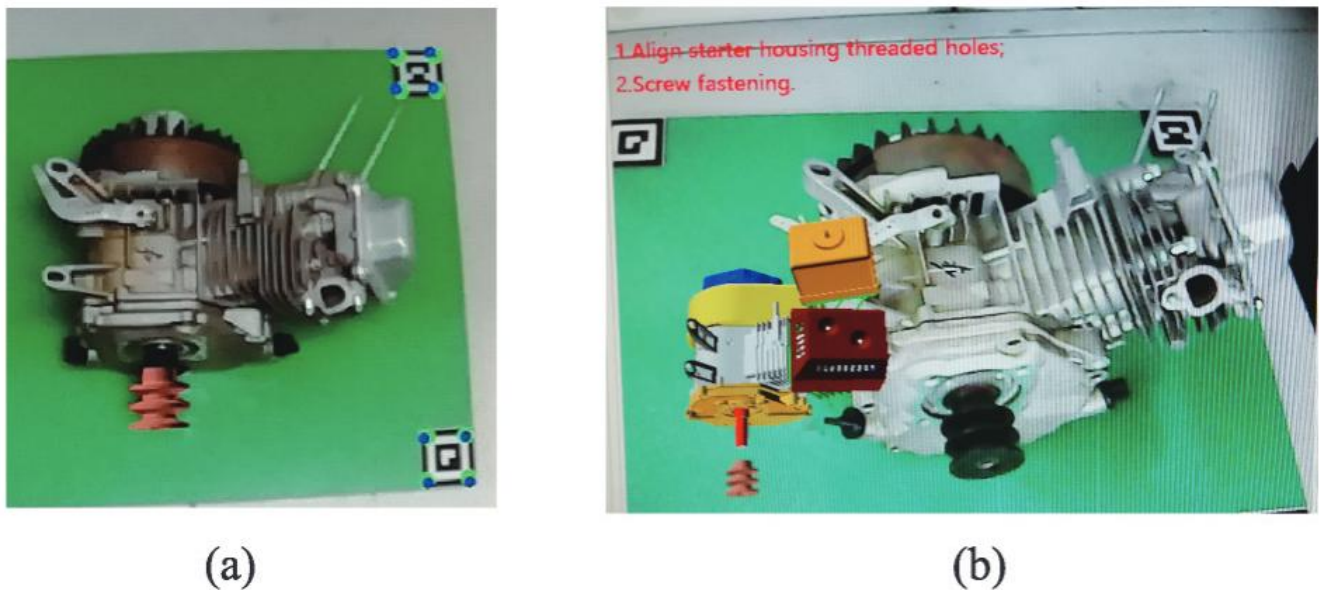


Figure 7 - a) Image of a motor captured by a camera; b) Augmentation of assembly animation instructions (Li et al., 2019)

With a different concept, simplified information to describe features promises avoiding distractions with a minimalistic interface. The main idea is to reflect the intention with visual information with short texts and signals, so the user can retain the idea of the tasks (Funk, Bächler, et al., 2015; Funk, Kosch, et al., 2015). Even though this system allows to avoid visual distractions, the established design is not based on cognitive rules and needs,

so the instructions could not be transmitted correctly. The use of this method implies the previous knowledge of the operator about the task to be effective.

2.3.5. Augmented reality devices

To visualize and enable the interaction man-machine with the augmented reality, it could be applied different types of equipment, if they are equipped with an interface to recognize the visual field and depth, as well as an exhibition interface. Nowadays, mobile devices are developed to use augmented reality in functions such as facial recognizing or entertainment. On the other side, to the use of mixed reality it is imperative to own a head mounted display (HMD) suitable for the purpose (Karthika et al., 2017).

It is defined as mobile devices all the computational equipment with reduced size, without the necessity of an external power supply. Among the existent equipment, stands out for their accessibility to augmented reality, the smartphones, tablets and laptops, although, the last one mentioned could be complex to scan a visual field without being the facial by the user (Saidani Neffati et al., 2021). Otherwise, smartphones and tablets allow to have a more dynamic movement, as well as have a stereoscopic rear camera interface, which assists on the tridimensional recognition of the space, as well as identifying entities, which could be seen in Figure 8. In general, the operating systems present are Android and IOS, with Android being the most used by the user and developer accessibility, once it works with a Linux architecture base, that covers a bigger spectrum of compatibility. It is important to highlight that, even though the hardware of these equipment had an considerable evolution, it could exist graphic limitations on some devices, due to the number of entities to present on the screen (Ariano et al., 2023).

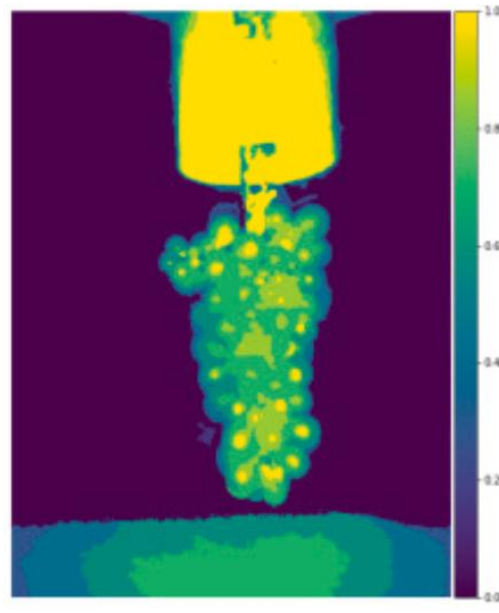


Figure 8 - Recognition of depth on a bunch of grapes by a Samsung Note 10+ stereoscopic camera (Parr et al., 2023)

As it is an expansion of augmented reality directly to the user visual field, the mixed reality requires specific equipment for its purpose. The HMD were developed with the meaning of providing virtual information, such as image and sound, from the visual and space recognition from the user perspective (Karthika et al., 2017). For such purposes, devices such as the Microsoft HoloLens, shown in Figure 9, use a set of sensors to spatial recognition and user interaction. To identify the field, the device uses two cameras, in that case one to precept depth and another to recognize color. For the user interaction, the focus point is captured by a pupil scanner, while the voice is captured by a directional microphone and the movements by a gyroscope, an accelerometer and a magnetometer. In turn, the mixed interface is visually generated by a coherent light interface display, and the audio is transmitted by spatial sound speakers, non-isolating the surrounding sounds. In addition to the voice and head gesture recognition, the HoloLens identify hands gestures to interact with the interface man-machine, such as open and close to grab and move objects, contract the index to select, or even shake to close tasks. In terms of development of the equipment, Microsoft makes available an emulator of the device, which allows us to test the programs without the equipment.

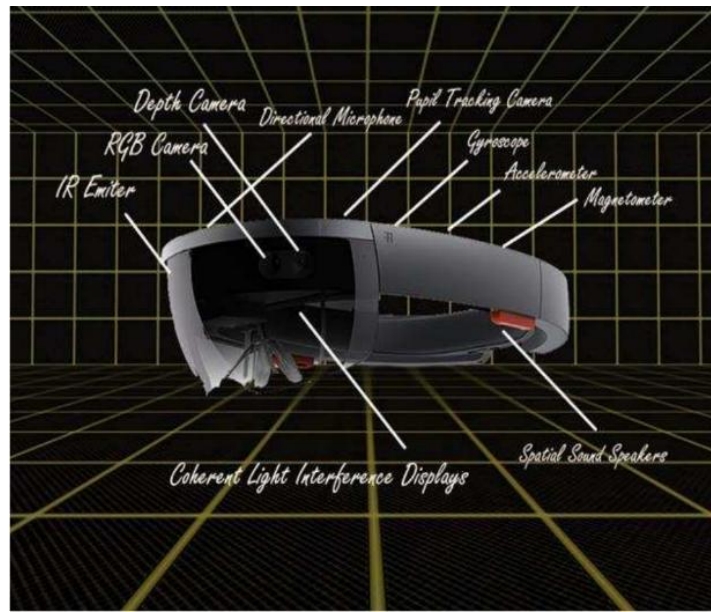


Figure 9 - Microsoft HoloLens 1 scheme of hardware (Karthika et al., 2017)

Another concept of AR devices is associated with fixed augmented reality, which was also the first way to develop the technique. The devices used to supply this method are the computer and the display, this being, in most cases, either a monitor or a projector, as exemplified in Figure 10. As a fixed display, the user could take advantage of free hands, although, to follow the information, it is imperative to look away to the display during the process, as well as being limited to the camera's field of view. For this reason, the method is mainly recommended to workbench operations, such as small parts assembly (Baertsch et al., 2023).

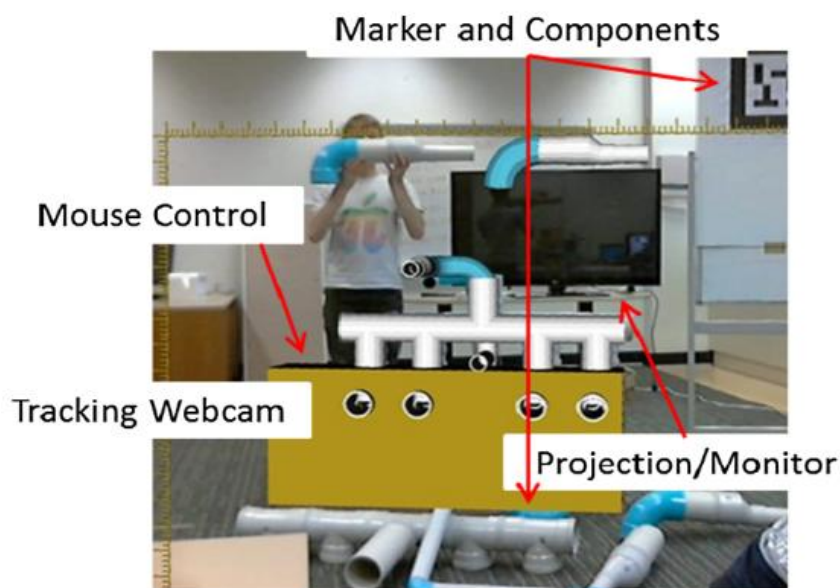


Figure 10 - Use of a fixed device as a pipe assembly instructure (Hou et al., 2015)

2.4. Structures of AR instructions applications

The advent of Augmented Reality (AR) has revolutionized the way instructional content is delivered, enabling a seamless integration of digital overlays into the physical world. AR instructions have become invaluable in domains such as manual assembly, training, and repair, where precise guidance and user engagement are crucial. These systems are designed to simplify complex tasks, reduce errors, and enhance efficiency by leveraging advanced technologies and interactive features (Z. Wang et al., 2022).

This chapter aims to present a review of the architecture and frameworks underpinning AR instruction systems. It explores the structural components, including visual representation, interactivity, contextual information, and real-time feedback, that define the effectiveness of these systems. Additionally, the chapter examines the technological frameworks that support AR instructions, such as integration with CAD models, IoT devices, and other digital systems. By synthesizing current advancements and design principles, this review provides a comprehensive understanding of how AR instructions are designed, implemented, and optimized to meet diverse industrial needs.

2.4.1. Framework of the instructions system

Before implementing an AR tool, it is crucial to understand the possibilities introduced during the years in the market, as well as the advantages and negatives of each one, in terms of instruction style.

The AR instruction types for maintenance and assembly are based on the client-server responsible for transmitting and receiving the data correlated to the operation in process, both outputs and inputs (Z. Wang et al., 2022). The client-server framework is divided into four different entities, namely the measuring client, the CAD/PDM system, the server, and the visualization client. The measuring client is responsible for the collection of data in real time in physical tasks, such as part features, relations, process, and others, based on physical measurements in the real world with sensors attached to the operator and the equipment. The CAD/PDM system includes digital assembly parameters in the frame/scene. The system is responsible for packing and sending data to the server by a communication interface. This interface is directly connected to the server which is responsible for the calculation, collection, and distribution of data to the user device in real-time, construction of the communication sockets and the obtention of data from the measurement client and the CAD/PDM system. Finally, the visualization client retrieves

the process information with the server and processes into instructions, in a summarized and convenient way for the user (Woodward et al., 2012).

Web-based guidance system operates on a network to send data, such as digital models and assembly parameters in CAD/PDM and receive parameters from the user as feedback. Once this method is decentralized, it could be implemented in every physical space with propitious conditions, without geographical restrictions (Lipson et al., 1998; Reinhart & Patron, 2003).

Agent-based guidance systems have an agent mechanism integrated, suggesting to the user the operational steps at the same time he performs the tasks, instead of the direct interaction with the system to proceed. This option has a fast adaptation to external conditions, although it is only possible to apply by focusing on the objects in study rather than functions (Song et al., 2009; Westerfield et al., 2015).

The more recent guidance system uses cloud based as a client. The main reason to use a cloud-based system as an AR platform resides in developing intelligent instruction, with flexibility, high-performance and omnipresence. As a platform on cloud, turns it possible to use a big data analyzing through an open-source programming framework, as well as supporting communication, sharing information and solving troubleshooting by a social media platform (Z. Huang et al., 2014; Mourtzis et al., 2017).

2.4.2. Architecture

Augmented Reality (AR) applications designed for assembly instructions present a unique blend of technological components and user experience considerations. These applications aim to guide users through complex assembly processes by overlaying digital information onto physical objects, creating an intuitive and interactive environment. The architecture of such systems is pivotal in determining their functionality, scalability, and user effectiveness (Z. Wang et al., 2022).

Considering other previous studies, combining different forms of interaction and representation could affect the perception and immersion of the user. Uva et al. (Uva et al., 2010) demonstrated that incorporating text, 2D graphics, and wireframes as assembly instructions can enhance user performance during the assembly process. Funk et al. (Funk, Kosch, et al., 2015) and Doshi et al. (Doshi et al., 2017) highlighted the viability of employing 2D images, videos, 2D graphics, and 3D graphics as AR-based instructional

tools. Murata et al. (Yoshitoshi Murata et al., 2008) presented a solution in the automotive sector that utilizes a device combining a magnetometer, accelerometer, and gyroscope to track the movements of the operator's hand.

2.4.2.1. Instruction style

In a way that 3D data could be used as instructions for manufacturing, the ASME Y14.41 standard covers the activity since 2003 (Pilkaite & Nenorta, 2013). Although it is allowed to use 2D project drawings the same way as physical instructions to form a model-based definition dataset (Alemanni et al., 2011). However, using a 2D monitor instead of AR glasses creates a separated digital environment from the physical task, which implies that the user checks the next step on the monitor and then perform, disturbing the natural man and machine communication (Nee et al., 2012), as well as not to use hands directly to interact, but instead a keyboard and mouse (Rekimoto, 1996).

2.4.2.1. Core rendering technology

The objective of AR instructions is transmitting the working intention through visual information. The impact of AR information could be based on the appropriation of the images, which is possible to judge by the virtual-real interactive environment, the spatial relation rendering, the physical cue rendering and the cognitive cue rendering (Z. Wang et al., 2022). The virtual-real interactive environment is the capability of stimulating the user enthusiasm and innovative spirit with the introduction of this new environment (R. T. Azuma, 1997), as well as showing the interaction between virtual and real worlds (Shen et al., 2010). Spatial relation rendering is defined by the objects position, perspective and occlusion, as fundamental features to clarify the virtual features in the real world and harmonizing the relation with the surrounding environment, which stimulates the user concentration, as well as understanding the state of physical tasks (Deshpande & Kim, 2018). Related to physical cue rendering, it is important to maintain the lighting consistency, so the objects do not appear to float and provoke discomfort on the user (Feng, 2008). The most important core of AR instructions, cognitive cue rendering, is based on having the confirmation that the user understood the task, implying the AR manual to be the closest to the user cognition, as well as the intention consistency (Z. Wang et al., 2022).

3. Development Stage

The development stage represents the practical realization of the concepts and architecture outlined in earlier chapters, culminating in the creation of an AR application tailored to assembly instructions. This chapter details the key processes involved, from selecting and preparing tracking targets to the integration of 3D assets and animations, and finally to the application deployment and testing. Each phase is pivotal to ensuring the app delivers a seamless and effective augmented reality experience.

A critical first step in the development process was identifying suitable targets for AR tracking. Initial testing involved simple, printed paper targets, enabling quick evaluation of tracking accuracy and reliability. As development progressed, the focus shifted to parts of the actual equipment used in the assembly process, leveraging their unique geometries and features to enhance markerless tracking capabilities and ensure a more realistic and practical application environment.

The creation of animations played a central role in illustrating assembly instructions. Using Blender, complex animations were developed to demonstrate the correct movements and procedures for each assembly step. These animations were seamlessly integrated with 3D models, which were acquired through high-resolution 3D scanning and modeling of the equipment. This approach ensured accurate digital representations, preserving the dimensions and details necessary for effective guidance.

The application itself was built for Android devices using Unity, taking advantage of its AR development tools and cross-platform capabilities, such as Vuforia engine. Throughout the process, iterative testing was conducted to refine the app's performance, evaluate the user experience, and ensure the reliability of tracking, animations, and interactions. This development cycle not only validated the system's feasibility but also provided insights into optimizing AR technologies for real-world assembly applications.

3.1. Choice of the targets to use

The AR positioning of models and animations is made resorting to image targets. These images do not have any requirement imposed, although, depending on some characteristics, the targets could be more accurate (Edwards-Stewart et al., 2021). Vuforia SDK is featured with a target making tool, allowing the introduction of targets inside the

application, as well as a system of accuracy evaluation, ranking on scale of 1,0 – 5,0 (Semerikov et al., 2021). Some of the characteristics that could affect accuracy are:

- The colors used, the more distinct, the easiest to identify, prioritizing dark and lighter divergency, such as black and white.
- The density of details, images with more details result in more accurate positioning.
- Flatness, targets with curvature cannot be used in this method, due to the difficulty of capturing all details without deformation.

For the creation and choice of targets two distinct groups were defined: equipment present targets and equipment non-present targets. Non-present targets could be used during the application testing stage, as well as perform the application without imposing the models on the equipment. Present targets relate to surface features, such as stickers, keyboards and LCD screens, that could be used to position the models imposed on the equipment or as triggers, in the case of LCD screens.

Creating the non-present targets began with the introduction of minimalistic geometries, in this case, circles, squares and numbers. Since six different targets were created, the distinction between them was the numbers from 1 to 6, present in the upper left and lower right corners, as can be seen in Figure 11. Vuforia target manager evaluated these targets with poor accuracy, with a rank of 2,0. To increase the accuracy, some texture was added to the images, whereas the pattern is different for each one, so it is less possible for the application to assume a target as another one. Once uploaded to Vuforia target manager, the targets were ranked with 5,0, ensuring that they are accurate to use.

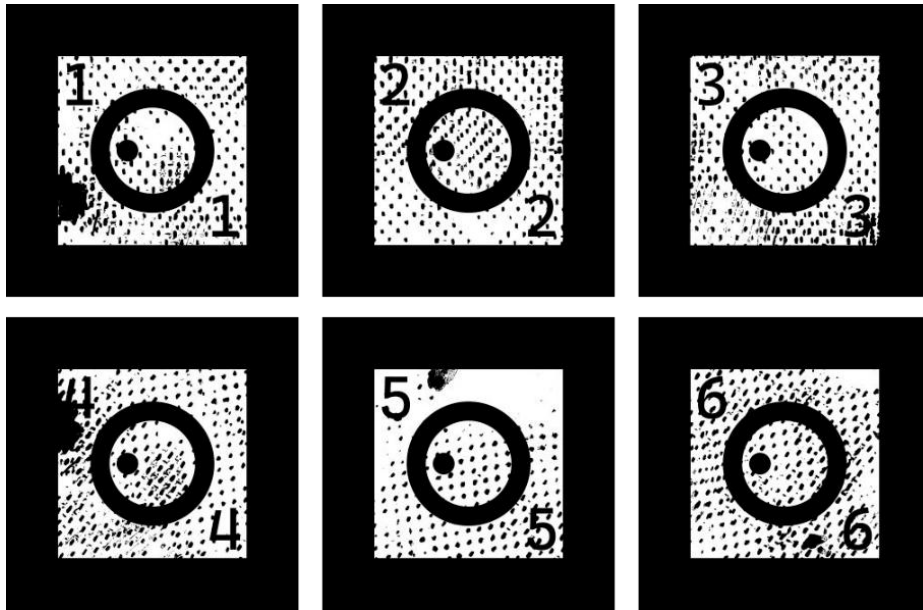


Figure 11 - Images developed to use as markers

The equipment's present targets were based on flattened patterns, in this case the keypads and the monochromatic LCD screens. To make the targets, first some photographs were taken to the equipment features and distorted to the real geometry. Testing the images on the target manager showed that the accuracy is relatively median, ranking the main keypad with 3,0, and the measuring encoder keypad with 1,0. The LCD screens were tested turned on, not as a way to position information, but instead as an input, so the application recognizes which step to progress. This method should not be used to identify characters, such as values measured by the equipment, although it could be applied with simple text or signs. To test on the monochromatic LCD, a photo of the screen with the text "ON" was used. First, without any editing, the result of the manager was 0,0, not finding any guide points. By simplifying the image colors, the result of the target manager was 1,0, which means that is relatively unstable, even though it is identified as a target, as compared in Figure 12. It was also noticed that the implementation of static entities without background light, such as button pads on LCD screens, improves the trackability of the targets, once there are more focus feature points, as could be seen on Figure 13.

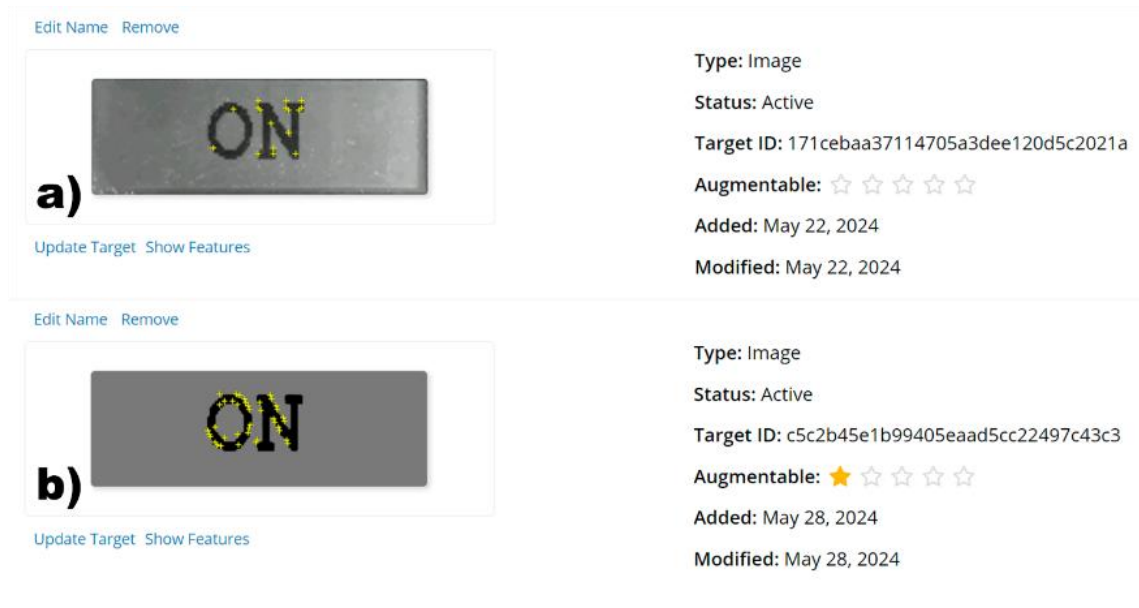


Figure 12 - a) Image of LCD used as marker without being edited; b) Image of LCD used as marker after being converted to a bicolor image

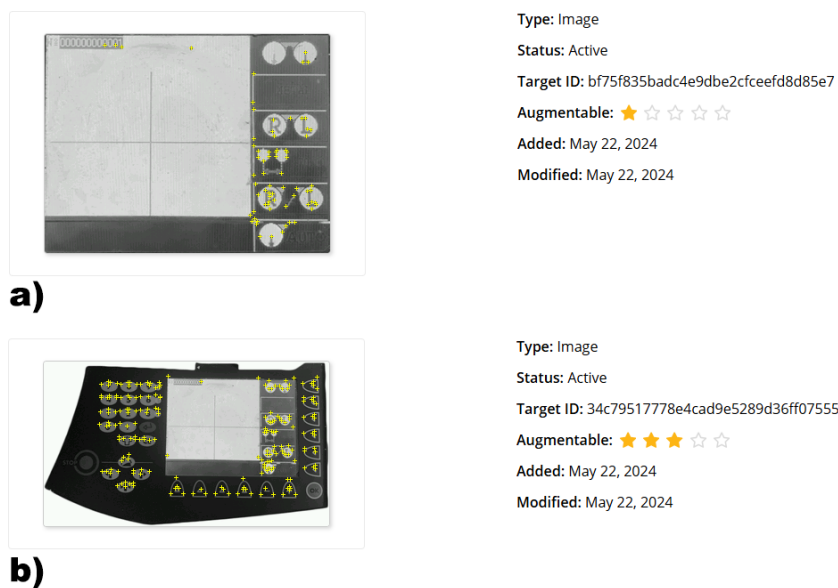


Figure 13 - a) Image of LCD used as marker without button pad b) Image of LCD used as a marker with button pad

3.2.Choice of computational resources

To develop the AR applications to proceed with the essays, it is essential to choose a proper set of software to program and design the resources need. The present chapter aims to justify the choice of software and other computational tools used during the process.

Developing the AR application starts with an engine associated with a Software Development Kit (SDK) (Vakaliuk & Pochtoviuk, 2021). The choice of the engine was based on multiple factors, in this case:

- Cross-platform compatibility: the engine needs to support development to Android, IOS and Windows (in case of building to Microsoft Hololens).
- Mobile application creation interface: as the tools will be mainly focused on mobile devices, it is required that the engine provides a dynamic interface for mobile development.
- Availability of educational content: Since the emergence of doubts during development is predictable, it was required that the choice of the engine be based on the availability of auxiliary content, as well as the level of expertise of the involved supervisors.
- Free for non-commercial use: Given that this is a development with exclusively experimental purposes, it is necessary to avoid costs associated with the development of the technique.

Based on this criterion, as well as a benchmark developed by Vakaliuk & Pochtoviuk, the engine chosen to develop the augmented reality tools was Unity3D, since it allows the development for all needed platforms in a friendly way, counts with multiple tutorials within the scope of AR, and does not require a professional license.

Moreover, the choice of a compatible SDK with Unity3D is recommended, given that Unity3D counts with AR development tools, although with limitations. The choice of an SDK was made considering:

- Markers support: Once the application generates AR via marker based, it is not conditional to support other methods, although it is important to consider the best performance when applied.
- Open access for non-commercial use: Once again, this project was done avoiding costs associated with the development of technique.
- Compatibility with Unity3D: The SDK needs support being implemented in Unity3D to directly act upon the application.

After a benchmark, three SDKs were selected: Wikitude, Vuforia and Kudan. The Wikitude consisted of a development platform for augmented reality development. Although it is vitality paid for a subscription, Wikitude has support for Android, IOS and HMD devices and allows three-dimensional monitoring based on geographic data, as well as image recognition from a database. The price starts on 1990€ with total access and has a trial version of 15 days. Vuforia SDK is the better indicated system for the majority of the AR development cases (Vakaliuk & Pochtoviuk, 2021), supporting platform development such as Android, IOS, Windows, MacOS and HMD devices, as well as Unity3D, being this the main interest of developers. Besides the capability of using established markers to perform AR, the system counts on a tool to recognize objects based on geometry and text, along with the functionality of VuMarks, combining images with markers to use as labels. The basic use has free open access, allowing the addiction of plugins from 99US\$ per month. KudanSLAM is the simplest to apply in comparison to the previous two, even though it only has compatibility with Android and IOS devices. The SDK allows the recognition of tridimensional objects and the inclusion of them on a Unity database. KudanSLAM is free to application test and vitality paid to developers starting at 1230 US\$.

Based on this data, the SDK chosen to use in pair with Unity 3D was Vuforia, not exclusively because it is a most economical option, but also because it is the most studied from the three, presenting multiple learning courses for different cases of applications.

3.3.Scanning of the equipment

Creating an augmented reality application implies the use of tridimensional models of the equipment. The majority of cases use existent models, previously made for another purpose, however, the equipment used on this project does not have any available models to use as open source, implying to make a reverse engineering of the existent parts. Some of them were simple enough to model using Autodesk Inventor 2024, in this case, the applied equipment to proceed with the encoder calibration process included inside the suitcase. Machine geometry is way complex to model by conventional method, so a scanner was used to make this model.

To scan the equipment, was used an EinScan Pro+ and the respective computer program. This scanner works with structured light and can be used fixed or moved around the part

(SHINING 3D., 2016). Once the machine is not small enough to use the fixed method, the scan was performed by moving the scanning tool around the machine on a fixed distance range. Simultaneously, the result could be seen on the computer screen, as well as knowing if the distance between the part and the scanner is correct. The location of the equipment to perform the scanning was way too short to move, impacting on the quality of the final result, as well as not allowing to scan all equipment sides, resulting on the model present on Figure 14. To work around this problem, the mesh was transformed using GeoMagic Studio 12. It is important to note that, once the bottom of the equipment cannot be accessed to scan, the final model presents a hole, as shown on Figure 15, that needs to be close. The software was applied to delete triangles, fill gaps in the mesh, such as shown on Figure 16, sharpen the edges, smooth the surfaces and reduce the number of triangles. During the process of scanning, there were multiple mistakes triangles floating in mesh spots where there was no material. Correcting this was based on deleting these triangles and filling the gap holes, if left. Gaps where the scanner could not get through, if simple enough, were filled using the bridge tool, to divide areas, and filled as well. In this sequence, each surface was smoothed individually, and the number of triangles was reduced. For the last, the edges were sharpened and the mech on them was reduced.



Figure 14 - Initial scan of the equipment viewed from different positions

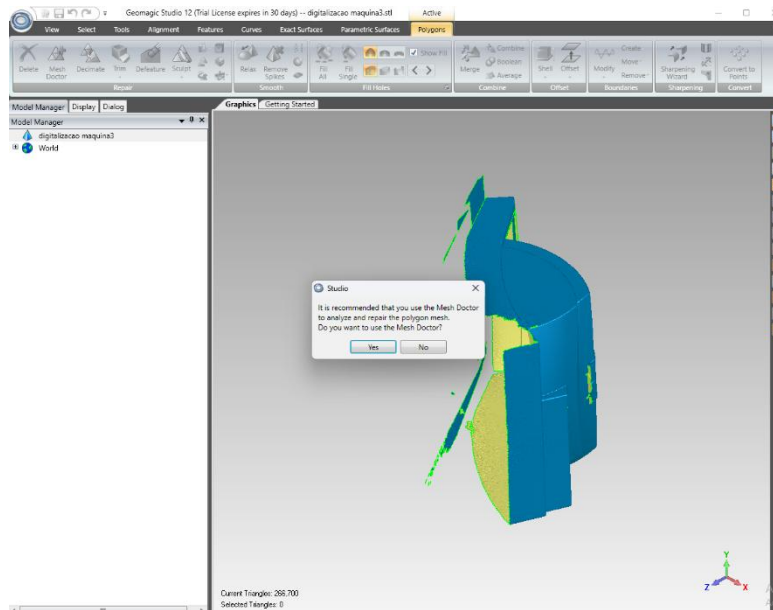


Figure 15 - First importation of the model to GeoMagic Studio 12

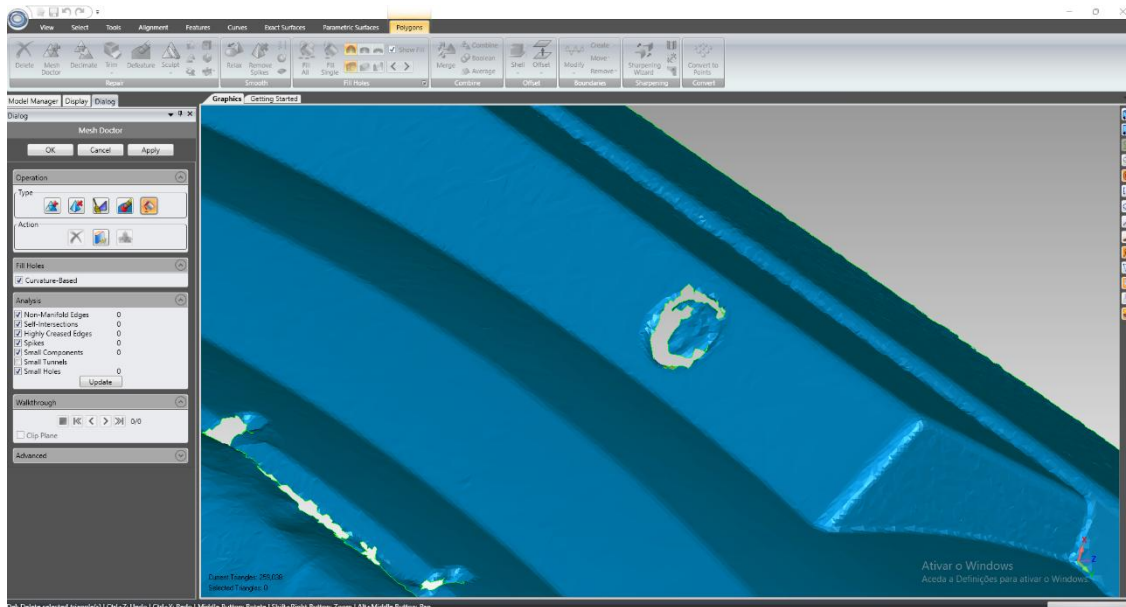


Figure 16 - Gap on the previously scanned model

3.4. Animations development

Depending on the stage of the process, the application will show different animations to guide the user executing different actions as well as on the action to demonstrate, the animations could use tridimensional models, bidimensional models or both. Unity 3D allows creators to import animations via FilmBox format (.fbx), which enables the development of animations with Blender.

As the tridimensional models are imported to Blender, the position is set automatically to align all axis with the current project, which in turn is the true position, as it has already been defined in Autodesk Inventor. Importing models to Blender results in the wrong scale, although this issue is solved by rescaling the entire model. To start animating, it is essential to set a bone structure, as a way to register the movement in relation to each part. In this case, one bone was set for the fixed parts and one for each moving part, although, one of the models is composed of two moving parts, which implied the use of two bones: a parent and a child. The other scene to be animated in blender was the measuring claws of the encoder.

For the development of future essays, two groups of animations were defined based on the suitcase. The first group consists of the tools being removed from the suitcase, where the parts float up, rotate and return to their position. Some of the parts are hidden beneath other ones, which implied the animation of extracting the upper parts first and then proceed with showing the tool in case, in way to make the user understand how to remove. The second group of animations is the assembly of a gauge formed by the parts inside the suitcase. Every animation is a step to follow, simulating the position of all parts and movement by associating each part to a bone entity, which defines all transformations in time and space, as seen in Figure 17, represented by the white triangular pillars.

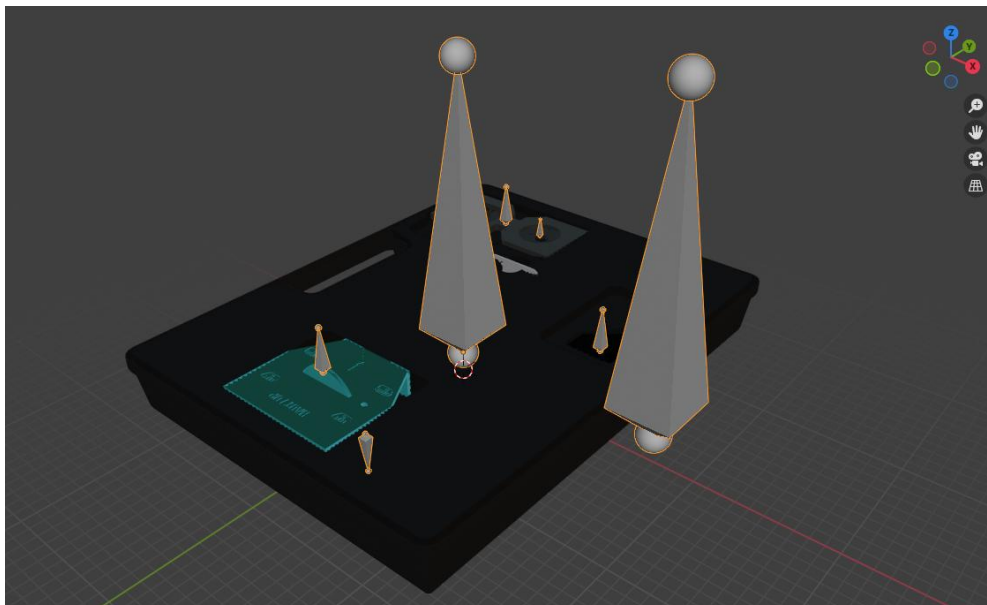


Figure 17 - Setup of parts and bones on Blender

3.5.Application development and test

With the models designed, they were imported to Unity 3D software, with the purpose of applying the animation to the application. The main focus was to develop the tools to test the interface in two of the three scenarios: Using the AR system without overlapping; Using the AR system with overlapping.

Proceeding with the development, as the .fbx files are imported, they are interpreted by the software as assets containing three dimensional models, animations, and other components, such as textures. Implementing animation consists of creating animation controllers associated with each scene.

3.5.1. Implementation of targets

To present the animations imported in Unity 3D via AR, the application needs to recognize patterns defined as a target previously implemented. There were two kinds of AR specified in this application: Augmented reality without overlapping; and augmented reality with overlapping. The augmented reality method without overlapping introduces 3D models out of real scale, contrary to overlapping AR which is required to the models to fit exactly their real position on physical environment.

Previously, Vuforia SDK allows developers to upload the images to use as targets and evaluate their accuracy to a project, as seen before in subchapter 3.1. The project is then implemented in Unity 3D, so the target images could be introduced as parents to the assets, in this case, the 3D models and animations associated with.

3.5.1.1. Targets without overlapping

Based on the protocol that would be described later, the targets used without overlapping were generated by an A4 paper sheet, presented on Figure 18 with the referenced target as a square with 200mm side printed on. In this way, the models associated as children to the target on Unity 3D were scaled to 1.3 from the real model and positioned on the center of the target with the base of the suitcase coinciding with the target plane.

As presented in Figure 19, the augmented model is considerably bigger than the real suitcase. This condition was performed with the intuit of not mistake the augmented model with the environment when observing the instructions, as well as the omission of textures

and color, once the objective of this study is to evaluate the performance of AR compared to the traditional method of paper manual, which was printed in black and white.

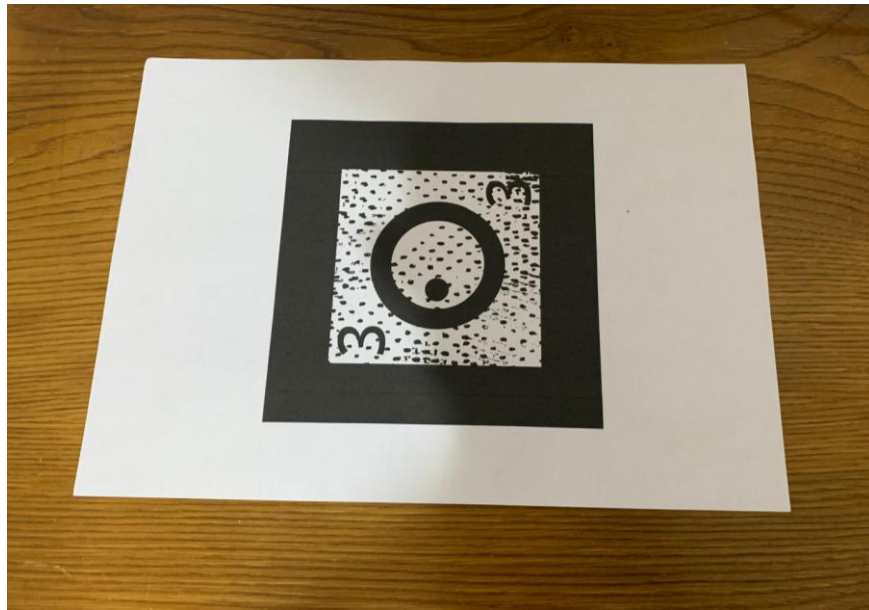


Figure 18 - Target used on non-overlapped AR printed on an A4 size piece of paper



Figure 19 - Model of the suitcase in AR side by side with the real suitcase

3.5.1.2. Targets with overlapping

Based Using overlapping AR when compared to without overlapping is a different procedure, once it begins with real features, as real dimensions and position, to implement in the application.

Conform Figure 20, to identify the position of the suitcase in real time, a target with an 80mm side was positioned on the surface of the suitcase. Based on this position and scale relation in the real environment, the 3D model was implemented in the application, in a similar fashion. Even though the virtual models scale is currently set, the position of the parts was odd to the suitcase, mainly because of the camera distortion. To repair this issue, the models were modified while running the program and adjusted to their real position, resulting in the environment shown in Figure 21. Different from the application without overlapping, the suitcase was removed.



Figure 20 - Open suitcase showing the target used for overlap



Figure 21 - Demonstration of the AR overlapped on the parts used

4. Experimentation

4.1. Case study 1: Identification of the tools

The following essay is defined as the first in a group of two essays to the public in way to evaluate the efficiency of a client help tool, applied to optometry measurement equipment. The objective of this essay will be to appreciate the efficiency of an augmented reality tool, in which the work tools will be specified, present in the operating space for maintenance.

4.1.1. Protocol

For the evaluation of this development stage, excerpts of the equipment calibration program were used, in which extracted useful tools for the activity are extracted. The procedure of identifying them could evolve five different parts presents inside a suitcase, however not all of them will be used during the essay, only the ones specified in the manual or the application.

4.1.1.1. Physical components

The evolved parts are in this case the jig1, the jig2, the jig3.1, the jig3.2, the jig3.3 and the suitcase itself. The suitcase, presented on Figure 22, is given as the space on which the jigs are located, with foam interior and black ABS plastic exterior, being considered an indirect part. The first animated part, the jig1, is similar to a trapezoidal prism made of black plastic material, as could be seen on Figure 22 a). The jig2 is a metallic part, in the shape of a square “8”, according to Figure 22 b), and needs to be removed for the extraction of jig3.3. The jig3.1 is the main part of jig3, shown in Figure 22 c), made of transparent acrylic on a non-regular hexagonal shape, while the jig3.2 is a black screw attached to the left side of this part, present in Figure 22 d). The jig3.3, shown on Figure 22 e), is the rounded corner rectangular shape to be inserted between the jig3.1 and 3.2, as well as jig3.4, not implemented in this essay.

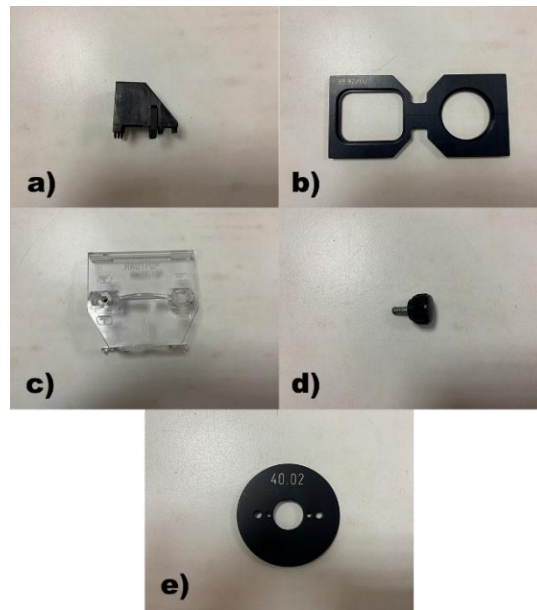


Figure 22 - a) Jig1; b) Jig2; c) Jig3.1; d) Jig3.2; e) Jig3.3

4.1.1.2. Procedure

The identification of the parts will be divided into three methods. In the first one the individual will have a physical manual as a resource, with an exploded view of the suitcase identifying the parts by number from 1 to 5. Although the manual is in English, it will be given an adapted version with only numbers identifying the parts in way to turn the essay equal to non-English speakers, as seen in Figure 23. During the process, the participant exclusively carries the suitcase and the paper manual, and this could be consulted anytime as intended necessary. After the instructions are given, in this case three parts to be removed by the number, the participant has a period of 30 seconds to analyze without touching and then start the identification process, that consists of tacking the asked parts of the case and line them in order. The asked parts to be removed are random. In the second method, instead of the use of a paper manual, the participant has a mobile device with an augmented reality app developed to visually identify the parts with the help of AR animations without overlapping, as well as a marker in to generate the suitcase model. Similarly to the previous method, the participant has 30 seconds after the instructions are given to analyze the interface, starting the identification process after that period and consulting the application as many times as he intends to. During this period, the participant could not move the paper target, but exclusively the mobile device. The third and last method is similar to the last one, but instead with tridimensional overlapping. This

allows to not to give the paper marker to the participant, but instead the marker is presented inside the suitcase surface.

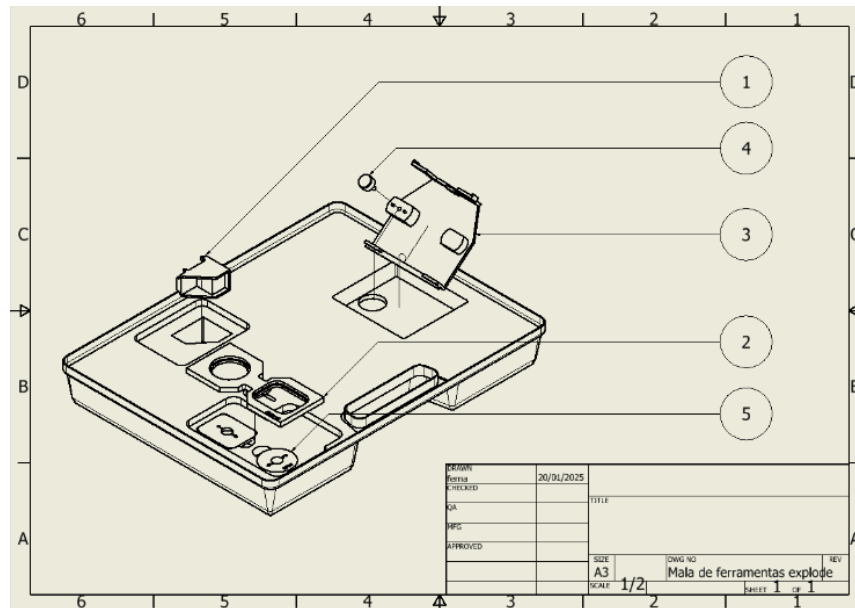


Figure 23 - Manual scheme of the suitcase with parts numbers

4.1.1.3. Evaluation

The division of times to evaluate was defined as pre-experimental, experimental and post-experimental. On pre-experimental, there is a questionnaire that approach the person profile, previous contact with AR, visual health and comfort with AR, expectations about the experience and technical habilitations, the importance of this first questions is to recognize the framework of the sample to the experience that they will be introduced and how they are affected after the experimental phase, as well as corelate parameters of their daily life with the shown efficiency in the process. During the experimental phase, it will be considered the number of times the participant visualized the instructions during the identification process, the total time taken, if the identification is correct, the number of errors performed and the perception to correct them or not. After this process, the participant is asked to identify the same parts, but this time without any instructions, in a way to evaluate the memory efficiency of each instruction method. The evaluation of this process is the same as the process before presented, without counting the number of times the participant visualized the instruction. Finishing the identification phase, the participant will be introduced to the other methods and will be questioned again about what they cognitional experienced, giving their opinion about which method they suppose has more

complexity and which is easier, immersivity of the method, if they think it has been useful in this case, if they felt tiredness and which method brings more motivation. They are also questioned emotionally if they felt frustrated, confident or satisfaction during the process. Once a participant is introduced to one of the methods, the other ones lose the first experience impact, so the other method is only introduced after the experimentation stage, without any kind of evaluation.

4.1.1.4. Experimentation group

The experimentation group referent to this case was composed of 12 volunteers, of which 5 have education level equal or inferior to middle school, 6 with bachelor's degree and one with PHD, as presented in Table 1. The participants' age varies from 17 to 70 years old, with the majority of 5 between 20 and 30 years old. About previous contact with technology, 9 have experienced VR once or more, 6 have experienced AR and 2 have never had contact with any of these forms of virtual content, besides the most used areas are in videogames and entertainment. About the frequency of use, 6 of the participants confess using this technology less than once per year, 3 of them once per semester and one monthly, of which 10 have used with mobile devices, 7 with VR helmets and 1 with HMD.

It is important to notice that two of the volunteers have related nausea and dizziness with VR and other media, such as 3D movies. Also 10 participants have vision problems, of which 7 have myopia and 6 with hypermetropia.

Table 1 - Results from pre-essay questionnaire of case study 1

	Category	Case 1
Scholar degree	High school or less	4
	Bachelor	6
	Master's degree	0
	PhD	0
Ages	< 20	0
	20 to 30	8
	30 to 40	0
	40 to 50	1
	50 to 60	1
	> 60	0
Used before	AR	5
	VR	9
	None	0
In	Videogames	8
	Entertainment	6
	Work	0
	Demonstrations	3
Frequency	Rarely	8
	Yearly	0
	Semestral	2
	Monthly	0
	Never	0
Devices	Mobile	10
	VR helmets	7
	HMD	2

4.2. Case study 2: Assemble of a three parts component

The following experimentation was defined as the second of a group of three experiments performed to a council of individuals, to evaluate the effectiveness of two methods applied

on a client help tool to optometry equipment. The objective of this experiment is to appreciate the perceptivity of an AR tool, which demonstrates the procedures of assembly on one of the jigs used to perform the equipment maintenance.

4.2.1. Protocol

For the evaluation of this development stage, excerpts of the equipment calibration program were used, in which extracted useful tools for the activity are extracted. The procedure of identifying them could evolve five different parts presents inside a suitcase, however not all of them will be used during the essay, only the ones specified in the manual or the application.

4.2.1.1. Physical components

The evolved parts in case are the jig n°2, n°3.1, n°3.2, n°3.3, n°3.4 and the tool case. The tool case is defined as an indirect part and assumed as the place where the jigs are located, with the interior in foam material and the case itself in ABS plastic. The jig n°2 is a black metal part on a shape of an “8” number, as shown on Figure 22 b), if is an indirect part as well, and its function is being removed from the case, to allow the extraction of jig n°3.3 and n°3.4. The jig n°3.1 is the body of the final mounted part, shown on Figure 22 c), made of transparent acrylic on a pentagonal shape, while jig n°3.2 is the bolt with black plastic head attach to n°3.1, that fix the jigs n°3.3 or n°3.4 individually. These last two are the shapes to be read by the equipment, made of metal, being the n°3.3 a rounded corner rectangle and n°3.4 a circle, as presented on Figure 22 e).

4.2.1.2. Procedure

The identification of the parts will be divided into three methods. In the first one the individual will have a physic manual as a resource, with a exploded view of the suitcase identifying the parts by number from 1 to 5. Although the manual is in English, it will be given an adapted version with only numbers identifying the parts in way to turn the essay equal to non-English speakers, as seen in Figure 25. During the process, the participant exclusively carries the suitcase and the paper manual, and this could be consulted anytime as intended necessary. After the instructions are given, in this case three parts to be removed by the number, the participant has a period of 30 seconds to analyze without touching and then start the identification process, that consists of tacking the asked parts of the case and line them in order. The asked parts to be removed are random. In the second

method, instead of the use of a paper manual, the participant has a mobile device with an augmented reality app developed to visually identify the parts with the help of AR animations without overlapping, as well as a marker in to generate the suitcase model. Similarly to the previous method, the participant has 30 seconds after the instructions are given to analyze the interface, starting the identification process after that period and consulting the application as many times as he intends to. During this period, the participant could not move the paper target, but exclusively the mobile device. The third and last method is similar to the last one, but instead with tridimensional overlapping. This allows to not to give the paper marker to the participant, but instead the marker is presented inside the suitcase surface.

The assemble of the parts is divided into two methods: manual and AR instructions. On the first one, the individual has a physical instruction manual as a resource, presented in Figure 25 where is determined how he needs to perform the jig n°3 assemble. Although the instruction manual is in English, non-native language of the place where it was performed, the resource gave was a technical drawing of the exploded view representing the process to assemble, as a general familiar alternative of the process. During the experiment, the participant is exposed exclusively to the tool case and the sheet of instructions, that could be seen anytime he needs to. After the participant has seen the instructions for the first time, it is allowed for 30 seconds to visually analyze the equipment and question about the process mechanic, before he starts to assemble. Once the assembly is correctly finished, such as the displayed-on Figure 24, the timer stops.

during the assembly. It is not allowed to rotate the AR marker when performing, but only the mobile device.

After this first stage, the jig is disassembled and the parts return to the tool case, then the instructions are taken from the participant and is requested to reassemble the parts without instructions. Once the jig is correctly finished, the timer stops, and it is presented to the individual with the other method that could be used as instructions: for the ones using the manual how it is to use the AR device and vice versa.

4.2.1.3. Evaluation

The division of times to evaluate was defined as pre-assembly, assembly and post assembly. On pre-assembly, there is a questionnaire that approach the person profile, previous contact with AR, visual health and comfort with AR, expectations about the experience and technical habilitations, the importance of this first questions is to recognize the framework of the sample to the experience that they will be introduced and how they are affected after the experimental phase, as well as corelate parameters of their daily life with the shown efficiency in the process. During the experimental phase, it will be considered the number of times the participant visualized the instructions during the assembly, the total time taken, if the assembly is correct, the number of errors performed and the perception to correct them. After this process, the participant is asked to assemble the same way without instructions, to evaluate the memory efficiency of each instruction method. The evaluation of this process is the same as the process before presented, without counting the number of times the participant visualized the instruction. Finishing the assembly phase, the participant will be questioned again about what they cognitional experienced, giving their opinion about which method they suppose has more complexity and which is easier, immersivity of the method, if they think has been useful in this case, if they felt tired and which method brings more motivation. They are also questioned emotionally if they felt frustrated, confident or satisfaction during the process. Once a participant in one of the methods, the other one loses the first experience impact to the same individual, the other method is only introduced after the assembly stage, without any kind of evaluation.

4.2.1.4. Experimentation group

The experimentation group referent to this case was composed of 10 volunteers, of which 4 have an education level equal or inferior to middle school and 6 with bachelor's degree, as

could be seen in Table 2. The participants' age varies from 20 to 52 years old, with the majority of 8 between 20 and 30 years old. About previous contact with technology, 9 have experienced VR once or more and 5 have experienced AR, besides the most used areas are in videogames and entertainment. About the frequency of use, 8 of the participants confess using this technology less than once per year and 2 of them once per semester, of which 10 have used with mobile devices, 7 with VR helmets and 2 with HMD.

It is important to notice that one of the volunteers has related nausea and dizziness with VR and other media, such as 3D movies. Also 6 participants have vision problems, of which 4 have myopia and 5 with hypermetropia.

Table 2 - Results from pre-essay questionnaire of case study 2

	Category	Case 2
Scholar degree	High school or less	5
	Bachelor	6
	Master's degree	0
	PhD	1
Ages	< 20	1
	20 to 30	5
	30 to 40	0
	40 to 50	1
	50 to 60	3
	> 60	2
Used before	AR	6
	VR	9
	None	2
In	Videogames	9
	Entertainment	6
	Work	1
	Demonstrations	3
Frequency	Rarely	6
	Yearly	0
	Semestral	3
	Monthly	1
	Never	2
Devices	Mobile	10
	VR helmets	7
	HMD	1

5. Results

Even though the applied sample has a reduced number of participants, the results presented were considered conclusive to this experiment. It is important to note that there were limited criteria during the essays and for future analyses, influenced by this number of participants, not allowing them to reach other conclusions, mainly based on the post experience questionnaires.

In the first case of study, there were 12 participants performing the essay, which were divided into four for each method, in this case the use of instruction manual, AR without overlapping and AR with overlapping, resulting in the average times presented in Table 3. Moreover, two participants did not reach the correct results, one using overlapping AR and other using physical manual, both with a number of errors of 1. Another participant using AR without overlapping performed one error, although he fixed during the essay. The participant that was using overlapping AR identified the Jig2 as it was asked to identify the Jig3.3, and the one using physical manual identified Jig3.1 instead of Jig 3.2. In this way, the two participants that proceed with incorrect identification were not considered to the average time of identification, even though this will be data considered as time of response.

As it could be seen, the difference between longest and shortest time in each method are considerably distinguish. The use of physical instructions resulted in 9 seconds of difference, followed by the overlapped AR, with 37 seconds, and the last being the AR without overlapping.

Table 3 - Results from essay 1

Method	Time of response [mm: ss]	Time of identification [mm: ss]	Longest time to complete [mm: ss]	Shortest time to complete [mm: ss]	Difference between longest and shortest time [mm: ss]
P/ Manual	00:19	00:17	00:25	00:16	00:09
AR n/ overlapping	00:26	00:26	03:15	00:13	03:02

AR overlapping	00:26	00:19	00:48	00:11	00:37
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For the second case of study with the resulting average times presented in Table 4, there were 10 participants, divided into 5 for the use of physical manual and 5 with the AR tool performing the essay. In general, all participants performed correctly both parts of the assembly essay, although with fixed errors. Using AR, two participants performed one single error each, that was corrected during the assembly, in both cases, the error was grabbing a wrong part. Also, two participants using AR did not notice after finishing the assembly that the task was completed. On the side of participants using physical manual, there were three participants performing one error and one performing two, all fixed during the essays. In all of these cases the errors were wrong parts grabbed and all the participants using the manual noticed when they had finished the task. It is important to notice that 6 of the total participants performed this case of study after the first one.

A comparison between the longest and the shortest times to assembly was proceed for each method. In contrast to the first case, the AR without overlapping resulted in the lowest difference, with a time of 1:04 minutes, while physical instructions achieved a time difference of 1:27 minutes.

Table 4 - Results from essay 2

Method	Time of response [mm: ss]	Time of identification [mm: ss]	Longest time to complete [mm: ss]	Shortest time to complete [mm: ss]	Difference between longest and shortest time [mm: ss]
P/ Manual	01:27	00:28	02:25	00:58	01:27
AR n/ overlapping	00:42	00:25	01:29	00:25	01:04

6. Discussion

The previous cases of studies presented had resulted in multiple factors correlating with the participants' profile and method used. Since there were two distinct cases, the results were divided into a base to evaluate the efficiency of the method properly said, related to the first case of study, and a base to evaluate the memorization, associated with the second.

6.1. Evaluation of efficiency between AR and manual instructions

The following essay is defined as the first in a group of two essays to the public in way to evaluate the efficiency of a client help tool, applied to optometry measurement

The first case of study allowed to inspect the efficacy to transmit information to a user from a physical manual of instructions, an AR application which represents models without overlapping and another application with overlapping. This evaluation is mainly based on the time of response, number of errors and the parts which the participants were asked to identify, once different parts induced participants into mistakes, such as identifying other parts.

From the first comparison of response time, the results were mildly similar, with both overlapping and without overlapping AR ensuing an average time of 26 seconds and the manual with 19 seconds. Although, once only considering the results with correct parts identified, the average time of identification with overlapped AR is reduced to 19 seconds and the manual to 17 seconds. These values could indicate that using AR as a tool to identify parts could not be beneficial if it does not use overlapping, even though using a physical manual result in reduced times when compared to overlapped AR. The reasoning found for this phenomenon could be based on the existence of multiple focus points that the user needs to observe. In case of using a physical manual, the participant focus exclusively on the manual and the suitcase alternately, while in AR without overlapping, the participant needs to focus on a virtual model from a mobile device and the real suitcase, besides it was noticed that the majority of the participants that used this method had the tendency to focus on the real suitcase from the mobile device as a way to compare with the virtual module, even though there were no results. Overlapping AR concentrates the same focus point from the mobile device to see the virtual and the real model, even though the method demands also focus on the physical suitcase without the device to act

by taking out the parts. With such a phenomenon, it can be concluded that the without overlapped method is more distracting than the with overlapped method.

After this experiment, the participants were asked about which method they considered the most complex and which they considered the easiest. Despite the fact that each participant only performed one of the methods without testing the others, this was just an opinion based on what they observed. The majority of 5 participants considered the without overlapping method more complex and 8 considered an overlapping method easier to use between the three. There were no significant cases of frustration, and all presented considerable satisfaction when completed. Also, it was not possible to compare fatigue, once any participant presented signs of tiredness. A previous study from Hanson et. al. (Hanson et al., 2017) shown that the picking time of parts comparing an AR and a paper based configuration was reduced by using AR methods. In this way, the optimization in terms of time efficiency was verified in this study.

About the total time range on results to identification from the longest to the shortest, there are possible justifications based on the different methods applied. The physical manual method presents the lowest difference of 9 seconds between the fastest and the slowest participant. This could be associated with the fact that the majority of participants were integrated into the use of common instructions on different daily tasks, which implies a similar base knowledge on part of the participants, while the use of other methods could require an adaptation time period. In this ideology, AR alternatives were trivial for the participants which presented shortest times of identification in overlapped and non-overlapped, as both of them replied during the questionnaire that had previously contacted with AR technologies in various environments, while slowest participants had never used the technique before. About the superior difference of non-overlapping AR when compared to overlapping AR, could be based on the natural immersive sensory perception that overlapped models promote to the user. This comparison was not linear, once none of both extremes presented the most unfavourable result.

6.2. Comparison of accuracy and memory development between assembly using manual and AR instructions

The process related to second case of study allowed us to compare both the use of physical manual and the use of non-overlapped AR. Overlapped AR was not considered to this case, once based on the previous case of study, concentrating the same number of participants to

a reduced number of variables, results in more accurate conclusions about the processes. The choice of the non-overlapped AR instead of the overlapped was due to non-overlapped instructions are closer to manual instructions in terms of simplicity, once compared to overlapped instructions.

Analyzing the first process of assembly, it could be directly seen that the average time to assemble the parts with the AR tool is significantly reduced when compared to the method using the physical manual. With the use of a mobile device with the AR tool, the average time was 42 seconds, while with the manual it was one minute and 27 seconds, in other words, the implementation of the AR assembly tool resulted in an improvement of efficiency of 51,3%. One of the main reasons for this improvement is due to the clarification of the location of the parts, a detail that is not present in the manual. During the essay, it was noted that the participants who worked using the manual tended to mistake multiple parts with others present inside the suitcase, such as the disk jig 3.3 with other round shaped parts or the bolt jig 3.2 with parts shaped the same way. This confusion with the jig 3.2 could also be interpreted as a lack of confidence or concentration from the participant, since it occurred mainly when they had identified the main body jig 3.1, which already had the jig 3.2 attached to. So, in these terms, the participant was distracted and did not notice the presence of the part immediately.

Moreover, replicability without instructions also presented conclusive results. In this part of the essay, both the participants whose worked with the manual and the AR tool were placed under the same conditions: after assembling correctly once and without any other equipment except the suitcase. At the end, the participants that had previously used the manual presented an average time to assemble of 28 seconds, while the participants whose used the AR tool presented an average time of 25 seconds. The difference between both times of 3 seconds does not seem significant, although it needs to be considered that this was an assembly of three parts. These results could conclude that using AR tools not only improves the efficiency of the user, but also the memory and cognition, which could be applied to educational purposes. Hou et al. (Hou et al., 2013) presented a study where the participants should assemble a LEGO set using AR and others using physical manual. The results show that the participants trained by AR performed a better memory assembling compared to those using the manual, which also was verified on the present study.

Distinct from the previous case, the AR method presented the shortest time period between slowest and fastest participants to assemble the jig. A possible justification to this

discrepancy should be the application interaction. On the previous case, participants had to interact with the technology by navigating between animations, while in this case, the single objective was to watch the movements of parts from the mobile device in way to assemble on the real environment. The elimination of interaction factors could be related to the participant's lack of familiarity with the system, once it seems to be simpler to operate. Moreover, the difference between the longest and shortest time to assemble on physical manual is superior, not verifying the previous proposition about the previous use of physical instructions before, although, this increase in time could be related to participants confusion between parts during the assembly, as mentioned above. Compared to the AR instructions, there were a group of elements not presented on physical manual, such as the suitcase and unused parts, which improves finding the position of the parts to assemble. Simplifying AR applications is a considerable alternative to improve, even though there is an importance to give in presenting crucial information to the user.

7. Conclusion

Over time, augmented reality is getting a more distinctive position inside the market as a tool than as an entertainment technology. A considerable number of companies and superior entities are developing systems that promise to assist users, as well as professional workers and trainees to perform tasks or even learn in secure environments.

In this work, there was reviewed a lack of previous research into technology, such as the different ways in which it is possible to implement and use AR, the range of applications that make use of the technology and the features involved. Consequently, there was presented detailed process to develop an AR project and the cases of study where it was applied. The results and discussion extracted from this research shown that not all cases are optimal to implement AR tools as a helpful resource, in reality in is a limited number of scenarios that it is worth upgrading. Nowadays, there are other methods different than the ones used in this work that make this development more accessible, depending on the application desired, although, the main implication that remains is the need for an AR device, in the majority of cases a mobile device. Even though it is possible to implement HMD systems to AR, the majority of users do not have access to this equipment, turning if almost mandatory to project AR applications for costumer use only for mobile devices, which reduce mobility and range of vision when compared to HMD.

Another detail noticed during the essays was that it was notice how trivial the first case was. Despite the fact that the majority of participants considered the use of AR helpful, both those who used AR as well as those who used physical manual, the average times were considerably close to conclude that which instruction style is better in this case. Moreover, using different parts to identify in every case helped concluding that there were harder components to identify without AR.

8. Future Works and Research

For the sequel of this study, the scope of AR tools applied not exactly to general maintenance auxiliary, although to optometry equipment should be maintained. This implies that the users of these tools are professionals in the optometry working environment, having previous knowledge about the equipment properly said. Once exploring the capabilities of AR tools, considering using virtual information in this scope is crucial in way to adapt the tools based on professional knowledge.

Moreover, it was confirmed during the essays that the use of mobile devices castrates the participants in terms of movement. In order to evaluate the efficiency of a free-handed AR system, it should be considered to develop a case of study using HMD devices compared to mobile devices and physical manuals. At the beginning of this thesis, it was considered to evaluate the procedures of maintenance using HMD, although, due to physical resources and methodology mistakes, the implementation of the applications to the devices was incompatible. Besides, based on the value and complexity of the equipment, introducing HMD devices to a common public could be challenging, even to professional workspaces, which could take a considerable time period from the date to be applied. Results from previous researchers, such as Baertsch et al. (Baertsch et al., 2023), shown that the use of HMD devices could influence negatively the concentration performance on different tasks. Even though, there is considerable motivation to introduce the technology to assembly assignments as a possible complement in terms of instructions.

Continuing in the context of the equipment used, this study had completely evolved on the equipment tool suitcase. Even though some parts of the machine properly said were studied and presented, such as the displays and recognition of them by AR systems, there was no case of study where it was introduced. In first, the main idea of the scope was to adapt a calibration plan as a step-by-step procedure using AR and evaluate compared to the physical manual. The fact is that, for a public not familiar with the equipment of the area, executing a calibration procedure could be complex, imply limiting the participants sample exclusively to people previously integrated in equipment maintenance, all the more because this procedure is considered extensive and fatiguing. Applying the study of the complete calibration procedure would give more accurate results compared to the ones obtained in this study, although it implies the use of more resources.

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