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Diploma Thesis

Design and implementation of a remote collaboration application with the use of smart glasses

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΔΥΤΙΚΗΣ ΑΤΤΙΚΗΣ

ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ

ΤΜΗΜΑ ΗΛΕΚΤΡΟΛΟΓΩΝ & ΗΛΕΚΤΡΟΝΙΚΩΝ ΜΗΧΑΝΙΚΩΝ

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Παράβαση της ανωτέρω ακαδημαϊκής μου ευθύνης αποτελεί ουσιώδη λόγο για την ανάκληση του διπλώματός μου.»

Ο Δηλών
Δημήτριος Φιλιόπουλος

DEDICATION

To my parents and friends

ACKNOWLEDGMENTS

I would like to thank my supervisor ,Prof. Charalampos Patrikakis for his guidance, ideas and support throughout this project. I am also grateful to my parents and friends for their encouragement and understanding during this time and across my studies.

Abstract

This thesis examines the technology of Augmented Reality (AR) and, more specifically, its role in enhancing remote collaboration through the design and implementation of an application using smart glasses. Initially, an overview of Augmented Reality is provided, describing the basic concepts and exploring the hardware and software that can be used. The study then focuses on remote collaboration and the fields in which it can be applied. It proceeds with an in-depth analysis of the fields and industries where augmented reality can be utilized, highlighting how it increases productivity and offers innovative ways to solve complex problems remotely. Finally, the thesis focuses on the design and implementation of a remote collaboration application in the selected field using smart glasses, presenting the implementation process, the methodologies used, and the challenges encountered during development. The implementation demonstrates how the use of augmented reality (AR) facilitates real-time collaboration, providing users with direct guidance and overcoming the issue of physical distance between them.

Keywords

Augmented Reality, Remote Collaboration, Smart Glasses , Unity, ARCore, AR Foundation

Περίληψη

Η εν λόγω διπλωματική εργασία εξετάζει την τεχνολογία της Επαυξημένης Πραγματικότητας (Augmented reality) και πιο συγκεκριμένα τον ρόλο της στην ενίσχυση της συνεργασίας από απόσταση μέσα από τον σχεδιασμό και την υλοποίηση μίας εφαρμογής με την χρήση έξυπνων γυαλιών. Αρχικά γίνεται η επισκόπηση της Επαυξημένης Πραγματικότητας όπου περιγράφονται οι βασικές έννοιες, εξετάζοντας τα εργαλεία και το λογισμικό που μπορούν να χρησιμοποιηθούν, ενώ στη συνέχεια επικεντρώνεται στην εξ αποστάσεως συνεργασία και στους τομείς που μπορεί να εφαρμοστεί. Η εργασία προχωράει σε μια εις βάθος ανάλυση των πεδίων εφαρμογής της επαυξημένης πραγματικότητας υπογραμμίζοντας το πως αυξάνει την παραγωγικότητα και προσφέρει καινοτόμους τρόπους επίλυσης σύνθετων προβλημάτων από απόσταση. Τέλος, η εργασία εστιάζει στην σχεδίαση και στην υλοποίηση μίας εφαρμογής εξ αποστάσεως συνεργασίας στο επιλεγμένο πεδίο με τη χρήση έξυπνων γυαλιών, παρουσιάζοντας τη διαδικασία υλοποίησης και τις μεθοδολογίες που χρησιμοποιήθηκαν καθώς και τις προκλήσεις που προέκυψαν κατά την ανάπτυξη. Η υλοποίηση δείχνει πως η χρήση επαυξημένης πραγματικότητας (AR) διευκολύνει τη συνεργασία σε πραγματικό χρόνο, παρέχει στους χρήστες άμεση καθοδήγηση, λύνοντας το πρόβλημα της φυσικής απόστασης που υπάρχει μεταξύ τους.

Λέξεις – κλειδιά

Επαυξημένη Πραγματικότητα, Εξ αποστάσεως συνεργασία, Έξυπνα Γυαλιά,Unity, ARCore,AR Foundation

Figures

Acronyms

AR : Augmented Reality
VR : Virtual Reality
MR : Mixed Reality
XR : Extended Reality
API : Application Programming Interface
SDK : Software Development Kit
IoT : Internet of Things
AI : Artificial Intelligence

INTRODUCTION

Augmented Reality (AR) is transforming the way we perceive and interact with the world integrating digital elements with the physical world. This technology has seen rapid advancements in recent years, enforced by improvements in hardware capabilities and the development of advanced software tools. One of the most significant developments in AR is the use of smart glasses, which offer a hands-free, immersive experience that enhances both personal and professional applications. The capacity to provide real-time assistance and share interactive experiences remotely not only boosts efficiency but also broadens the horizons for innovation and problem-solving. The fusion of AR with remote collaboration tools, especially through smart glasses, opens new possibilities for enhanced communication and operational effectiveness.

This thesis is about the design and implementation of an AR remote collaboration application utilizing smart glasses, developed using Unity. The objective is to create a system that enables users to interact with digital overlays in real-time, facilitating improved communication and assistance in situations where immediate expertise is required but physical presence is not feasible.
Specifically it explores the design and implementation of an AR-based remote collaboration application aimed at assisting users in automotive emergencies, such as changing a tire or using a first aid kit. By combining real-time remote guidance with AR overlays, this application demonstrates how AR can enhance user experiences and improve task performance in high-pressure scenarios.

Purpose and general framework

The purpose of this thesis is to explore how augmented reality (AR) technology can enhance remote collaboration, particularly in situations where immediate guidance is required, such as automotive emergencies. By developing an AR-based remote assistance application, the project aims to provide users with real-time, hands-free support from a remote expert during tasks like changing a tire or offering first aid.
The general framework of the thesis involves using smart glasses or smartphones in conjunction with AR technology to overlay visual guidance directly onto the user's real-world environment. The system is designed to bridge the gap between remote experts and users who need step-by-step instructions to complete complex tasks efficiently.

Scope and Objectives

The scope of this thesis is focused on the development and evaluation of an augmented reality (AR) application for remote assistance in automotive emergencies, such as tire changes and first aid. The project is designed to create a functional prototype using Unity and ARCore, tested primarily on smartphones due to hardware limitations with smart glasses. While the scope is centered on automotive emergencies, the broader goal is to explore the potential for AR in real-time remote assistance scenarios. The thesis does not extend to other applications of AR beyond these emergency contexts.

The objectives of this project are to develop an AR application capable of providing real-time guidance using key AR functionalities, such as 3D object placement, drawing tools, and directional arrows. The integration of WebRTC enables real-time video streaming and communication between the expert and the smartphone user, enhancing the system’s collaborative capabilities. The application will be tested in practical scenarios like tire changes and first aid situations, allowing an assessment of its effectiveness and ease of use. In addition, the thesis will explore challenges related to system performance, communication delays, and user interaction with both smart glasses and smartphones.

Methodology

The methodology combines theoretical research with practical application development. Initially, a literature review is conducted to gather information on the latest developments in AR, smart glasses technology, and remote collaboration tools, establishing a strong knowledge base. This is followed by a technical evaluation to assess different hardware and software options, determining the most suitable platforms for development. The design process involves creating detailed design documents, including user interface layouts, user experience flows, and system architecture diagrams. Development then proceeds by implementing the design using Unity, programming the necessary features, and integrating with smart glasses hardware. This structured approach ensures a systematic progression from concept to implementation, with continuous evaluation at each stage.

Structure

The thesis is organized into several chapters to ensure a logical flow of information, guiding the reader from the theoretical foundations to the practical outcomes of the project. The first chapter, "Technological Background and Tools," introduces the core concepts of AR, explores the extended reality spectrum, and discusses the various types of AR. It also reviews the hardware devices, software platforms, and tools relevant to AR development, and delves into the significance of remote collaboration. The second chapter, "Fields and Industries of AR Application," examines the diverse sectors where AR technology is applied, highlighting case studies and industry-specific implementations. The third chapter, "Design and Implementation of an Augmented Reality Application for Remote Assistance in Automotive Emergencies," details the process of conceptualizing and developing the AR application, focusing on design considerations and implementation strategies. The fourth chapter, "Requirements of the Application and Design," outlines the technical specifications, user requirements, and design principles that guided the development of the application. The fifth chapter, "Implementation and Presentation of Application," showcases the developed application, illustrating its features and functionalities through descriptions and visual representations. The final chapter, "Conclusions," summarizes the research findings, reflects on the achievement of the objectives, and provides recommendations for future work and potential improvements in AR remote collaboration technologies. This structure ensures that the thesis provides a comprehensive journey from conceptual understanding to practical implementation, allowing readers to fully grasp the project's significance and contributions.

1 TECHNOLOGICAL BACKGROUND AND TOOLS

1.1 Augmented Reality

Augmented Reality (AR) is a technology that superimposes digital information onto the physical world, enhancing users' perception and interaction by blending virtual and physical elements. [1] It is mostly used to provide information and interactive experiences, which can significantly improve learning, efficiency, and engagement. The growing accessibility of AR, made possible by advancements in mobile devices and wearable technology, has broadened its application across various fields such as education, healthcare, manufacturing, and remote collaboration [2]. The primary function of AR is to integrate virtual objects into the real-world environment in real-time, enabling users to interact with both digital and physical elements [3]. This is achieved through devices like smartphones, tablets, and smart glasses, which project digital content onto the user’s view of the real world. Unlike Virtual Reality (VR), which creates an entirely immersive virtual experience, AR augments the real environment without isolating users from their physical surroundings, making it very effective for applications that require interaction with the real world while providing additional information or guidance [4].

1.1.1 The Extended Reality Spectrum: AR, VR, MR, XR

Extended Reality (XR) is a general term that includes all types of immersive technologies that combine real and virtual worlds. This includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). [5] XR covers a wide range of experiences, from completely virtual environments to digital content layered over the real world, which can be used for gaming, training, healthcare, and remote collaboration.

Virtual Reality (VR) is a technology that immerses users in a completely digital world, cutting them off from the physical environment. Users typically wear headsets that show them a 360-degree virtual space, allowing them to move and interact as if they were actually inside this computer-generated world. [6] VR is commonly used for gaming, simulations, and training, where a fully controlled environment is useful.

Augmented Reality (AR) adds digital information to the real world, so users can see and interact with both physical and virtual objects at the same time. Unlike VR, which creates an entirely separate digital world, AR enhances the real world by adding things like text, images, or sounds through devices such as smartphones, tablets, and smart glasses. AR is often used in areas like navigation, education, and maintenance to provide useful, real-time information and interactive experiences. [4]

Mixed Reality (MR) combines real and virtual worlds in a way that allows digital objects to interact with the physical environment. MR goes beyond AR by not just placing digital content over the real world, but by integrating it so that virtual objects and the real environment affect each other. For example, in MR, a digital object can appear to sit on a real table and be moved around like it's actrually there.[7] The main difference between AR and MR is that AR simply overlays digital overlays and 3D objects to the real world, while MR allows for a more interactive experience where digital objects seem to exist and interact naturally within the physical space.

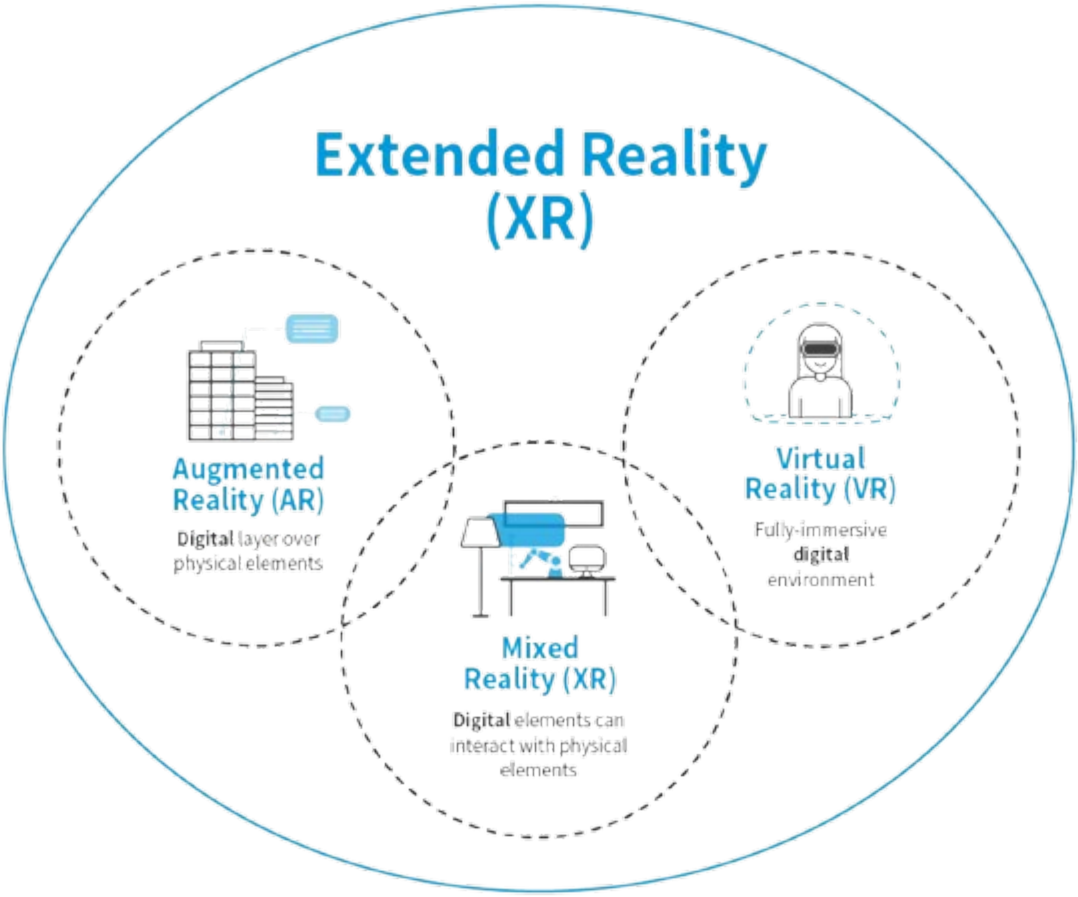


Figure 1.1:Extended reality Spectrum [8]

1.1.2 Different types of Augmented Reality

Marker-Based Augmented Reality

Marker-based Augmented Reality (AR) uses predefined images or objects, known as markers, to trigger and display digital content overlaid onto the real world. When the AR system detects a marker, it calculates the position and orientation of the user's viewpoint relative to the marker, allowing virtual objects to be anchored and interacted with in the real environment. This method is commonly used in educational tools, interactive marketing, and training applications due to its simplicity and reliability. [9] Marker-based AR provides a stable reference point, which helps maintain accurate placement and alignment of digital elements, enhancing user experience and engagement**.**

Markerless Augmented Reality

Markerless Augmented Reality (AR) does not require predefined markers to display digital content. Instead, it relies on natural feature detection and tracking to overlay virtual objects in the real world. This makes markerless AR more flexible and adaptable to various environments, as it can operate without specific markers or images. It is widely used in applications such as navigation, interactive gaming, and industrial training, where the AR content needs to adapt dynamically to the user’s surroundings. [10]

Location-Based AR:
Location-based AR utilizes the device's GPS, accelerometer, and compass to determine the user’s geographic position and orientation. This technology overlays digital content based on the user's real-world location, such as displaying information about nearby landmarks or providing navigation guidance. [11] It is commonly used in applications like augmented reality maps, tourism guides, and location-based games, where the digital content is tied to specific physical locations.

Projection-Based AR:
Projection-based AR uses digital projectors to cast virtual content directly onto physical surfaces. This type of AR does not require a screen, as the projections are overlaid onto real-world objects and can interact with them. For example, in retail settings, projection-based AR can display product information or visual effects on a product’s surface, enhancing customer engagement. [12] It is also used in interactive installations and exhibitions to create immersive experiences without the need for wearable devices.

SLAM (Simultaneous Localization and Mapping):
SLAM-based AR creates a real-time map of the environment while simultaneously tracking the position of the device. This technology allows for accurate placement of virtual objects in environments where there are no predefined markers. SLAM is widely used in applications requiring detailed spatial awareness, such as indoor navigation, robotics, and complex industrial processes, where precise mapping and tracking are essential. [13]

Superimposition-Based AR:

Superimposition-based AR replaces or adds to the view of the real world with a virtual overlay of an object or scene. This type of AR is often used in medical applications, where digital information, such as anatomical models, is superimposed onto the patient’s body to assist in diagnostics or surgical planning. [14] It can also be used in architecture and interior design to visualize how new structures or furnishings would look in a real environment.

1.2 Devices and hardware platforms

Augmented Reality (AR) applications are highly dependent on the devices and hardware platforms that deliver immersive experiences by integrating digital content with the physical world. The performance and capabilities of these hardware platform (processing power, display technology, sensors, and user interaction methods) play a crucial role in the effectiveness of AR applications. The primary devices and hardware platforms used in AR include smartphones, computers and laptops, tablets, AR projectors, smart glasses, wearable AR devices and handheld controllers.

1.2.1 Smartphones

Smartphones are one of the most accessible platforms for Augmented Reality (AR) applications due to their widespread use, portability and built-in sensors such as cameras, accelerometers, and gyroscopes. [15] With support from frameworks like ARCore (for Android) and ARKit (for iOS), smartphones enable a variety of AR experiences, from interactive gaming to real-time navigation and educational tools.

1.2.2 Computers and Laptops

Computers and laptops provide the processing power needed for complex AR applications, making them suitable for high-performance tasks such as 3D modeling, industrial simulations, and professional training. Equipped with external peripherals like webcams, motion sensors, and graphics cards, these devices can handle intensive rendering and data processing required for immersive AR experiences. They are often used in environments where detailed visualization and collaboration are critical, such as design studios and engineering firms.

1.2.3 Tablets

Tablets are in between the previous two devices as they offer portability but higher processing power than smartphones. They also offer a larger display surface compared to smartphones, enhancing the user experience in AR applications by providing more screen space for interaction and visualization. This makes them particularly effective for educational purposes, where detailed visual content, such as 3D anatomical models or interactive learning environments, can be explored in depth. Tablets are also commonly used in retail and real estate to showcase products or properties in an immersive, interactive manner.

1.2.4 AR Projectors

AR projectors create augmented experiences by projecting digital content onto physical surfaces, eliminating the need for wearable devices. These projectors can transform any surface into an interactive display, allowing users to interact with virtual content using touch or gestures. [16] They are often used in exhibitions, retail environments, and collaborative workspaces to create shared, immersive experiences that engage multiple users simultaneously.

1.2.5 AR Smart Glasses

Smart glasses are wearable devices that integrate augmented reality (AR) features by overlaying digital information onto the user's view. They are equipped with advanced sensors, cameras, and displays to provide hands-free access to data and interactive AR experiences. These devices are widely used in various fields enabling users to access real-time information, perform remote assistance, and improve productivity. [17] Smart glasses vary in design and functionality, offering solutions from basic information display to complex AR interactions.

Why I chose Smart Glasses

I chose smart glasses for the application because they enable hands-free interaction with the environment, allowing users to engage fully with the task without the need to hold or manipulate another device. Unlike laptops or smartphones, smart glasses keep the user’s focus directly on the work, while still providing real-time visual guidance. This ensures that AR content is seamlessly integrated into the task, improving efficiency, safety, and the overall immersive experience. Additionally, smart glasses offer mobility and freedom, making them ideal for interactive tasks in dynamic environments.

1.3 Software platforms and tools

The development of Augmented Reality(AR) applications becomes possible by the help of powerful sotftware platforms. These platforms provide developers with features like tracking, rendering graphics, and ways for users to interact with the AR environment. This makes the process of building AR applications easier. In this section, we will give an overview of the main software platforms and tools used in the AR industry, grouped into development frameworks, game engines, and software development kits (SDKs). [18]

1.3.1 Game Engines

- **Unity:** Unity is one of the most popular game engines for AR development due to its versatility and ease of use. It supports both 2D and 3D game development and provides tools for creating interactive AR experiences using the AR Foundation framework. Unity’s asset store and extensive community make it accessible for beginners and professionals alike. It is widely used for developing games, simulations, and AR applications across various industries. [19]

- **Unreal Engine:** Known for its high-fidelity graphics and robust rendering capabilities, Unreal Engine is a powerful tool for developing visually stunning AR applications. Its Blueprints visual scripting system allows for rapid development and prototyping, making it suitable for complex projects like architectural visualization and interactive simulations. [20]

- **Godot:** Godot is an open-source game engine that supports both 2D and 3D development. Although less commonly used for AR, it provides a lightweight and flexible platform for creating interactive experiences. Its node-based architecture simplifies the development process, and its active community contributes to a growing library of resources. [21]

1.3.2 AR Development Frameworks

AR development Frameworks are essential for building AR applications because they offer pre-build functionalities and Application Programming Interfaces (APIs) that helps the developer intergrade AR components into applications and then build them into the devices.
Frameworks can include SDKs along with the other features.

- **ARCore (Google):** ARCore is Google's AR framework for Android devices. It offers features like motion tracking, environmental understanding, and light estimation, allowing developers to create immersive AR experiences by integrating digital content into the real world. It supports a range of devices and provides tools for depth sensing and augmented images.

- **ARKit (Apple):** ARKit is Apple's AR framework for iOS devices, enabling high-quality AR experiences on iPhones and iPads. It offers advanced capabilities such as face tracking, object detection, and scene understanding. ARKit also supports real-time rendering and people occlusion for a more immersive experience.

- **AR Foundation:** AR Foundation is a cross-platform framework provided by Unity that allows developers to build AR applications for both ARCore and ARKit. It abstracts the underlying SDKs, providing a unified API for AR development across Android and iOS, enabling developers to create consistent AR experiences on multiple platforms.

1.3.3 Software Development Kits (SDKs)

- **Vuforia** is an AR SDK that supports image recognition, object tracking, and environment mapping. It is compatible with multiple platforms and devices, making it a popular choice for industrial and enterprise AR applications.
- **Wikitude** offers location-based services, image recognition, and object tracking capabilities. It supports various platforms and enables developers to create diverse AR experiences, from navigation to interactive marketing.
- **EasyAR** provides AR functionalities such as image recognition, 3D object tracking, and cloud recognition. It is known for its scalability and ease of integration, making it suitable for developers of all levels.
- **Kudan AR** is a lightweight SDK focused on efficient tracking and performance. It is particularly useful for mobile applications where resource optimization is crucial, supporting both 2D and 3D tracking.
- **DeepAR** specializes in real-time face tracking and 3D rendering, often used for creating AR filters and effects. It is widely used in social media and advertising for interactive and engaging user experiences.
- **Maxst AR** provides robust image and object tracking capabilities, along with support for SLAM-based tracking. It is used in various applications, from gaming to industrial training, where accurate spatial awareness is essential.
- **Microsoft Mixed Reality Toolkit** is an open-source toolkit designed for building mixed reality applications on Microsoft devices like HoloLens. It provides tools for spatial interactions, hand tracking, and voice commands, enabling developers to create immersive and interactive experiences.

1.4 Remote Collaboration

Remote collaboration refers to the ability of individuals or teams to work together from different geographical locations using digital communication tools and technologies. With the rise of global workforces and the increasing need for flexible work arrangements, remote collaboration has become a critical component of modern work environments. Augmented Reality (AR) plays a transformative role in remote collaboration by enabling real-time interaction and visualization, allowing users to share information and provide support as if they were physically present in the same space. [22] This section explores the various aspects of remote collaboration and how AR enhances these experiences.

1.4.1 Importance of Remote Collaboration

Remote collaboration has grown significantly in importance due to globalization, the rise of distributed teams, and the demand for flexible work arrangements. It allows organizations to leverage talent from around the world, reduces travel costs, and supports real-time problem-solving. [23]

The COVID-19 pandemic further accelerated the adoption of remote collaboration technologies, making them an integral part of business continuity and resilience strategies.

1.4.2 AR in Remote Collaboration

AR enhances remote collaboration by overlaying digital content onto the physical environment, enabling users to share visual information and instructions in real time. This technology is particularly valuable in fields such as manufacturing, healthcare, and education, where remote guidance, training, and support can be delivered more effectively. For example, an expert can guide a technician through a complex repair process by annotating the real-world view seen through the technician's AR-enabled device. [24]

1.4.3 Challenges and Considerations in Remote Collaboration

Remote collaboration, while offering significant benefits such as flexibility and access for a global use, presents several challenges and considerations that must be addressed to ensure effective communication and productivity [25]. One of the primary challenges is maintaining clear and effective communication among team members, especially when working across different time zones and cultural backgrounds. Miscommunications can lead to misunderstandings, project delays, and reduced team cohesion.

Another critical challenge is ensuring data security and privacy. Remote collaboration often involves the exchange of sensitive information over digital platforms, making it essential to implement robust cybersecurity measures to protect against data breaches and unauthorized access. Additionally, the use of Augmented Reality (AR) in remote collaboration requires high-quality, real-time video and data transmission, which can be affected by network instability and bandwidth limitations.

Moreover, the integration of AR into remote collaboration introduces technical complexities, such as the need for compatible hardware and software, as well as the ability to accurately track and render virtual objects in real-world environments. Ensuring that all team members have access to the necessary technology and are adequately trained in its use is also a key consideration.

Finally, managing the human factors of remote collaboration is crucial. Issues such as reduced social interaction, lack of team cohesion, and difficulty in maintaining engagement and motivation can impact the overall effectiveness of remote work [25]. Addressing these challenges requires careful planning, clear communication protocols, and the use of collaboration tools that facilitate both work and interpersonal interactions.

2 FIELDS AND INDUSTRIES OF AR APPLICATION

Augmented Reality (AR) has rapidly evolved from a futuristic concept to a transformative technology across various sectors. Its ability to overlay digital information onto the physical world has opened new avenues for innovation and efficiency. Industries are leveraging AR to enhance user experiences, improve operational workflows, and create immersive environments that bridge the gap between the virtual and real worlds. This integration has led to significant advancements in how businesses operate and interact with customers, ultimately driving growth and competitiveness in the global market [26]. The following subsections explore the diverse fields where AR applications have made or is going to make substantial impacts.

2.1 Healtcare

In the healthcare industry, AR is making significant strides by enhancing patient care, medical training, and surgical procedures. Surgeons are utilizing AR headsets and smart glasses to overlay critical information onto the surgical field, which enhances precision and reduces risks associated with complex operations [27]. For example, AR can project 3D reconstructions of a patient's anatomy, such as blood vessels, nerves, and tumors, directly onto the patient during surgery. This real-time guidance allows surgeons to navigate with greater confidence, leading to improved patient outcomes and reduced operative times.

Medical education has also been revolutionized by AR technology. Traditional methods of learning anatomy and surgical techniques are being supplemented with AR applications that provide interactive 3D models of human anatomy [28]. Students can manipulate these models to explore different physiological systems, observe pathological conditions, and simulate surgical procedures. This hands-on approach enhances engagement, facilitates deeper understanding, and improves knowledge retention compared to conventional learning methods.

Moreover, AR is making significant contributions to rehabilitation and physical therapy. AR-based rehabilitation programs offer interactive exercises that adapt to a patient's progress, providing real-time feedback and motivation [29]. For instance, patients recovering from strokes or injuries can engage in gamified therapy sessions that make repetitive exercises more engaging. Therapists can monitor patient performance remotely, allowing for adjustments in treatment plans without the need for frequent in-person visits—a feature that has proven especially beneficial during times of restricted movement, such as the COVID-19 pandemic.

AR also supports telemedicine and remote consultations. Specialists can guide on-site clinicians by overlaying annotations and instructions onto live video feeds viewed through AR devices. [30] This technology facilitates real-time collaboration across different locations, enabling patients to receive expert care without the need for travel. Additionally, AR can assist in patient education by visually explaining medical conditions and treatment plans, enhancing patient understanding and adherence to medical advice.

Furthermore, AR is aiding in mental health treatment by providing immersive therapeutic experiences. Applications are being developed to help manage conditions such as anxiety, phobias, and PTSD by exposing patients to controlled virtual stimuli in a safe environment. This innovative use of AR demonstrates its versatility and potential to address a wide range of healthcare needs.

2.2 Education

Augmented Reality is significantly reshaping the education landscape by introducing immersive and interactive learning experiences. Educators are integrating AR into curricula across various subjects to enhance student engagement and comprehension, particularly in complex or abstract topics [31].For instance, in science classes, AR applications can bring concepts like molecular structures, planetary systems, and biological processes to life by allowing students to visualize and interact with 3D models in real-time.

In STEM (Science, Technology, Engineering, and Mathematics) education, AR facilitates virtual experiments and simulations that might be too costly, dangerous, or impractical to conduct in a traditional classroom setting [32]. For example, chemistry students can perform virtual lab experiments that demonstrate chemical reactions without the risks associated with handling hazardous materials. This approach not only enhances safety but also broadens the range of experiments that students can experience.

AR also supports personalized learning by adapting content to individual student needs and learning styles. Interactive AR applications can assess a student's performance and provide immediate feedback, helping to identify areas that require additional attention [4]. This personalized approach fosters a more effective learning environment where students can progress at their own pace.

Collaborative learning is another area where AR is making an impact. Multi-user AR platforms enable students to work together on projects, solving problems and sharing ideas in a shared virtual space [33].This fosters teamwork, communication skills, and a sense of community among learners, which is particularly valuable in remote or hybrid learning scenarios.

Furthermore, AR breaks down geographical and socioeconomic barriers by providing access to educational experiences that might otherwise be unavailable. Virtual field trips powered by AR can transport students to historical landmarks, natural wonders, or cultural events around the world, enriching their understanding and appreciation of global diversity. [34]

The integration of AR in education also extends to teacher training and professional development. Educators can use AR tools to enhance their teaching strategies, receive feedback, and collaborate with peers, leading to improved instructional practices.

Despite the challenges of implementing AR—such as the need for adequate technological infrastructure and teacher training—the potential benefits for enhancing learning experiences are driving continued research and investment in this field. As AR technology becomes more accessible and user-friendly, its adoption in education is expected to grow, transforming how we teach and learn.

2.3 Manufacturing and Industry

In the manufacturing and industrial sectors, AR is revolutionizing operations by enhancing productivity, efficiency, and safety. Workers equipped with AR devices can access real-time information and guidance directly within their field of view, streamlining complex tasks and reducing the likelihood of errors [35]. For example, during assembly processes, AR can overlay step-by-step instructions, torque specifications, and component locations onto physical equipment, enabling workers to perform tasks accurately without referring to manuals or screens.

Maintenance operations benefit significantly from AR by allowing technicians to visualize internal components of machinery and receive remote assistance from experts [36]. AR can display diagnostic data, highlight faulty parts, and provide animated repair instructions, thereby reducing downtime and improving repair quality. This remote support capability is particularly valuable for addressing issues in remote or hazardous locations where expert presence is limited.

AR also enhances training programs in the industrial sector. New employees can be trained using AR simulations that replicate real-world scenarios, providing hands-on experience without the risks associated with operating actual machinery [35]. This approach accelerates the onboarding process, improves skill acquisition, and ensures that workers are better prepared for their roles.

Inventory management and logistics are optimized through AR applications that assist workers in navigating warehouses and locating items efficiently [37]. AR can guide workers along optimal paths, display real-time inventory data, and reduce errors in order fulfillment. Integrating AR with IoT sensors and warehouse management systems further enhances visibility and control over supply chain operations.

Safety in manufacturing environments is significantly improved with AR by providing hazard warnings, safety protocols, and emergency information directly to workers [38]. For instance, AR can alert workers to high-temperature equipment, moving machinery, or restricted areas, helping to prevent accidents and injuries. Additionally, AR can facilitate compliance with safety regulations by ensuring that workers are aware of and adhere to necessary precautions.

Quality control processes are also enhanced through AR by enabling inspectors to compare products against digital models in real-time, quickly identifying deviations or defects [39]. This leads to higher product quality, reduced waste, and increased customer satisfaction.

By integrating AR, manufacturing and industry sectors are achieving greater operational efficiency, reducing costs, and enhancing their competitive advantage in the global market. The ongoing development of AR technologies promises to bring even more innovative solutions to the challenges faced by these industries.

2.4 Maintenance and Repair

Augmented Reality (AR) is transforming the maintenance and repair industry by providing real-time, interactive support for complex tasks. Through AR, technicians can view step-by-step instructions directly overlaid on the equipment they are working on, ensuring greater accuracy and reducing the risk of human error. AR-powered systems enable remote experts to guide on-site personnel, making troubleshooting faster and more efficient. This is particularly valuable in industries where equipment downtime can lead to significant costs, such as manufacturing, aviation, and energy sectors.

AR can display digital overlays highlighting the internal components of machines, showing precise instructions for repair or maintenance, and even providing live sensor data to diagnose issues. This hands-free method allows workers to execute tasks without needing to constantly refer back to manuals or videos, enhancing productivity and safety.

Moreover, AR tools offer predictive maintenance capabilities by integrating with IoT sensors to alert technicians to potential problems before they lead to equipment failure. Companies using AR in maintenance report fewer errors, shorter repair times, and improved employee training processes. By minimizing the need for on-site visits from experts, AR reduces travel costs and enhances the speed of service in geographically remote locations.

2.5 Entertainment and Gaming

The entertainment and gaming industries are at the forefront of AR adoption, using the technology to create immersive experiences that blend digital content with the physical world. AR games encourage users to explore their real-world environments, fostering social interaction, physical activity, and community building [40].A prime example is the global phenomenon of location-based AR games, which motivate players to visit specific locations to progress in the game, thereby merging gaming with exploration.

AR enhances live events such as concerts, sports matches, and theater performances by adding interactive layers that enrich the audience's experience [41].Attendees can access additional content, such as real-time statistics, alternate camera angles, or backstage views, through AR applications on their devices. This not only adds value to the event but also offers opportunities for personalized experiences and engagement.

Theme parks and museums are integrating AR to create dynamic attractions that respond to guest interactions [42].Visitors can unlock hidden features, participate in interactive storytelling, or engage with exhibits in new ways, making the experience more engaging and memorable. AR can also provide educational content in an entertaining format, enhancing the edutainment value of such venues.

In film and television production, AR is used to visualize special effects, set designs, and characters in real-time during shooting [42] This allows directors and actors to interact more naturally with digital elements, improving performance and reducing post-production time and costs. AR is also enabling new forms of storytelling by blending live-action footage with digital overlays that viewers can experience through AR-enabled devices.

Artists and performers are experimenting with AR to create novel forms of expression and audience engagement. For instance, AR art installations can transform public spaces or traditional artworks by adding interactive digital layers that viewers can explore [43].This democratizes art by making it more accessible and encourages public participation.

Monetization strategies in AR entertainment include in-app purchases, advertising partnerships, and exclusive content offerings [44].These revenue streams contribute to the industry's growth and encourage further investment in AR technologies.

As AR hardware and software continue to advance, the potential for creating even more immersive and interactive entertainment experiences grows. The entertainment and gaming industries are poised to continue leveraging AR to captivate audiences and redefine the boundaries of digital and physical experiences.

2.6 Architecture and Construction

AR is transforming the architecture and construction industries by enhancing design visualization, collaboration, and project execution. Architects use AR to overlay digital 3D models onto physical spaces, allowing clients and stakeholders to experience designs within the actual environment where they will be built [45].This immersive visualization helps identify design flaws, spatial relationships, and aesthetic considerations early in the project lifecycle, reducing costly changes during construction.

Construction teams utilize AR for on-site guidance, overlaying blueprints, and installation instructions onto the physical environment [46].Workers can visualize the placement of structural elements, plumbing, and electrical systems with precision, enhancing accuracy and reducing errors. This technology supports real-time decision-making and problem-solving on the construction site.

AR facilitates better collaboration among architects, engineers, contractors, and clients by providing a shared visual platform for reviewing designs and making decisions. Stakeholders can interact with the AR models, provide feedback, and suggest modifications in a more intuitive and engaging manner than traditional 2D plans allow. [46]

Maintenance and facility management also benefit from AR by enabling professionals to access and visualize information about building systems, such as HVAC, electrical, and plumbing, without invasive inspections [47].AR can display maintenance histories, performance data, and alerts for equipment, aiding in predictive maintenance and reducing downtime.

Moreover, AR supports sustainable building practices by allowing designers to simulate environmental impacts, energy efficiency, and material usage during the design phase [45]. This helps in creating buildings that are environmentally friendly and compliant with sustainability standards.

Challenges in adopting AR in architecture and construction include ensuring data accuracy, integrating with existing workflows, hardware costs, and the need for training professionals to use the technology effectively [48]. However, the potential benefits in terms of cost savings, efficiency gains, and improved client satisfaction are driving increased interest and investment in AR solutions within the industry.

As AR technology continues to mature, its applications in architecture and construction are expected to expand, further revolutionizing the way we design, build, and maintain our built environment.

3 INTRODUCTION TO DESIGN AND IMPLEMENTATION OF AN AR REMOTE COLLABORATION APPLICATION IN AUTOMOTIVE EMERGENCIES

The fields and industries covered in this AR application are healthcare, maintenance and repair. It is designed to assist users in automotive emergencies, specifically focusing on two use cases: changing a tire and using a first aid kit. In both scenarios, a professional from a remote distance provides real-time, step-by-step guidance through AR overlays, ensuring that the user can perform these tasks safely without errors.

3.1 Usefulness of the Application

The proposed AR application provides critical support in automotive emergencies by enabling users to perform tasks such as changing a tire or using the first aid kit. In high-stress situations, it can be difficult to recall detailed instructions, especially for individuals without prior experience. This app offers real-time, step-by-step visual guidance overlaid directly onto the physical environment, ensuring that users can follow procedures correctly. The inclusion of remote professional assistance further enhances its utility, allowing professionals to monitor and guide the user’s actions, reducing the risk of errors. This is particularly valuable for individuals who may be in isolated locations without immediate access to help. The hands-free interaction provided by smart glasses ensures that users can focus entirely on the task at hand without the need to refer to manuals or videos, which can be difficult when you are in an emergency.

3.2 Exporting AR Capabilities

Using AR, digital instructions are overlaid to the user's real-world environment, guiding them through the process of changing a tire or using a first aid kit. In both use cases the visual guidance includes arrows to point out something on the screen, or curved arrows to suggest which direction to turn a tool. The professional providing assistance can also superimpose 3D tools on the screen with the ability to rotate or scale them making it easier for the user to understand how to perform the task. Additionally, there is a drawing tool that enables the professional to highlight things on the screen increasing the amount of information he can share and making the guidance more interactive.

3.3 Existing applications

3.3.1 Vuforia Chalk

Vuforia Chalk is a remote assistance tool designed to allow professionals to provide real-time guidance through augmented reality (AR) annotations over a live video stream. It is particularly useful in fields like technical support, field services, and maintenance, where hands-on guidance is needed. Users can share their real-time view with a professional, who can then draw or annotate directly on the screen. These annotations remain anchored to real-world objects, helping users understand complex instructions more effectively. The app's intuitive interface and cross-platform support make it highly accessible across smartphones, tablets, and desktop systems. Vuforia Chalk reduces downtime by providing quick problem resolution without requiring on-site professional visits, making it a cost-effective and efficient solution for businesses.

3.3.2 TeamViewer Assist AR

TeamViewer Assist AR enhances traditional remote support by integrating augmented reality into the troubleshooting process. This application allows users to connect with professional who can see exactly what they see through a live video feed. Using AR technology, professionals can place markers, draw, and highlight parts of the user’s view to provide instructions. This real-time visual assistance is especially valuable in industries like engineering, IT, and healthcare, where complex systems often require precise, hands-on guidance. TeamViewer Assist AR also supports enterprise-level security, ensuring that sensitive information remains protected during remote support sessions. The ability to provide such real-time, interactive guidance reduces errors and improves task completion times, making it a powerful tool in various technical fields.

3.3.3 Remote Eye

Remote Eye by Wideum is an AR-based remote assistance tool designed specifically for industrial applications such as field services, inspections, and equipment maintenance. It allows remote professionals to view the user’s environment through smart glasses, smartphones, or tablets, offering step-by-step instructions in real time. AR overlays enable professionals to draw on the user’s screen, highlight areas of interest, and guide workers through complex tasks. This solution is particularly valuable in sectors such as manufacturing, oil and gas, and telecommunications, where on-site visits by professionals are often costly or impractical. The ability to record sessions for future training or analysis adds another layer of utility, making Remote Eye an all-encompassing solution for technical support.

3.3.4 AIRe Link

AIRe Link is a remote assistance platform that integrates AR to offer real-time support for industrial and technical environments. The platform allows professionals to remotely view a machine or system through a technician’s camera and provide interactive guidance using AR annotations. AIRe Link helps reduce machine downtime by enabling professionals to guide technicians through repairs and troubleshooting without needing to be physically present. Its ease of use and cross-device compatibility make it suitable for industries such as manufacturing, utilities, and logistics. The app supports web-based access, eliminating the need for additional software installations, which further simplifies the process of providing immediate remote support.

3.3.5 MediView

MediView is an innovative augmented reality (AR) healthcare application that aims to improve medical procedures and surgeries by providing real-time, 3D visualizations of a patient's anatomy. Using devices like Microsoft HoloLens, MediView allows surgeons to "see" inside the patient's body without making incisions, offering a holographic overlay of organs, bones, and other structures. This capability enhances precision and minimizes invasive procedures. It's particularly useful in interventional radiology and complex surgeries, where spatial awareness is crucial. MediView also enables remote collaboration, allowing professionals to assist from afar, improving both training and patient outcomes.

4 REQUIREMENTS OF THE APPLICATION AND DESIGN

This section outlines the key requirements for developing the AR remote collaboration application, including the necessary hardware, software, and core functionalities. It also explains how the user, both the smart glasses/smartphone user and the remote professional interact with the system. Finally, the section covers the communication and data flow between the devices, ensuring real-time collaboration during automotive emergencies.

4.1 System Requirements

The AR remote collaboration application requires specific hardware, software, and network infrastructure to function effectively. These requirements ensure that both the smart glasses and the professional's computer can seamlessly interact, providing real-time video streaming and AR functionality.

4.1.1 Hardware Requirements

Smart Glasses: The application is designed to run on Android. We use Vuzix blade or a smartphone that uses android software. These devices come equipped with an embedded camera and AR display, allowing the user to share their view with the professional and interact with AR elements in real time.

4.1.2 Software Requirements

- **Development Platform**: The application was developed using Unity, a versatile cross-platform game development engine that supports AR and real-time communication features. Unity was chosen due to its comprehensive support for ARFoundation, which allows for smooth integration with ARCore to manage AR functionalities, including object tracking and rendering. Additionally, Unity's compatibility with WebRTC and Unity Render Streaming made it the ideal choice for enabling real-time communication and video streaming between the smart glasses and the professional's computer.

- **AR SDKs**: The system uses ARCore and ARFoundation for managing AR functionality on the Vuzix Blade. These SDKs handle object recognition, tracking, and the placement of AR elements within the user's field of view.

- **Real-Time Communication Tools**: To facilitate real-time video streaming and collaboration between the smart glasses and the professional's computer, the application integrates WebRTC for real-time communication

4.1.3 Network Requirements

A reliable and fast WiFi network is required to support the real-time communication between the smart glasses and the professional's computer. The network must offer low latency and sufficient bandwidth to handle continuous video streaming and data exchange between the devices. Slow or unreliable network connections can result in lag and affect the collaboration process.

4.2 Core Functionalities and User Interactions

The augmented reality (AR) remote collaboration system, developed for use with smart glasses, is designed to facilitate real-time collaboration between a user in the field (wearing the smart glasses) and a remote professional (using a computer). This section outlines the key functionalities and features that enable effective communication and collaboration.

4.2.1 Real-Time Video Streaming

The system provides real-time video streaming from the camera embedded in the smart glasses to the remote professional's computer. The professional can view the live camera feed from the glasses, enabling them to see exactly what the user sees. This functionality ensures that the professional can guide the user through tasks or procedures with full visibility of the user's environment.

4.2.2 AR Annotations and 3D Object Manipulation

The remote professional has the ability to place AR annotations and manipulate 3D objects in the shared view. These elements are visible to both the professional on the computer and the user wearing the smart glasses, enabling real-time visual guidance. The following AR functionalities are supported:

- **Placing AR arrows**: The professional can click on the screen to select an arrow from a group of pre-defined arrows and place it in the camera view, guiding the user's attention to specific areas. Only the selected arrow can be moved or manipulated.
- **Drawing**: The professional can switch to the drawing mode by selecting the Drawing toggle. Once activated, the professional can draw lines or shapes on the live video feed by clicking and dragging on the screen. This functionality allows for flexible and quick visual communication without the need to spawn or manipulate objects.
- **Spawning and manipulating 3D objects**: The system includes a library of 3D models (such as tools like scissors, forceps, and syringes). When the Tools toggle is selected, the professional can click on a tool from the group, spawning it into the view. Once the object is placed, the professional can move the 3D objects around the scene by dragging and dropping them on the computer screen. ii. Scale the objects by using on-screen sliders to increase or decrease their size. iii. Rotate the objects along all three axes (X, Y, Z) using rotation sliders to adjust their orientation to match the real-world setting for the user.

4.2.3 Interaction with AR Elements

The professional interacts with the system via four toggle buttons that define the interaction mode, ensuring that each action is precise and reduces the likelihood of accidental interactions:

1. **Tools Toggle**: When selected, a set of 3D tools is displayed. The professional can select and spawn these tools into the shared view. Once spawned, only the selected tool can be moved, scaled, or rotated by the professional.

2. **Drawing Toggle**: When this toggle is selected, the professional can freely draw lines and shapes directly on the screen.
3. **Arrows Toggle**: A group of arrows is presented when this toggle is selected. The professional can click on a specific arrow to place it into the view and adjust its position. Once an arrow is placed, only the selected arrow can be moved.
4. **No Interaction Mode**: This toggle ensures that no objects or annotations are interacted with, allowing the professional to observe the video feed without any risk of accidentally moving objects or making changes.

4.2.4 Deleting AR Elements

The system includes a delete function that allows the professional to remove specific AR elements (tools, arrows, or drawings). The deletion functionality is mode-specific, meaning the professional can only delete items that are selected in the current toggle mode:

- **Tools**: The professional can only delete 3D objects when the Tools toggle is active, and only the selected tool can be removed.
- **Arrows**: The professional can delete arrows only when the Arrows toggle is active, and only the selected arrow can be deleted.

This mode-specific deletion ensures that only the intended elements are removed from the shared view, preventing accidental deletions and keeping the workspace clean and organized.

4.3 Communication and Data Flow

The augmented reality (AR) remote collaboration system relies on WebRTC (Unity Render Streaming) to manage real-time communication between the smart glasses worn by the user and the professional's computer. The system ensures low-latency data transmission over a local WiFi network, facilitating smooth interaction between the two parties.

The system operates with three key components:

- **Smart Glasses (Peer 1)**: The smart glasses capture real-time video from the user's environment and send it to the professional's computer. All AR elements, including 3D objects and annotations, are rendered on the smart glasses, and the professional interacts with these elements remotely.
- **Signaling Server**: The signaling server handles the WebRTC signaling process, establishing a connection between the smart glasses and the professional's computer. It enables peer-to-peer communication once the connection is established.

- **Computer (Peer 2)**: The professional views the video feed from the smart glasses and interacts with the scene via touch inputs. These inputs control existing AR elements (annotations, 3D objects, UI) in real time on the smart glasses.

The data flow is **bidirectional**:

- **From Smart Glasses (Peer 1)**: The glasses send real-time video and audio to the professional's computer.
- **From Professional's Computer (Peer 2)**: The professional sends interaction inputs back to the smart glasses, modifying the AR scene.

The **WebRTC (Unity Render Streaming)** protocol is used to ensure smooth real-time video and data streaming between the devices. The local WiFi network connects both clients (smart glasses and the professional's computer), providing a low-latency environment for real-time collaboration.

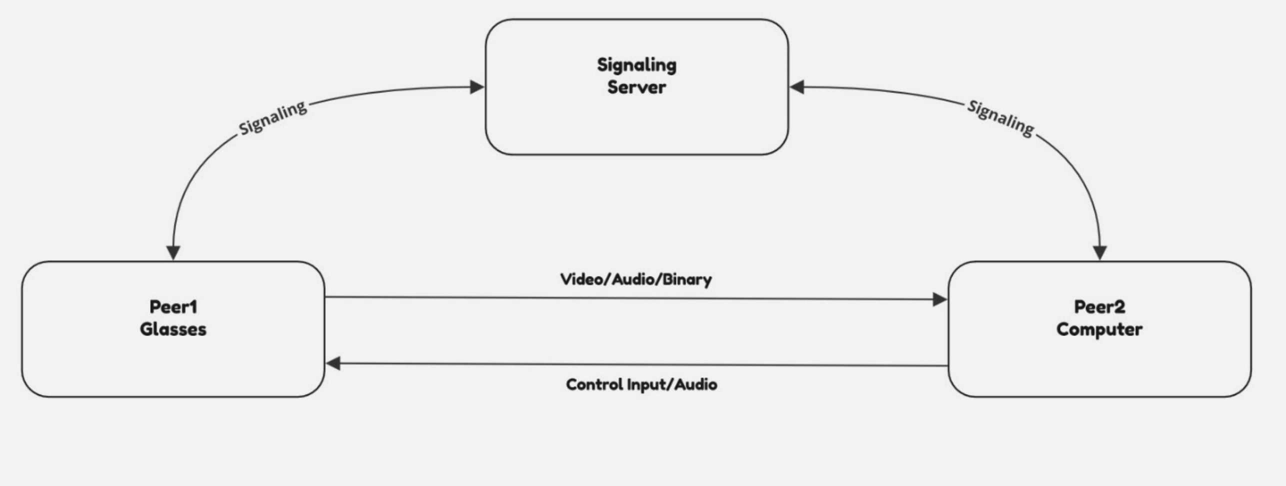


Figure 4.1: Bidirectional Connection

4.4 Use Case Scenarios

The AR remote collaboration system supports real-time audio and visual communication between the smart glasses user and the remote professional, allowing for seamless guidance during critical tasks. Below are two key scenarios demonstrating how the system is applied in automotive repair and healthcare emergencies.

4.4.1 Use Case 1: Automotive Remote Repair – Changing a Tire

In this scenario, a mechanic, acting as the remote professional, uses the AR system to guide a driver (smart glasses user) through the process of changing a flat tire. This is a common automotive emergency, where the driver needs assistance to safely and effectively complete the repair.

Scenario Flow:

1. **Initial Setup**: The driver, wearing smart glasses, streams a live video feed of the vehicle to the remote mechanic. The two communicate via the system's audio feature, allowing the mechanic to ask questions and gather details about the situation.
2. **3D Tool Guidance**: The mechanic selects a 3D model from the system's interface and places it in the correct orientation in the AR view. While positioning the tool, the mechanic explains the process to the driver using the audio connection, ensuring the driver understands where and how to use the tool.
3. **Arrows for Direction**: The mechanic uses curved AR arrows to show the driver the correct direction for turning the tire iron to loosen or tighten the lug nuts. As the mechanic gives verbal instructions on the proper technique, the driver follows along, asking questions when necessary.
4. **Drawing for Highlights**: The mechanic can switch to Drawing Mode to highlight areas of the wheel or vehicle where the jack needs to be placed. The mechanic provides real-time verbal guidance through the audio link, explaining each step as the driver moves the jack into position.
5. **Task Completion**: The driver follows the step-by-step AR and audio instructions, successfully replacing the flat tire. Throughout the process, the mechanic monitors the driver's actions through the live video feed and provides immediate feedback, ensuring the job is done correctly.

4.4.2 Use Case 2: Healthcare Emergency – First Aid Guidance using First Aid Kit

In this scenario, a healthcare professional (remote professional) uses the AR system to guide a non-professional smart glasses user through administering first aid during an emergency. The two-way audio communication allows the healthcare professional to provide detailed instructions and immediate feedback to the user.

Scenario Flow:

1. **Initial Emergency Setup**: The smart glasses user begins streaming the situation to the healthcare professional, who assesses the emergency. Using the system's audio feature, the professional asks the user questions about the patient's condition and the contents of the first aid kit.
2. **3D Object Placement**: The healthcare professional selects a 3D model of the necessary first aid tool, such as a syringe or bandages, and positions it in the AR view. The professional explains each step verbally, ensuring the user knows how to correctly apply the tool. For

example, the professional guides the user on how to hold and use the syringe while giving real-time instructions via the audio link.

3. **Pinpointing with Arrows**: To ensure accuracy, the healthcare professional uses AR arrows to indicate specific areas for the user to address, such as where to inject the syringe or clean a wound. The professional communicates the importance of these actions through the audio system, guiding the user through the process.
4. **Drawing for Emphasis**: The professional switches to Drawing Mode to highlight areas that require special attention. For instance, the professional may mark the location where pressure should be applied to stop bleeding, while explaining the technique verbally.
5. **Real-Time Guidance**: The smart glasses user follows the professional’s AR and audio instructions step by step, applying first aid correctly. The healthcare professional monitors the user’s actions through the video feed and offers verbal feedback, ensuring the first aid is administered properly and promptly.

5 IMPLEMENTATION AND PRESENTATION OF THE APPLICATION

This section provides a detailed, step-by-step overview of the implementation process for the AR remote collaboration application. It documents the chronological development stages, starting from setting up the Unity environment to configuring ARFoundation, ARCore, and WebRTC, and concluding with the final presentation of the system.

Each step outlines the specific tasks completed, the tools and technologies used, and how key features were implemented.

By the end of this section, the full implementation of the system will be presented, showcasing the collaboration between the smart glasses user and the remote professional via real-time AR interactions and video streaming.

5.1 Implementation of the Application

The implementation of the AR remote collaboration system involved several key stages, from setting up the development environment to integrating advanced features like 3D object interaction and real-time video streaming. This section outlines the process chronologically, highlighting the tools and techniques used at each stage.

Beginning with the installation of Unity and the necessary packages, the project progressed through the development of core AR features using ARFoundation and ARCore, the creation of interactive UI elements, and the integration of WebRTC for real-time communication. Each phase played a critical role in building a robust system for seamless collaboration between a smart glasses user and a remote professional.

Development Environment and Initial Setup

The first step in building the AR remote collaboration system was setting up the development environment in Unity 2022.3. Unity 2022.3 was chosen specifically for its Long Term Support (LTS), offering a stable foundation for the development process compared to more recent versions. This ensured reliability during the project’s lifecycle.

Hardware Limitation and Adaptation

The application was initially intended for use with Vuzix Blade smart glasses, which were the targeted hardware for the project. However, a key limitation was identified: the Vuzix Blade operates with a camera API level of 22, which is below the minimum required API level of 24 for ARCore compatibility. Due to this limitation, ARCore functionalities could not be implemented on the smart glasses as planned.

As a result, the application was adapted for use on a smartphone, which fully supports ARCore. This adaptation allowed the AR features to function as intended. While the development and testing were conducted using a smartphone, the application remains designed for smart glasses or any ARCore-compatible devices in the future.

Installing Packages

After installing Unity, several critical packages were added to enable the core functionality of the AR system:

- **Google ARCore XR Plugin**: This package provides the tools necessary to implement AR features on Android devices and smart glasses.
- **ARFoundation**: ARFoundation was used to manage the AR session and handle interactions between virtual objects and the real-world environment. It provides a unified interface for working with multiple AR platforms.
- **New Input System**: The New Input System replaced Unity's legacy input handling, allowing for more advanced input detection, including touch interactions and gesture-based controls. This was essential for managing how the user interacted with 3D objects and annotations in the AR environment.

Setting Up the Initial Scene

To begin working with AR in Unity, several GameObjects were added to the Hierarchy:

- XR Origin: This object was the cornerstone of the AR functionality. It contains the AR Camera, which is responsible for rendering the AR content and tracking the user's movement in the real-world environment.
- AR Session: The AR Session manages the AR experience, handling the initialization and lifecycle of the AR environment.
- Directional Light: A directional light was added to illuminate the scene, ensuring that the AR objects would be properly lit and visible when placed in the environment.
- Event System: The Event System was necessary for managing UI events and interactions, particularly useful for touch-based interactions on mobile devices or smart glasses.

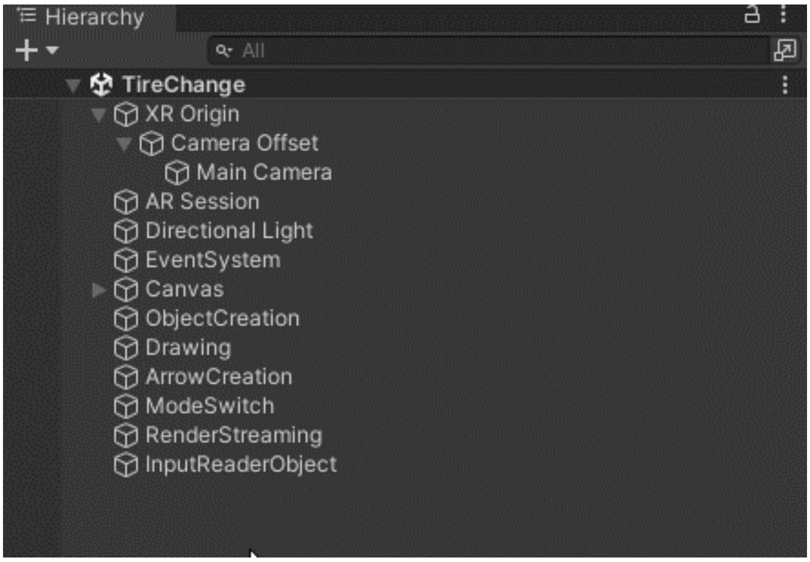
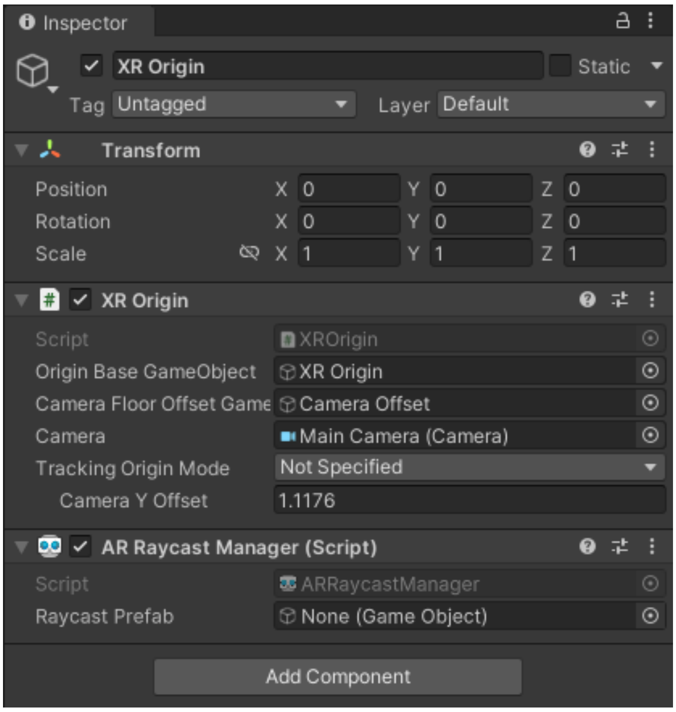


Figure 5.1: Hierarchy of the project with all GameObjects used throughout the implementation.

Enabling Raycasting

To enable the placement and manipulation of objects in the AR environment, the AR Raycast Manager was added to the scene. The AR Raycast Manager detects real-world surfaces where virtual objects can be placed, allowing the user to interact with the scene by tapping on their device's screen.



☑ XR Origin

Tag Untagged

Layer Default

Position X 0 Y 0 Z 0

Rotation X 0 Y 0 Z 0

Scale X 1 Y 1 Z 1

☑ XR Origin

Script XROrigin

Origin Base GameObject XR Origin

Camera Floor Offset Game Camera Offset

Camera Main Camera (Camera)

Tracking Origin Mode Not Specified

Camera Y Offset 1.1176

☑ AR Raycast Manager (Script)

Script ARRaycastManager

Raycast Prefab None (Game Object)

Figure 5.2 : XR Origin Inspector with AR Raycast Manager

Configuring Input Actions

Using the New Input System, a series of InputActions were created to manage the interactions within the AR environment. These input actions were designed to handle:

- Moving 3D objects: This allowed the user to select and manipulate 3D models, placing them in the correct position within the AR scene.
- Drawing: Input actions were configured to enable drawing directly on the screen, which was important for real-time annotations and guidance.

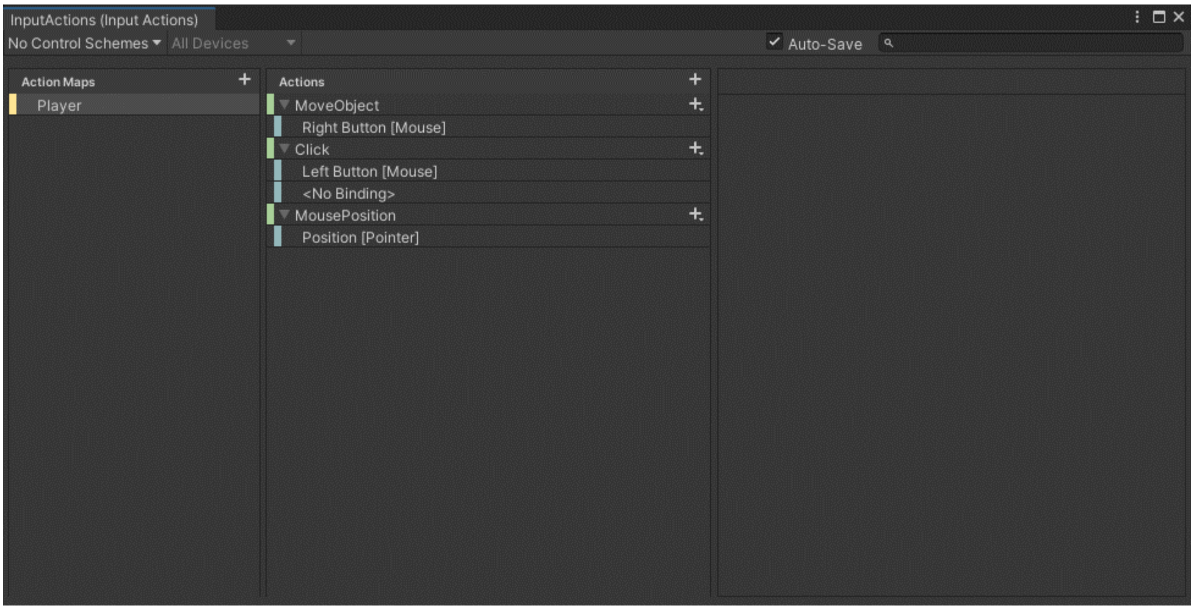


Figure 5.3: Input Actions

AR 3D Object Spawning, Manipulation, and Drawing

With the AR environment set up, the next focus was on implementing the core interaction mechanisms: spawning, moving, and manipulating 3D objects (such as tools and arrows), as well as enabling the drawing functionality within the AR scene. These features are essential for allowing the remote professional to guide the smart glasses user through tasks in real-time.

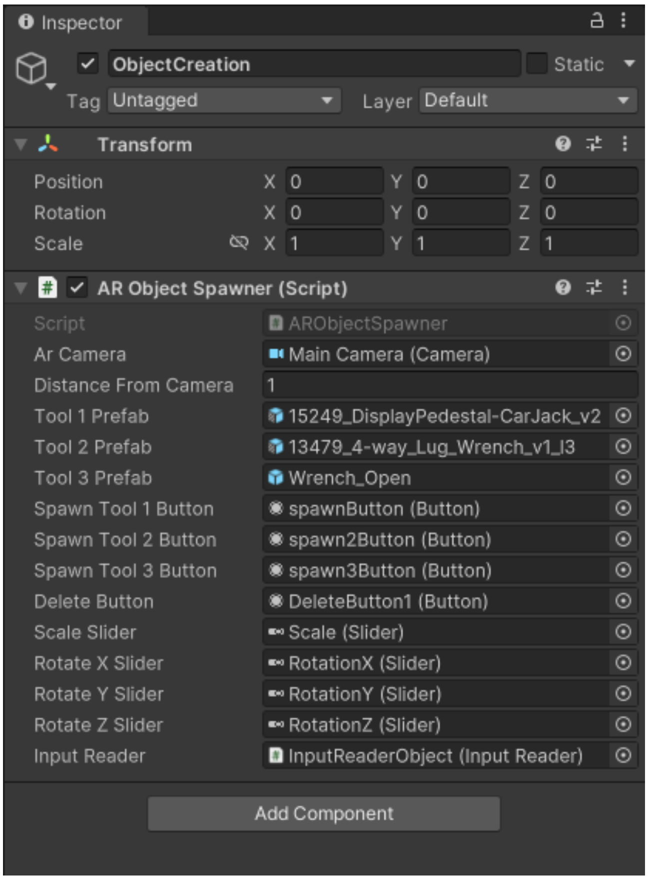
AR Object Spawning, Manipulation, and Drawing

With the AR environment set up, the next focus was on implementing the core interaction mechanisms: spawning, moving, and manipulating 3D objects (such as tools and arrows), as well as enabling the drawing functionality within the AR scene. These features are essential for allowing the remote professional to guide the smart glasses user through tasks in real-time.

3D Object Spawning and Movement

To enable the spawning and movement of 3D objects, a script was created using Unity's New Input System. The functionality ensures that only one instance of each object can be active at a time.

- A script was developed to handle object creation and movement based on touch inputs or mouse clicks. When pressing the icon of the wanted 3D object, the object is spawned at the center of the screen. Once the object is placed, the user can drag it to move it around the scene.
- The ObjectCreation GameObject was created to hold this script, and all 3D prefabs, were attached to the GameObject via the Inspector.



ObjectCreation
Static
Tag Untagged
Layer Default

Transform
Position X 0 Y 0 Z 0
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1

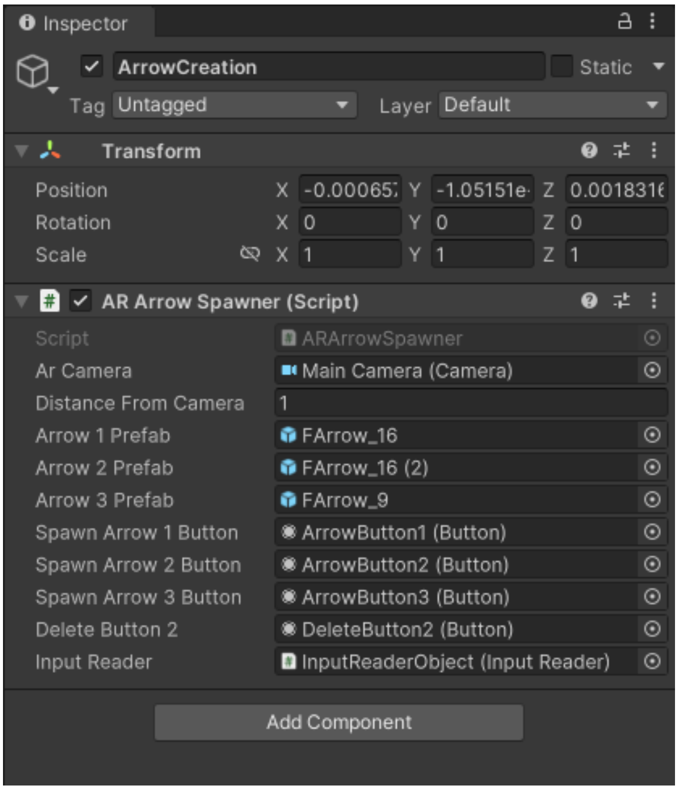
AR Object Spawner (Script)
Script ARObjectSpawner
Ar Camera Main Camera (Camera)
Distance From Camera 1
Tool 1 Prefab 15249_DisplayPedestal-CarJack_v2
Tool 2 Prefab 13479_4-way_Lug_Wrench_v1_l3
Tool 3 Prefab Wrench_Open
Spawn Tool 1 Button spawnButton (Button)
Spawn Tool 2 Button spawn2Button (Button)
Spawn Tool 3 Button spawn3Button (Button)
Delete Button DeleteButton1 (Button)
Scale Slider Scale (Slider)
Rotate X Slider RotationX (Slider)
Rotate Y Slider RotationY (Slider)
Rotate Z Slider RotationZ (Slider)
Input Reader InputReaderObject (Input Reader)

Figure 5.4: Inspector of ObjectCreation GameObject

Arrow Spawning and Movement

Similarly, arrows were implemented as part of the guidance system, allowing the professional to highlight specific areas or directions in the AR environment. A separate script was created to handle the spawning and manipulation of arrows in much the same way as the tools.

- A GameObject named ArrowCreation was created to manage this functionality. Just like with the tools, arrows can be selected and placed within the environment by clicking or touching the screen.
- The professional can drag arrows to different positions providing clear visual guidance.



ArrowCreation

Tag Untagged
Layer Default

Transform

Position	X -0.00065	Y -1.05151e	Z 0.001831
Rotation	X 0	Y 0	Z 0
Scale	X 1	Y 1	Z 1

AR Arrow Spawner (Script)

Script	ARArrowSpawner
Ar Camera	Main Camera (Camera)
Distance From Camera	1
Arrow 1 Prefab	FArrow_16
Arrow 2 Prefab	FArrow_16 (2)
Arrow 3 Prefab	FArrow_9
Spawn Arrow 1 Button	ArrowButton1 (Button)
Spawn Arrow 2 Button	ArrowButton2 (Button)
Spawn Arrow 3 Button	ArrowButton3 (Button)
Delete Button 2	DeleteButton2 (Button)
Input Reader	InputReaderObject (Input Reader)

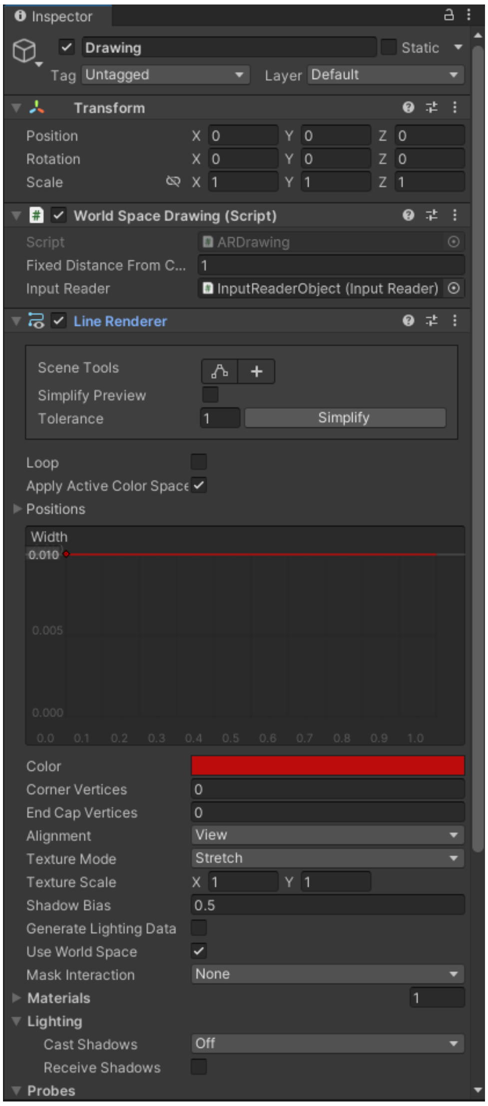
Figure 5.5 : Inspector of ArrowCreation GameObject

Drawing on the Screen

In addition to spawning 3D objects and arrows, the system supports drawing directly on the screen. This is particularly useful for marking areas or highlighting specific objects in the scene.

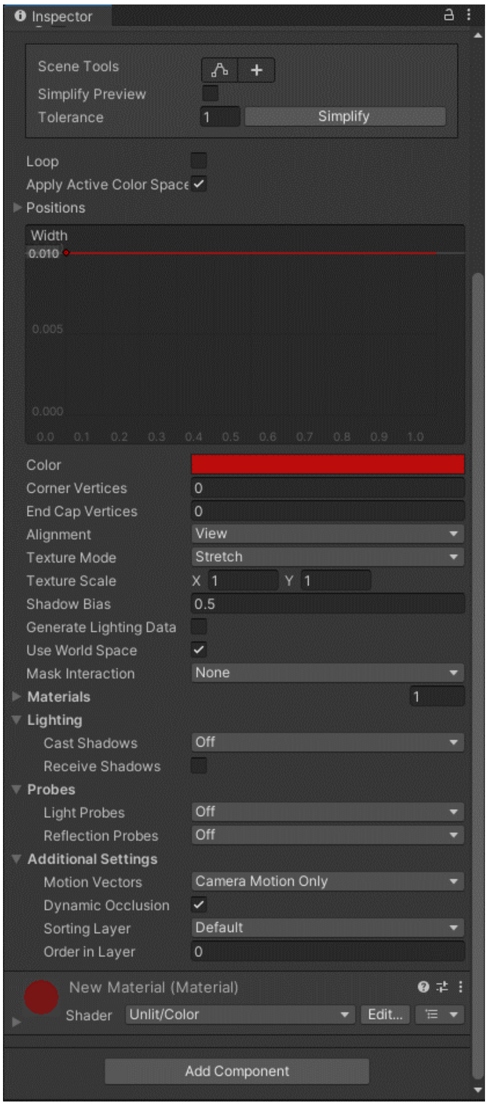
- A dedicated script was developed to handle drawing. When the user touches the screen or clicks with a mouse, drawings appear in the AR view.
- The Drawing GameObject manages this functionality, allowing the professional to make quick annotations, similar to drawing on a whiteboard, but in real-time and in the AR environment that stay always relative to the world coordinates.

The combination of these interaction mechanisms object spawning, arrow placement, and drawing gives the remote professional the ability to provide comprehensive guidance to the smart glasses user, helping them perform tasks accurately.



☑ Drawing ☐ Static
Tag Untagged Layer Default
Transform
Position X 0 Y 0 Z 0
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1
☑ World Space Drawing (Script)
Script ARDrawing
Fixed Distance From C... 1
Input Reader InputReaderObject (Input Reader)
☑ Line Renderer
Scene Tools
Simplify Preview ☐
Tolerance 1
Loop ☐
Apply Active Color Space ☑
Positions
Width
Color 🟥
Corner Vertices 0
End Cap Vertices 0
Alignment View
Texture Mode Stretch
Texture Scale X 1 Y 1
Shadow Bias 0.5
Generate Lighting Data ☐
Use World Space ☑
Mask Interaction None
Materials 1
Lighting
Cast Shadows Off
Receive Shadows ☐
Probes

Figure 5.6: Inspector of Drawing 1



Scene Tools
Simplify Preview ☐
Tolerance 1
Loop ☐
Apply Active Color Space ☑
Positions
Width
Color 🟥
Corner Vertices 0
End Cap Vertices 0
Alignment View
Texture Mode Stretch
Texture Scale X 1 Y 1
Shadow Bias 0.5
Generate Lighting Data ☐
Use World Space ☑
Mask Interaction None
Materials 1
Lighting
Cast Shadows Off
Receive Shadows ☐
Probes
Light Probes Off
Reflection Probes Off
Additional Settings
Motion Vectors Camera Motion Only
Dynamic Occlusion ☑
Sorting Layer Default
Order in Layer 0
New Material (Material)
Shader Unlit/Color

Figure 5.7: Inspector of Drawing 2

UI and Interaction Mode

The UI system and interaction modes are essential for managing various actions such as 3D object spawning, drawing, and arrow creation. The technical setup relies on a series of toggles and UI elements that allow the professional to switch between different interaction modes in a controlled and intuitive way.

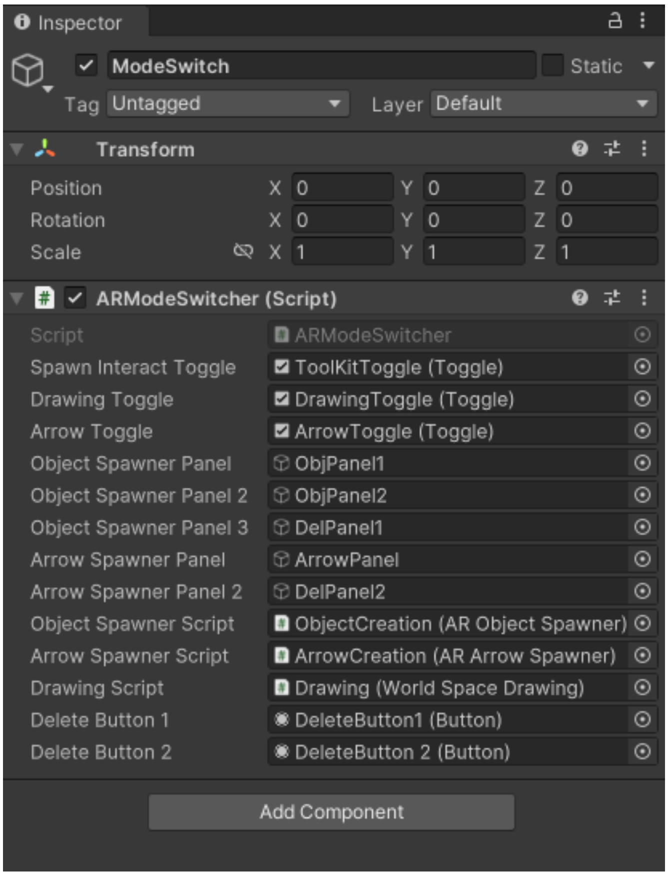
ModeSwitch GameObject

The ModeSwitch GameObject acts as the core controller for managing different interaction modes. These modes include:

1. **Tools Toggle**: Enables the spawning and manipulation of 3D tools within the AR environment.
2. **Drawing Toggle**: Activates the drawing functionality for annotations and highlighting.
3. **Arrows Toggle**: Allows the professional to spawn and manipulate arrows for directional guidance.
4. **No Interaction Mode**: Disables all interaction to prevent accidental changes in the AR environment.

The ARModeSwitcher script, attached to the ModeSwitch GameObject (as shown in the inspector), is responsible for ensuring that only one interaction mode is active at a time. When one toggle is selected, the others are deactivated to avoid conflicts between actions like drawing and object manipulation.

- Inspector Setup: The ModeSwitch GameObject links the toggles, panels, and other relevant UI elements via the ARModeSwitcher script. This ensures smooth transitions between different interaction modes.



☑ ModeSwitch

Tag Untagged   Layer Default

Position	X 0	Y 0	Z 0
Rotation	X 0	Y 0	Z 0
Scale	X 1	Y 1	Z 1

☑ ARModeSwitcher (Script)

Script	ARModeSwitcher
Spawn Interact Toggle	ToolKitToggle (Toggle)
Drawing Toggle	DrawingToggle (Toggle)
Arrow Toggle	ArrowToggle (Toggle)
Object Spawner Panel	ObjPanel1
Object Spawner Panel 2	ObjPanel2
Object Spawner Panel 3	DelPanel1
Arrow Spawner Panel	ArrowPanel
Arrow Spawner Panel 2	DelPanel2
Object Spawner Script	ObjectCreation (AR Object Spawner)
Arrow Spawner Script	ArrowCreation (AR Arrow Spawner)
Drawing Script	Drawing (World Space Drawing)
Delete Button 1	DeleteButton1 (Button)
Delete Button 2	DeleteButton 2 (Button)

Figure 5.8 :Inspector of ModeSwitch GameObject

GameObject Setup for Toggles in the Hierarchy

Each interaction mode is controlled by a UI toggle button, which is organized as individual GameObjects in the Hierarchy. These toggles are linked to their functions through the ModeSwitch script.

The toggle buttons are visible in the Hierarchy, and each one corresponds to a specific interaction mode. This hierarchy organization helps ensure that the toggles are properly linked to their functions within the UI.

Interaction Panels and Buttons

Each toggle activates a dedicated UI panel containing buttons for selecting tools or arrows:

- Tools Panel: When the Tools Toggle is active, a set of buttons appears, representing various 3D tools. Selecting a button spawns the corresponding tool in the AR environment.
- Arrows Panel: Similarly, when the Arrows Toggle is selected, a panel of arrow buttons appears, allowing the user to select and place arrows in the scene.

These panels are linked to the ModeSwitch script to ensure they only appear when their respective toggle is selected.

- TireChange
  - XR Origin
  - AR Session
  - Directional Light
  - EventSystem
  - Canvas
    - ToggleGroup
      - ToolKitToggle
      - DrawingToggle
      - ArrowToggle
      - NoneToggle
    - ObjPanel1
      - spawnButton
      - spawn2Button
      - spawn3Button
    - ObjPanel2
      - Sliders
    - DelPanel1
      - DeleteButton1
    - DelPanel2
      - DeleteButton 2
    - ArrowPanel
      - ArrowButton1
      - ArrowButton2
      - ArrowButton3
  - ObjectCreation
  - Drawing
  - ArrowCreation
  - ModeSwitch
  - RenderStreaming
  - InputReaderObject

Figure 5.9: Hierarchy with Canvas Unfold

Sliders for Tool Manipulation

To provide additional control over the 3D objects, the system includes sliders that control the scale and rotation of spawned objects. These sliders become visible when the Tools Toggle is active and allow the professional to adjust the size and orientation of the 3D objects within the AR environment.

The sliders are connected to the ObjectCreation GameObject, which manages the spawning and manipulation of 3D tools. This allows for real-time adjustments based on the professional's needs.

Delete Button

A Delete Button was added to allow the professional to remove objects or arrows from the AR scene. The delete functionality is mode-specific:

- In Tools Mode, the Delete Button removes the selected tool.
- In Arrows Mode, it removes the selected arrow.

The Delete Button is linked to the ObjectCreation and ArrowCreation GameObjects, ensuring that only the objects relevant to the current mode are deleted.

Visual Feedback and User Interface Enhancements

Toggle Button Animation and Visual Feedback

To ensure that the active toggle is easily distinguishable from the others, an animation effect was created using an Animator component and a custom script that manages the toggles.

- Toggle Animator Script: A script was created to control the visual feedback for the toggles. This script was attached to each Toggle GameObject in the Hierarchy. Its purpose is to manage the Animator that enlarges the selected toggle icon while keeping the other toggles at their default size.
- Animator Component: The Animator was added to each toggle, and the animation clips were linked in the Inspector. The animator plays two animation clips:

    1. Selected Toggle Animation: Enlarges the scale of the toggle icon to indicate that it is currently active.
    2. Default Toggle Animation: Keeps the inactive toggles at their normal scale size.

The script is responsible for switching between these animations based on the currently active toggle, providing clear visual feedback to the user.

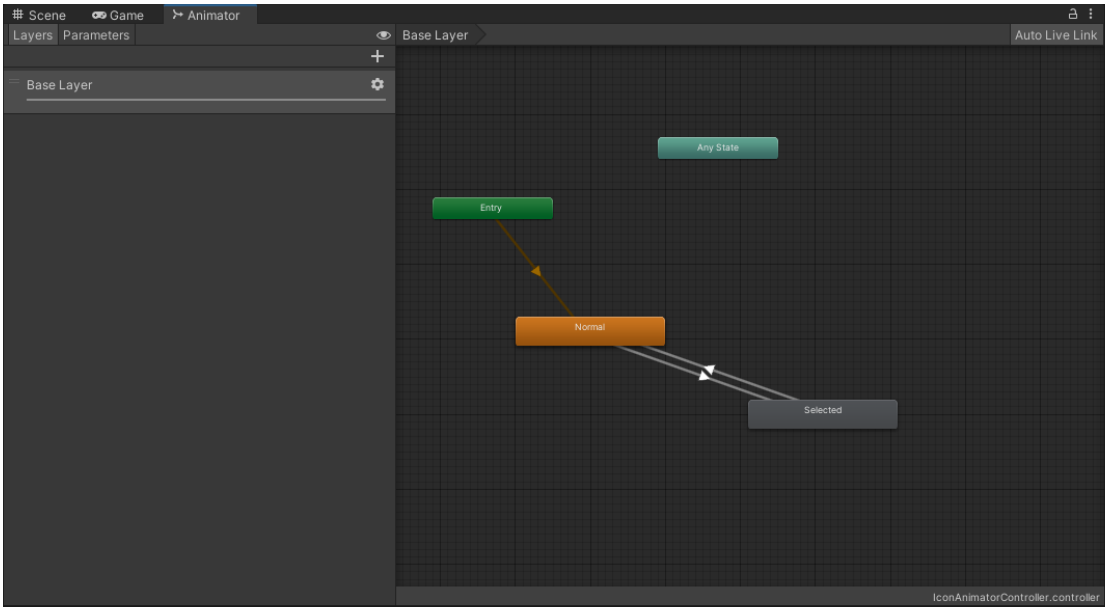
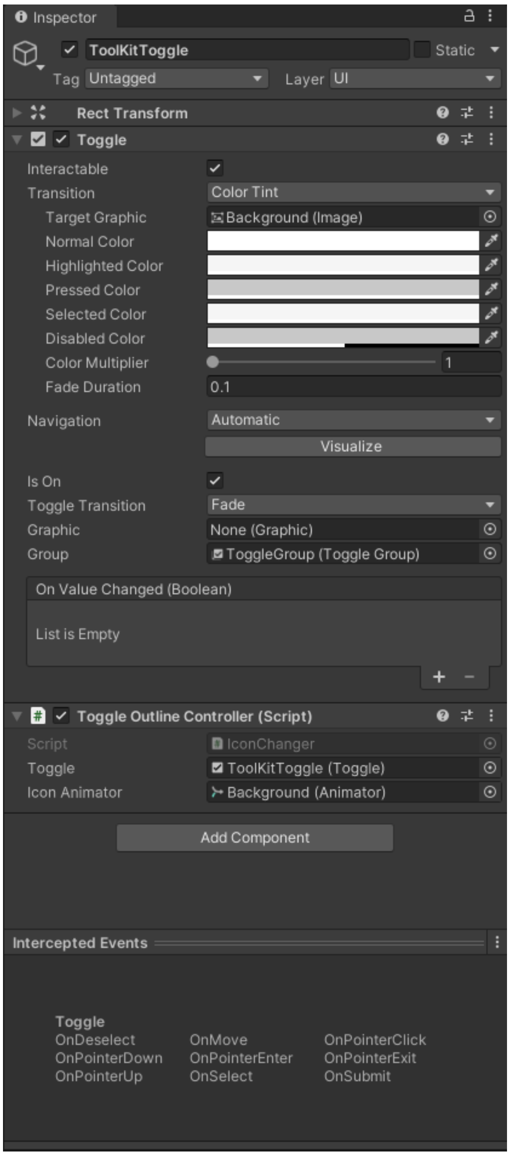


Figure 5.10: Animator with 2 Clips



ToolKitToggle
Tag Untagged
Layer UI

Toggle

Interactable ☑
Transition: Color Tint
Target Graphic: Background (Image)
Normal Color
Highlighted Color
Pressed Color
Selected Color
Disabled Color
Color Multiplier: 1
Fade Duration: 0.1
Navigation: Automatic
Is On ☑
Toggle Transition: Fade
Graphic: None (Graphic)
Group: ToggleGroup (Toggle Group)
On Value Changed (Boolean)
List is Empty

Toggle Outline Controller (Script)

Script: IconChanger
Toggle: ToolKitToggle (Toggle)
Icon Animator: Background (Animator)

Intercepted Events

Toggle
OnDeselect
OnMove
OnPointerClick
OnPointerDown
OnPointerEnter
OnPointerExit
OnPointerUp
OnSelect
OnSubmit

Figure 5.11: Inspector of ToolkitToggle Showing Animator

3D Asset Import and Integration

To provide realistic tools for the Tire Change and First Aid Kit use cases, 3D models were imported. These models were linked to the ObjectCreation GameObject, allowing the professional to spawn and manipulate these objects in the AR environment.

Custom Icons and Button Design

To improve the user interface, icons were added to the buttons and toggles:

- Button Icons: Each button, corresponding to a specific tool or arrow, was updated with a custom icon that visually represents the object it spawns.
- 2D Packages Installation: In order to add these icons, Unity's 2D packages were installed .

UI Color for Different Use Cases

To differentiate between the Tire Change and First Aid Kit use cases, the UI was color-coded:

- Blue for Tire Change: All UI elements related to the tire change scenario were colored blue, creating a consistent theme for that use case.

- Red for First Aid Kit: The UI elements for the medical use case were colored red, clearly distinguishing the two emergency scenarios.

Scene and User Flow Setup

To provide a seamless user experience for both the smart glasses/phone user and the remote professional, four distinct scenes were created. Each scene serves a specific purpose in the system, either allowing the user to interact with the AR environment or facilitating the connection and interaction between the two devices.

Scenes for Glasses/Phone User

1. **TireChange Scene**

This scene contains all the tools, UI elements, and interaction modes necessary for the tire change use case. The 3D models of tire tools are available in this scene for the professional to spawn and manipulate. The UI color is blue for this scenario, ensuring that the user can quickly identify the context of the current task.

2. **FirstAidKit Scene**

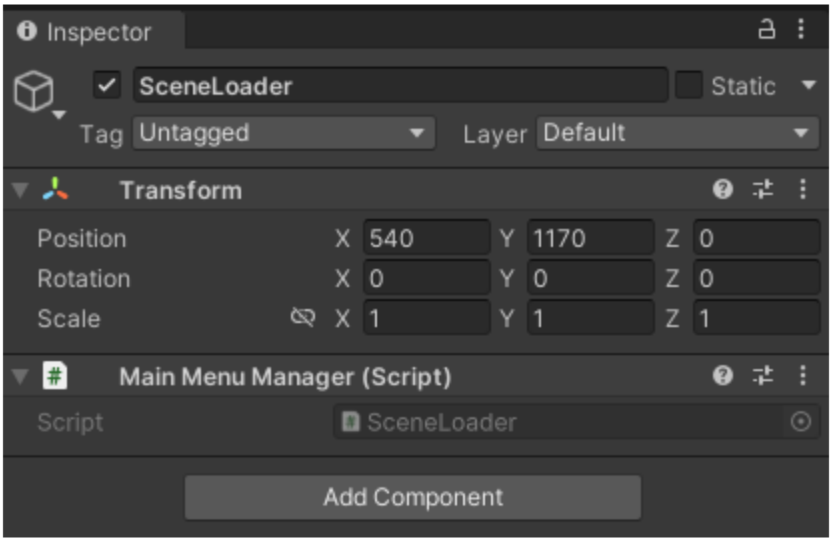
This scene is similar to the TireChange Scene but is set up for the medical use case. The UI is color-coded to red for easy differentiation between the two scenarios.

3. MainMenu Scene

This scene allows the glasses/phone user to select between the two use cases: Tire Change or First Aid Kit.The MainMenu Scene consists of four components in the Hierarchy:

- Main Camera
- Directional Light
- EventSystem
- Canvas : Contains two buttons and the icons of the buttons
- SceneLoader GameObject : Contains a script called MainMenuManager.This script handles the scene loading based on the user's selection. The user can choose between two buttons.Tire icon button that loads the TireChange scene and First Aid Kit icon button that loads the FirstAidKit scene.

Figure 5.12: Hierarchy of MainMenu Scene



☑ SceneLoader ☐ Static

Tag Untagged
Layer Default

Position X 540 Y 1170 Z 0
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1

Script SceneLoader

Figure 5.13: Inspector of SceneLoader GameObject

Scene for the Computer User

This scene is specifically designed for the remote professional. In this scene, the professional can connect to the smart glasses/phone and interact with the AR environment by manipulating the objects, placing annotations, and giving real-time guidance.

The scene contains no AR objects but includes the necessary components to establish the WebRTC connection, display the video feed from the smart glasses, and allow the professional to control the AR elements via the UI.

The professional must enter the IP address of the local network to connect with the smart glasses/phone user. This IP address allows the devices to communicate via WebRTC and establish a low-latency connection for video streaming and input sharing.

The scene contains the following components:

- Main Camera
- Receiver: Manages the WebRTC connection setup and communication.
- Canvas
- EventSystem

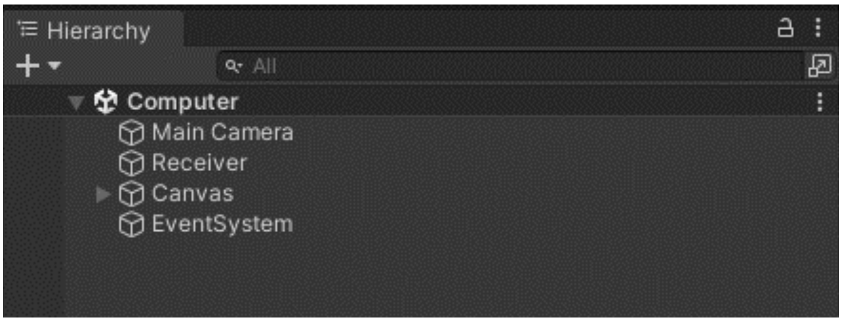


Figure 5.14: Hierarchy of Computer Scene

Implementing Video Streaming and WebRTC

In order to enable real-time video streaming and interaction between the smart glasses/phone user and the remote professional, the Unity Render Streaming and WebRTC packages were installed and integrated into the project. This group outlines the steps taken to establish the video streaming functionality and ensure smooth input handling between the two devices.

Installing Unity Render Streaming and WebRTC

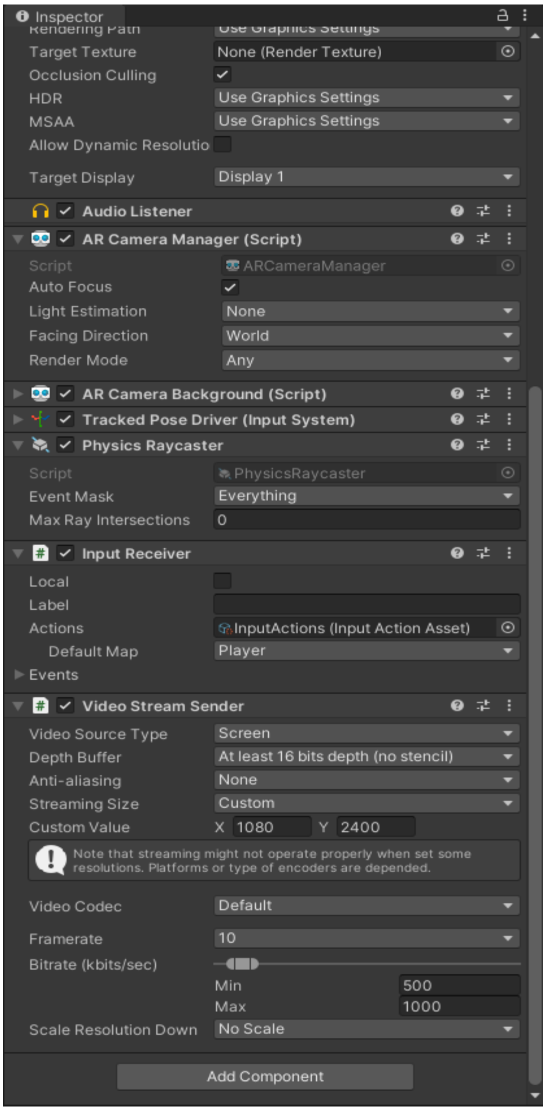
Unity Render Streaming and WebRTC packages were installed. These packages provide the core functionalities needed for peer-to-peer communication, enabling the smart glasses/phone to send video and receive inputs from the remote professional’s computer.

InputReceiver for Glasses/Phone User

The InputReceiver script was added to the MainCamera (AR Camera) in both the TireChange and FirstAidKit scenes. This script is responsible for handling the input sent from the computer user and applying them to the AR scene.
In the actions field the Input Actions

VideoStreamSender for Glasses/Phone User

The VideoStreamSender script was added to the MainCamera in both scenes to handle the real-time streaming of the video feed from the glasses/phone to the professional's computer.
The Streaming Size was adjusted to match the screen resolution of the smart glasses/phone, ensuring that the streamed video displayed correctly on the professional's side.



Target Texture	None (Render Texture)
Occlusion Culling	☑
HDR	Use Graphics Settings
MSAA	Use Graphics Settings
Allow Dynamic Resolutio	☐
Target Display	Display 1

☑ **Audio Listener**

☑ **AR Camera Manager (Script)**

Script	ARCameraManager
Auto Focus	☑
Light Estimation	None
Facing Direction	World
Render Mode	Any

☑ **AR Camera Background (Script)**

☑ **Tracked Pose Driver (Input System)**

☑ **Physics Raycaster**

Script	PhysicsRaycaster
Event Mask	Everything
Max Ray Intersections	0

☑ **Input Receiver**

Local	☐
Label	
Actions	InputActions (Input Action Asset)
Default Map	Player
Events	

☑ **Video Stream Sender**

Video Source Type	Screen
Depth Buffer	At least 16 bits depth (no stencil)
Anti-aliasing	None
Streaming Size	Custom
Custom Value	X 1080 Y 2400

Note that streaming might not operate properly when set some resolutions. Platforms or type of encoders are depended.

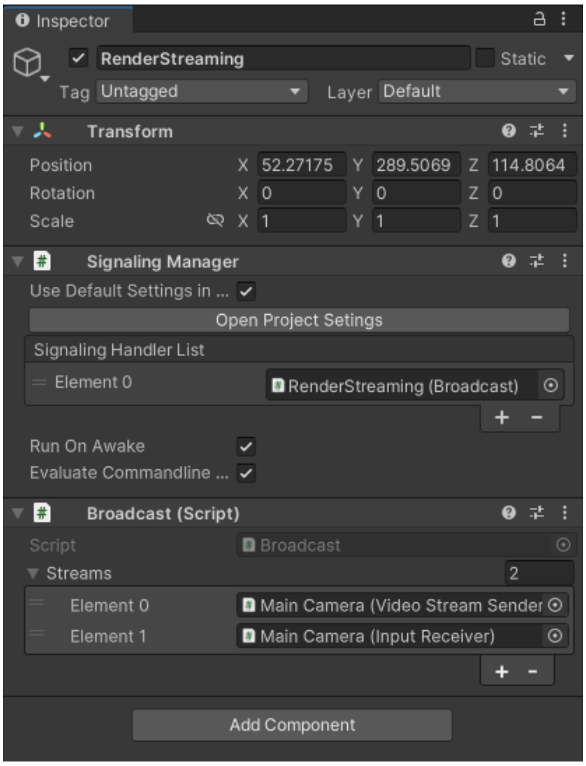
Video Codec	Default
Framerate	10
Bitrate (kbits/sec)	Min 500 Max 1000
Scale Resolution Down	No Scale

Figure 5.15 :Inspector of MainCamera showing InputReceiver and VideoStreamSender

RenderStreaming GameObject for Signaling and Broadcasting

A RenderStreaming GameObject was created in both the TireChange and FirstAidKit scenes. This GameObject is responsible for handling the signaling and broadcasting required for WebRTC communication.

- Signaling Manager was attached to manage the WebRTC connection.
- A Broadcast script was added to handle the VideoStreamSender and InputReceiver from the MainCamera.
- The setup allowed the system to broadcast the video stream and manage input handling between the smart glasses and the computer.



☑ RenderStreaming ☐ Static
Tag Untagged
Layer Default

Position X 52.27175 Y 289.5069 Z 114.8064
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1

Use Default Settings in ... ☑
Signaling Handler List
Element 0 RenderStreaming (Broadcast)
Run On Awake ☑
Evaluate Commandline ... ☑

Script Broadcast
Streams 2
Element 0 Main Camera (Video Stream Sender
Element 1 Main Camera (Input Receiver)

Figure 5.16: Inspector of RenderStreaming GameObject

InputReader Script for Input Handling

A custom script named InputReader was created to connect the AR interaction scripts (ARObjectSpawner, ARArrowSpawner, and ARDrawing) with the input actions defined earlier.
This script was attached to the relevant GameObjects (ObjectCreation, ArrowCreation, and Drawing) to ensure they correctly handle inputs sent from the professional's computer.

Computer Scene Setup

In the Computer Scene, a Receiver GameObject was created to handle the input and video feed from the glasses/phone. The following components were added:

- Signaling Manager to handle the WebRTC connection setup.
- SingleConnection script to manage the WebRTC connection.
- InputSender script to send touch input commands back to the smart glasses user.
- VideoStreamReceiver to display the video feed from the glasses/phone on the professional's computer.

Pivot X 0.5 Y 0.5
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1

Signaling Manager
Use Default Settings in ... ✓
Signaling Handler List
Element 0 Receiver (Single Connection)
Run On Awake ☐
Evaluate Commandline ... ✓

Single Connection (Script)
Script SingleConnection
Streams 3
Element 0 Receiver (Video Stream Receiver)
Element 1 Receiver (Audio Stream Receiver)
Element 2 Receiver (Input Sender)

Video Stream Receiver
Render Mode API Only
Video Codec Default

✓ **Audio Stream Receiver**
Target Audio Source None (Audio Source)
Audio Codec Default

Input Sender
Script InputSender
Local ✓
Label input

Intercepted Events
SingleConnection
OnAddChannel OnAddReceiver
OnCreatedConnection OnDeletedConnection
OnOffer

Figure 5.17 :Inspector of Receiver GameObject

Network Configuration

In the Render Streaming settings in Project Settings, the websocket IP address of the local network was entered. This is crucial for the two devices (smart glasses/phone and computer) to communicate via WebRTC over the local Wi-Fi network.

Render Streaming

Render Streaming Settings Asset: Assets/RenderStreamingSettings.asset

Automatic Streaming: ☐

Signaling Type: WebSocket

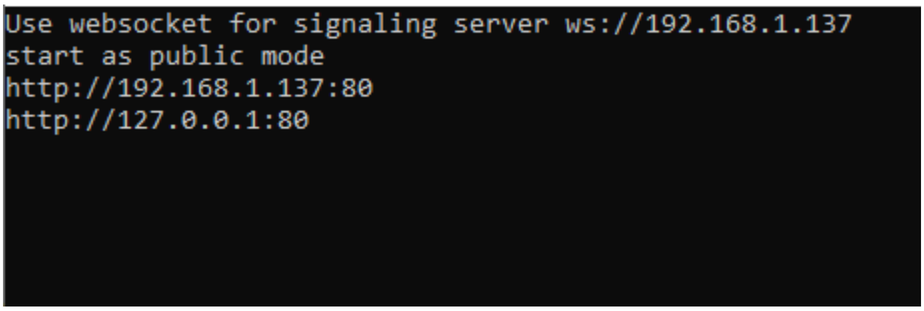
URL: ws://192.168.1.137:80

Figure 5.18: RenderStreaming Settings

Establishing the Connection using Webserver

The Unity Render Streaming package includes a webserver that allows the devices to connect via Wi-Fi. Once the webserver is launched, both devices can connect and establish a real-time video and data streaming connection.

After the connection is established, the professional can view the real-time video feed and interact with the AR scene through inputs that are sent back to the smart glasses/phone, enabling collaborative tasks.



```
Use websocket for signaling server ws://192.168.1.137
start as public mode
http://192.168.1.137:80
http://127.0.0.1:80
```

Figure 5.19: Start of the WebServer

5.2 Presentation of the Application

The following section demonstrates the key components of the AR remote collaboration system, providing a detailed look at the user interface, interactive elements, and core functionalities. Each feature, from object manipulation to drawing annotations, is visually explained using screenshots taken from the application interface. The collaboration between the smartphone user and the remote professional is highlighted, showcasing how the system enables real-time guidance and object placement in the AR environment.

5.2.1 User Interface and Interaction in the Unity Environment

In this section, we showcase the user interface elements and interaction modes as they are set up inside the Unity environment for each scene.

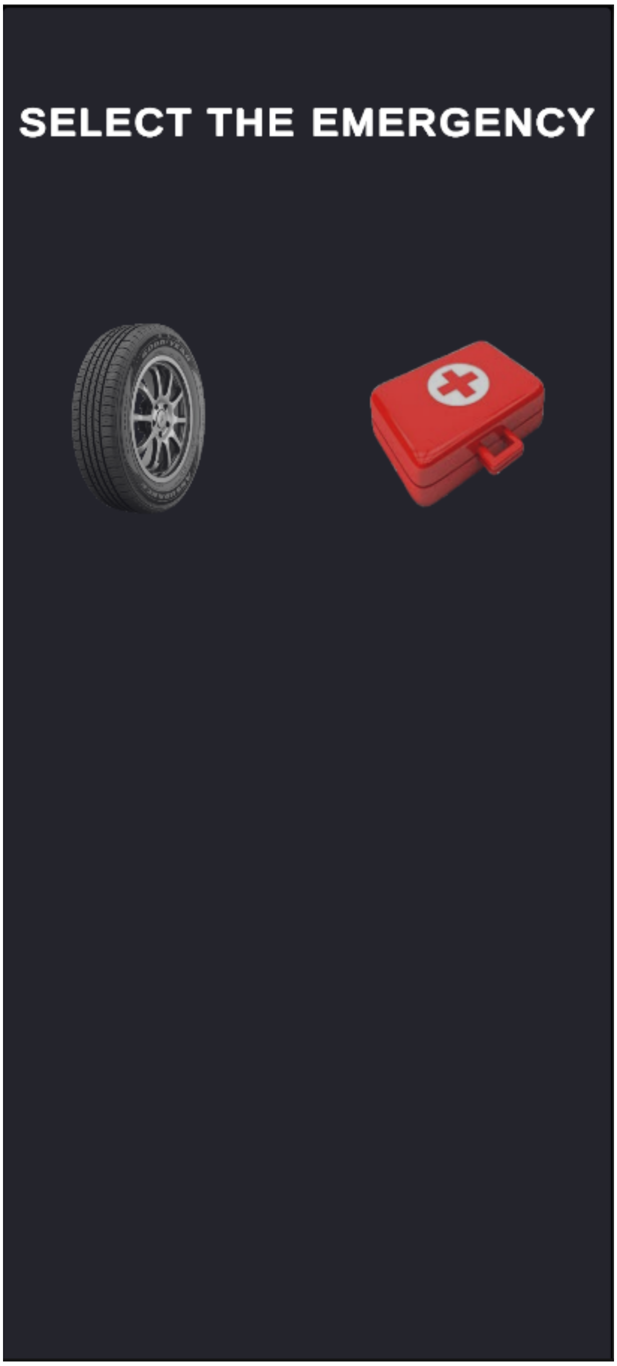


Figure 5.20: MainMenu Scene

Overview of Main Menu Scene

Before the professional and the smart glasses/smartphone user can begin collaborating the MainMenu Scene allows the user to selected between the two use cases.

The interface contains two buttons:
TireChange Button: This button displays a tire icon .When clicked the Tire Change Scene loads.
FirstAidKit Button: This button displays a first aid kit icon .When clicked the FirstAidKit Scene loads.

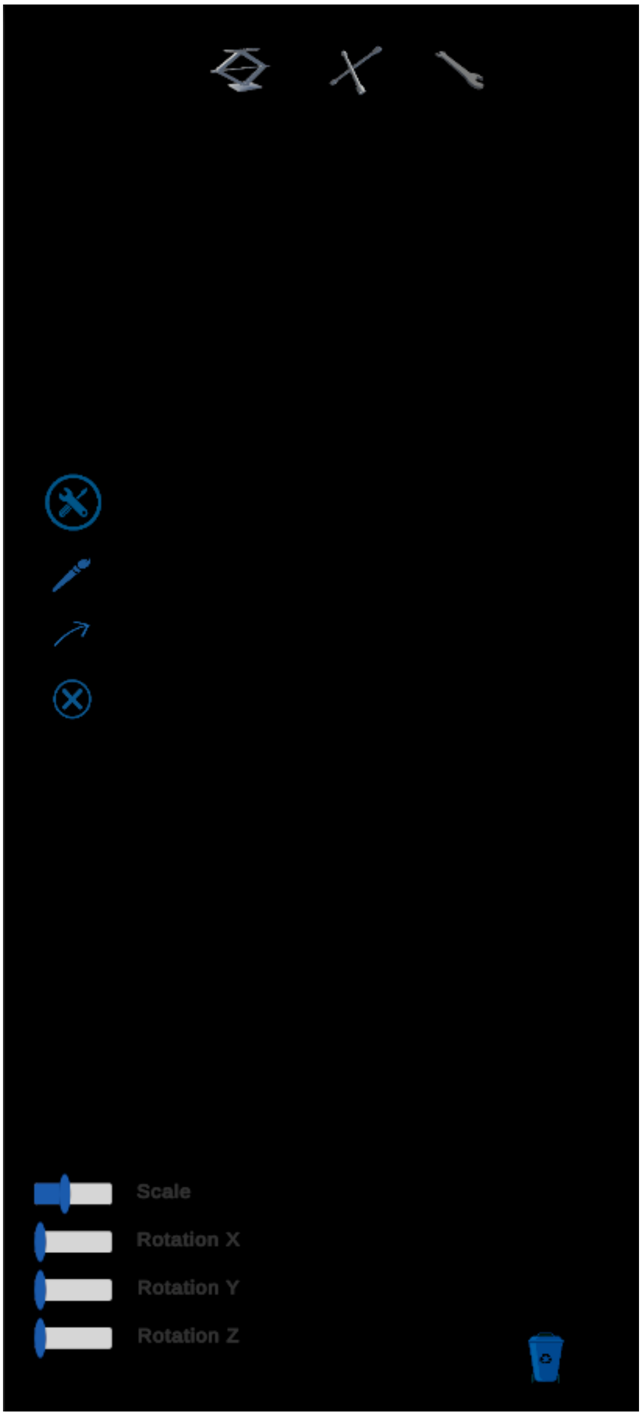


Figure 5.21: TireChange Scene

Overview of the TireChange Scene

The image on the left shows the primary user interface elements as seen within the Unity environment. These components are critical for enabling interaction in the AR space, allowing the professional to spawn and manipulate 3D objects, draw annotations and control the scene through the interface.

Toggles

On the middle and left side of the UI we see the four toggle buttons:Tools toggle(Selected),Drawing Toggle,Arrow Toggle ,No interaction Toggle.

3D Tools Buttons

At the top center of the screen, there are three buttons representing different 3D tools. Clicking on any of these buttons spawns the respective 3D tool into the AR scene. The tools are visible only when the Tools toggle is selected.

Sliders For Object Manipulation

On the bottom left of the screen, there are four sliders:

- Scale Slider: Adjusts the size of the 3D tool.
- Rotation X: Rotates the object along the X-axis
- Rotation Y: Rotates the object along the Y-axis
- Rotation Z: Rotates the object along the Z-axis

Delete Button

On the bottom of the screen, we see a delete button(represented by a recycle bin icon). This button is used to remove 3D tools or other objects from the scene. The delete function is context-specific, meaning it will only delete objects from the active toggle mode.

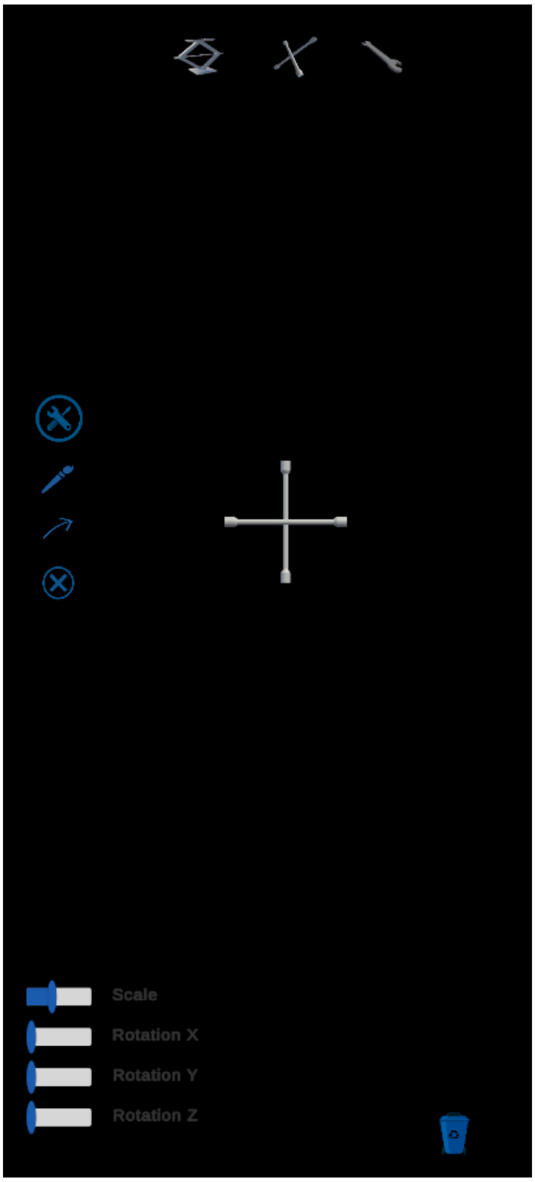


Figure 5.22: ToolToggle with 3D tool spawned

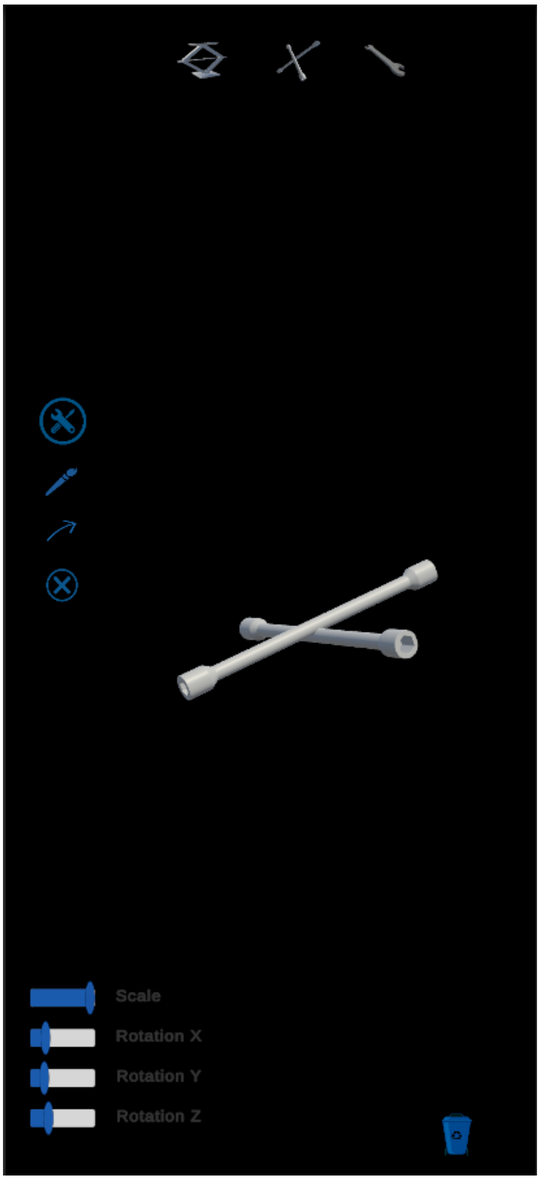


Figure 5.23: ToolToggle with 3D tool spawned scaled & rotated

Spawning and Manipulating 3D Tools

Once the Tools Toggle is selected the professional can spawn a 3D tool in the AR scene by clicking on one of the icons at the top of the screen. Figure 5.22 shows an example of a tool spawned in the center of the screen.

The spawned tool can now be manipulated using the sliders. In the figure 5.23 we can see the 3D tool scaled and rotated.

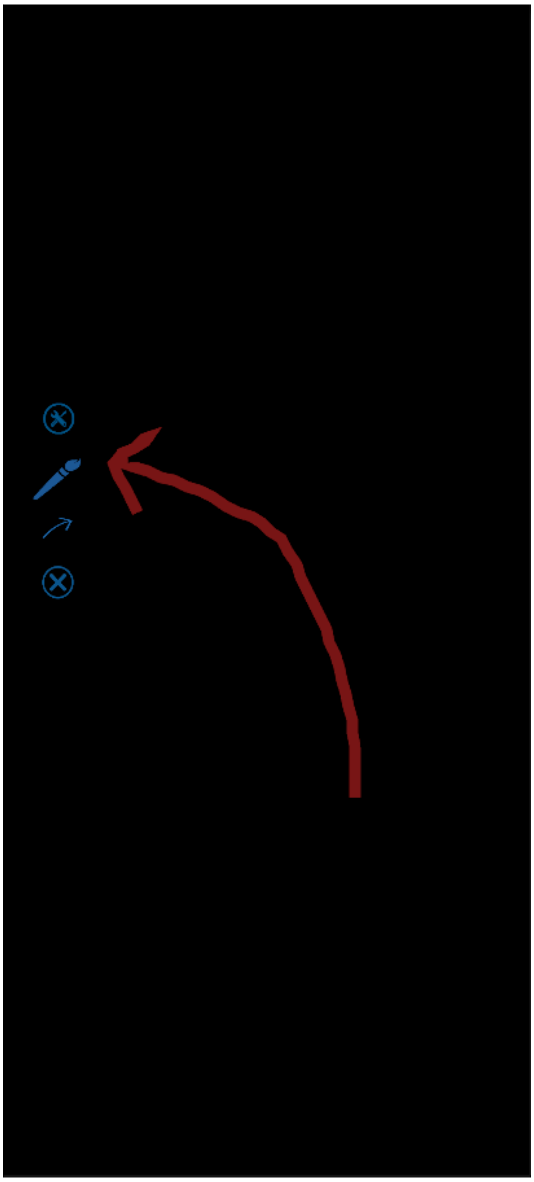


Figure 5.24: DrawingToggle with a drawing

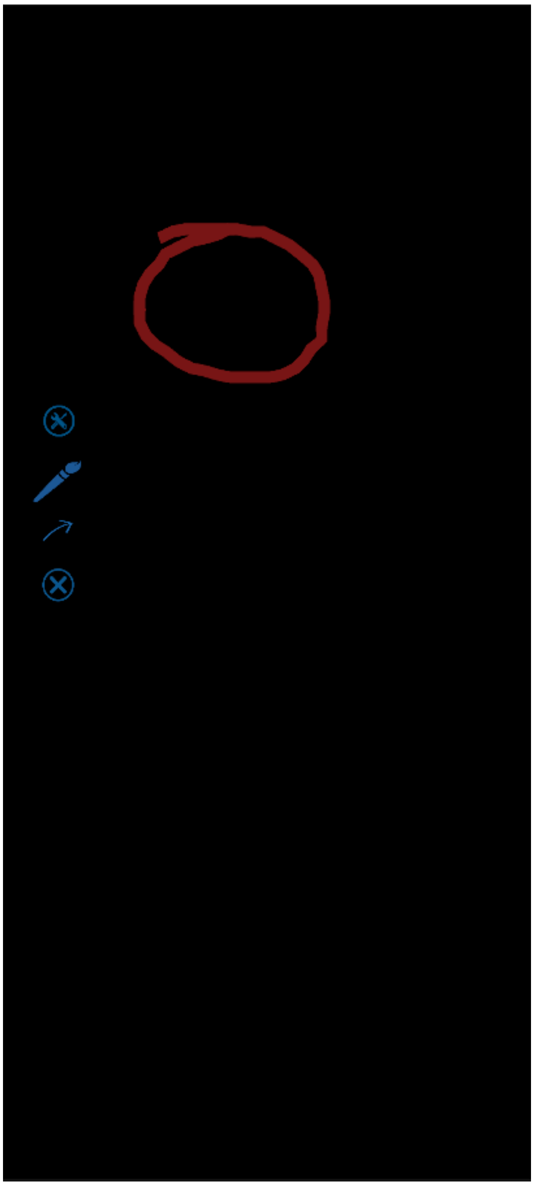


Figure 5.25: DrawingToggle with a drawing

Drawing

Once the Drawing toggle is selected the icon becomes bigger than the other toggle buttons. The professional starts drawing by clicking and dragging on the screen.

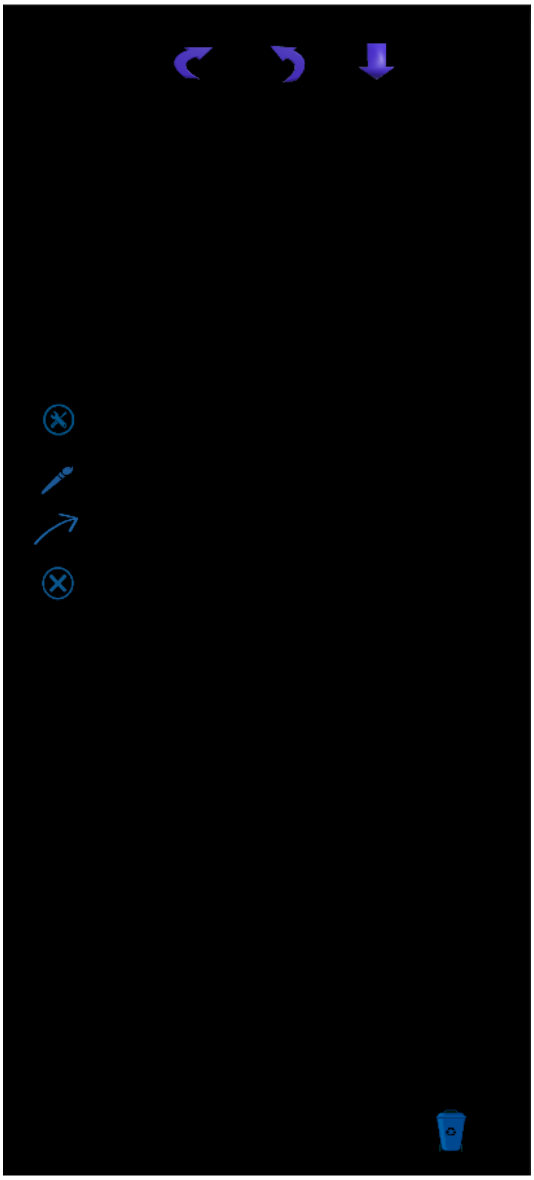


Figure 5.26: ArrowToggle

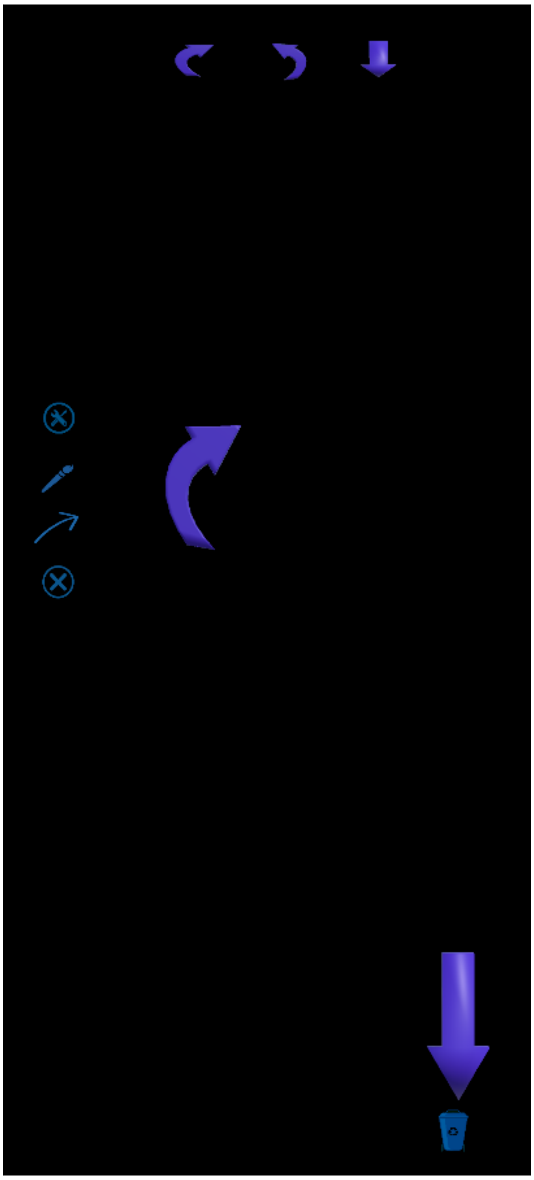


Figure 5.27: ArrowToggle with two arrows spawned

Spawning and Manipulating Arrows

Just like the Tools toggle, when the Arrow toggle is selected the professional can spawn an Arrow in the AR scene by clicking on one of the icons on the top of the screen. Figure 5.26 shows how the Arrow toggle appears when is selected, and the figure 5.27 shows two arrows spawned in the scene and moved.

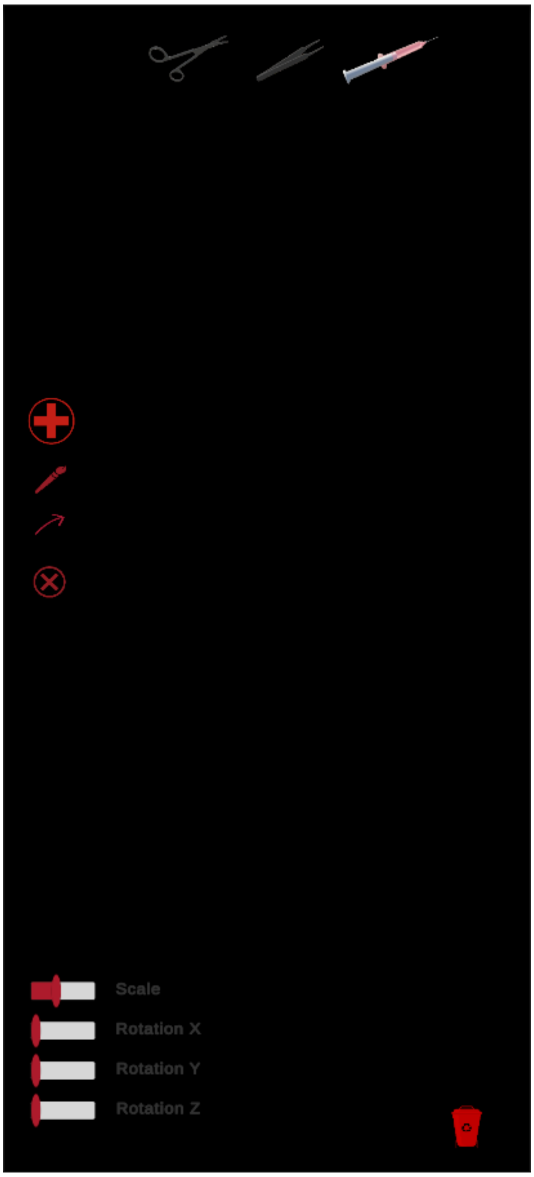


Figure 5.28: FirstAidKit Scene

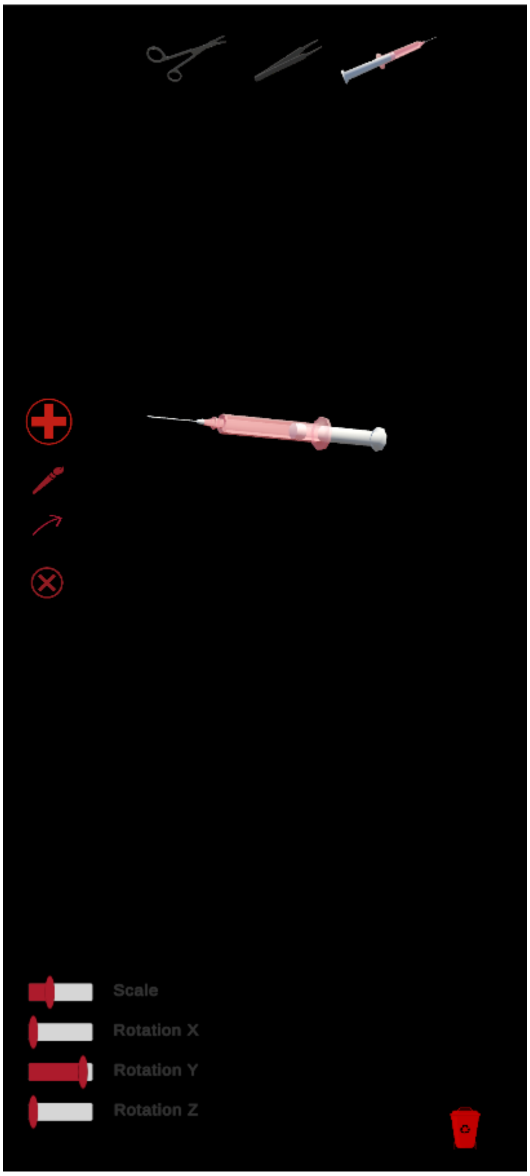


Figure 5.29: FirstAidKit Scene with 3D tool spawned

Overview of FirstAidKit Scene

The figure 5.28 shows the FirstAidKit Scene,it has exactly the same structure as the TireChange Scene,except the 3D tools on the top of the screen and the red colour on the UI.

The second figure 5.29 shows a 3D syringe spawned in the FirstAidKit scene.

5.2.2 Real-Time Connection Between Devices

This section demonstrates the real-time synchronization between the computer and the smart glasses/smartphone. The professional’s actions are instantly mirrored on the smartphone .

In Figure 5.30, we can observe the smartphone’s screen displaying the live feed from the computer, demonstrating the real-time connection between the two devices. This illustrates the synchronized interaction between the smartphone and the computer.

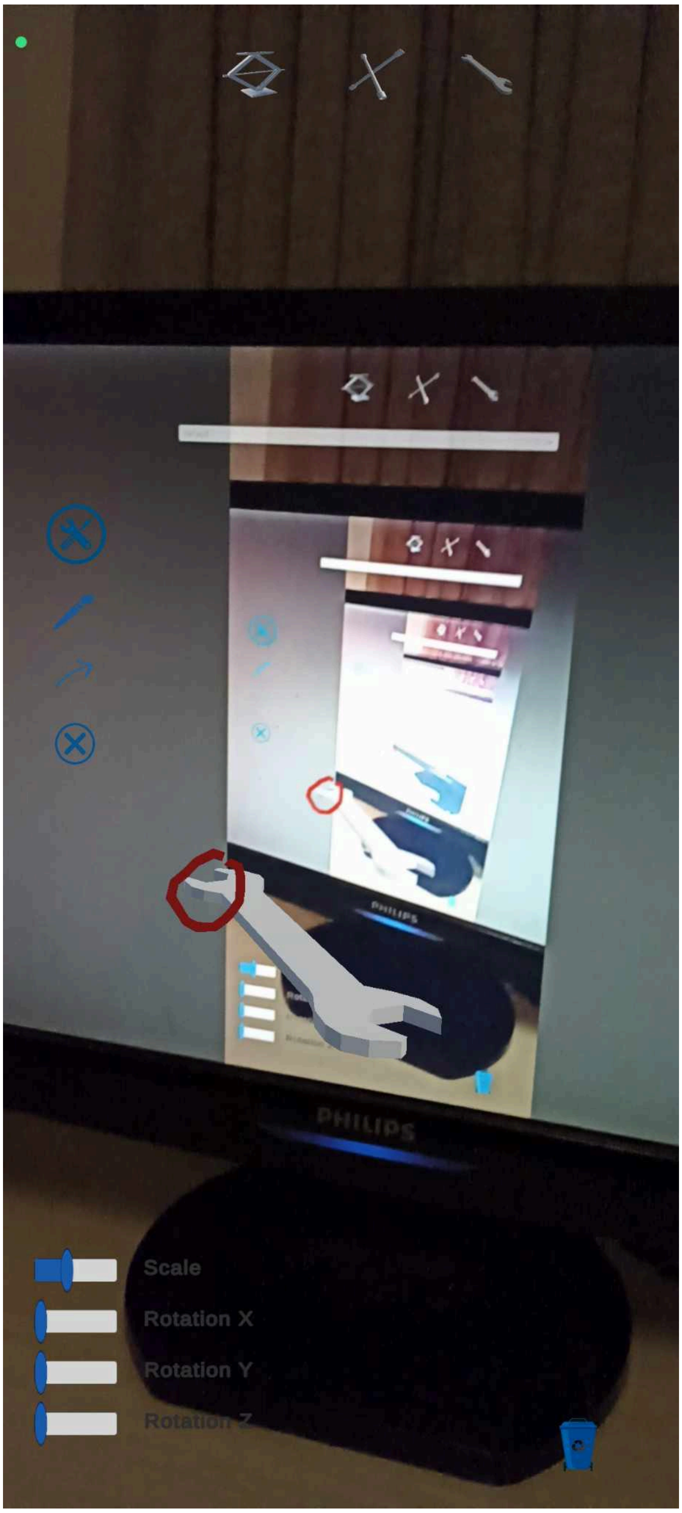


Figure 5.30: View of SmartPhone and Computer

5.2.3 Real-World Example of the Application in Use: Changing a Tire

In this section, we showcase how the AR remote collaboration system assists in guiding a user through the process of changing a car tire. By using a combination of 3D objects, arrows, and drawings, the professional can provide real-time visual instructions to the user. Below, we walk through the steps of the tire-changing process, demonstrating both the AR overlay on the smartphone and the corresponding actions on the real car.

Slacking the Bolts with the Lug-Wrench

Figure 5.31: 3D Lug-Wrench

Figure 5.32: 3D Lug-Wrench with curved arrow

In this step as we can see in the figure 5.31, the professional places a 3D model of a lug-wrench onto the bolt of the car tire, showing the user where to position the real wrench. This visual guide helps the user to align the tool correctly before slacking the bolts.

Then to guide the user further the professional places an arrow indicating the direction in which the lug-wrench should be turned to slacken the bolt.

Figure 5.33: Real Lug-Wrench with arrow

In the figure 5.33 the user place the real lug-wrench attached to the bolt,with the AR curved arrow providing clear guidance for turning the wrench.

Positioning the Car Jack

Figure 5.34: Highlighting with a drawing

Next, the professional uses the Drawing Toggle to draw a circle, highlighting where the car jack needs to be positioned under the car. This helps the user identify the correct point of attachment for the jack.

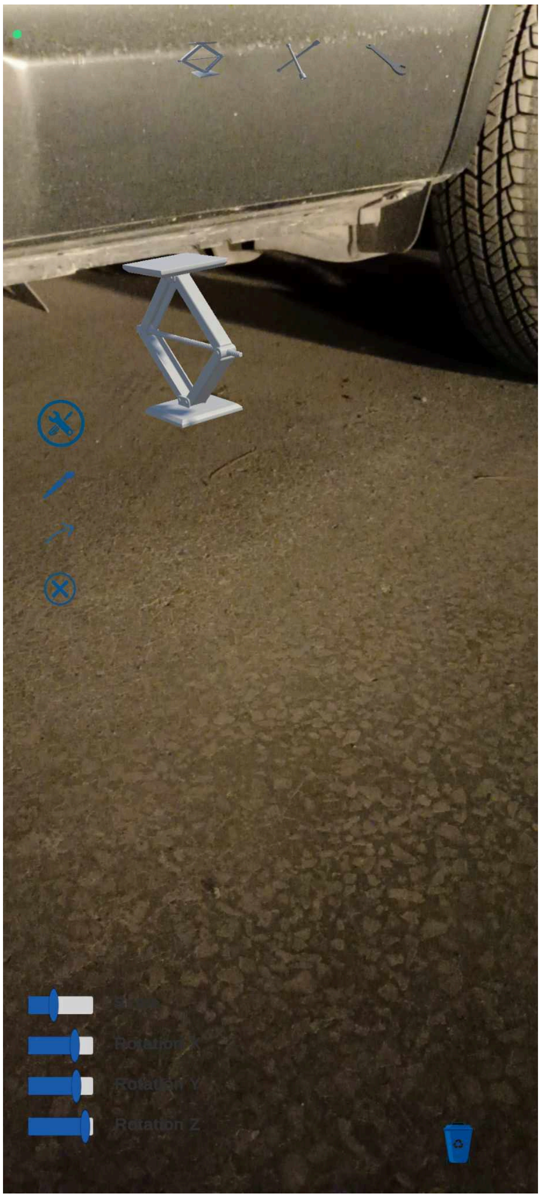


Figure 5.35: 3D Car Jack

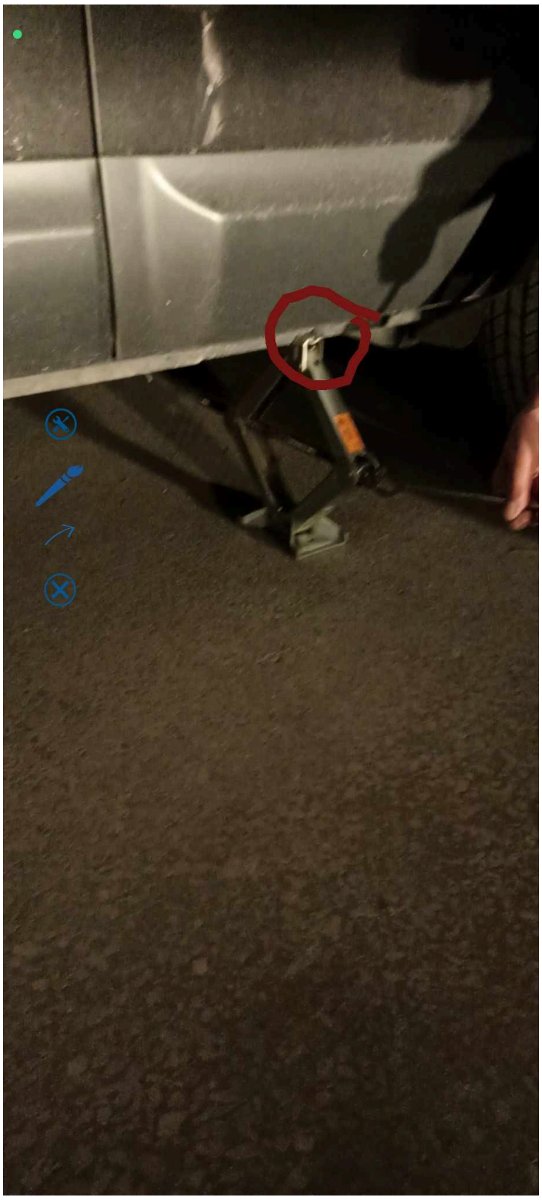


Figure 5.36:Real Car Jack Highlighted

To ensure accuracy, the professional in the figure 5.35 also places a 3D model of the car jack in the correct position on the screen. This allows the user to match the position of the real jack with the AR guidance.

In figure 5.36 the professional highlights again the spot where the car jack has to be positioned and the user positions the car jack.

Unscrewing the Bolts and Replacing the Tire

For this step we are going to use again the figure 5.33. The user now has to completely unscrew the bolts the same way he did the slacking before.

Tightening the Bolts on the New Tire

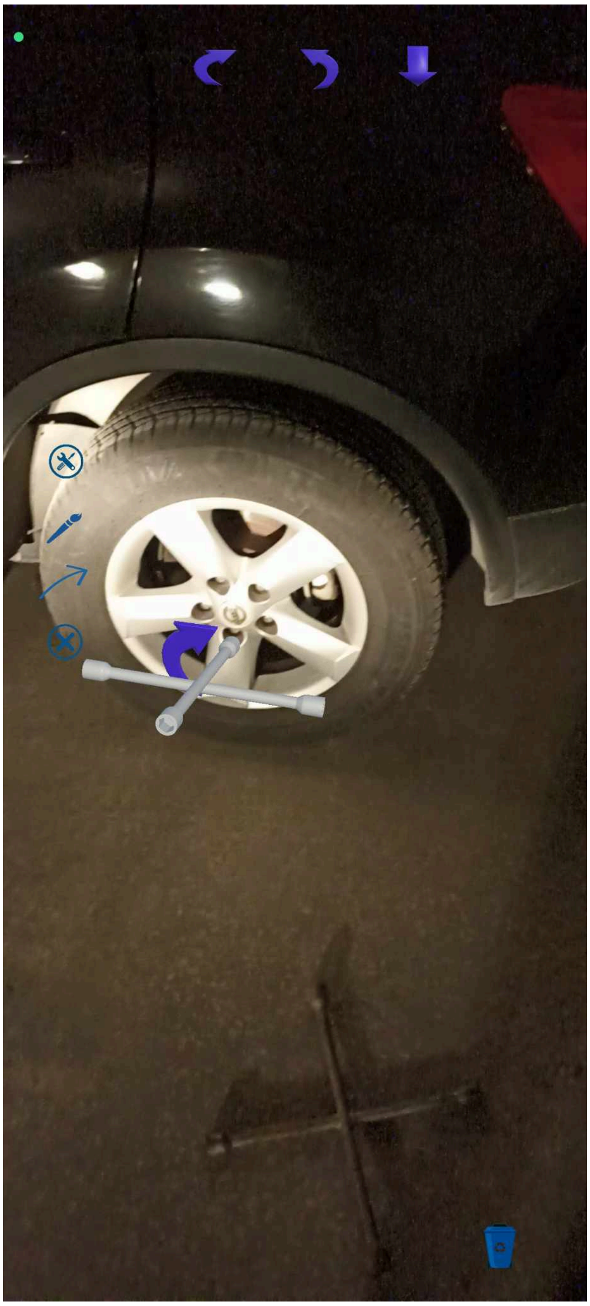


Figure 5.37: 3D Lug-Wrench with opposite direction arrow

Finally, after the new tire has been placed, the professional shows how to use the 3D lug-wrench to tighten the bolts. The arrow now points in the opposite direction to indicate tightening.

This section illustrates how the application provides step-by-step ,real time visual guidance using AR elements to support the user in performing a tire change.

6 CONCLUSIONS AND FUTURE WORK

This thesis demonstrates the significant potential of augmented reality (AR) in enhancing remote collaboration, particularly in the context of automotive emergencies, through the use of smart glasses/smartphone technology. The development of a functional prototype using the Unity platform highlights how AR can be applied in real-time remote assistance scenarios, offering a practical solution to communication challenges when physical presence is not feasible.

This system effectively reduces the barriers of physical distance, allowing remote professionals to provide detailed, context-specific instructions that users can follow with ease. The visual overlays eliminate much of the miscommunication that can arise during traditional forms of remote collaboration, where guidance is often provided verbally or through handheld devices. The direct mapping of AR information onto the user's environment ensures a more accurate understanding of the tasks at hand, enhancing both the efficiency and accuracy of remote assistance.

A key achievement of this thesis is proving that the technology works effectively in real-life situations, such as changing a tire or giving first aid. The implementation showed how useful AR can be in helping users complete tasks that need both hands-on skills and clear instructions. This example highlights how AR can be valuable in urgent situations where immediate guidance is important. While this project focused on automotive emergencies, the results suggest that similar methods could be used in other areas where real-time, remote assistance can make a big difference.

However, the development process uncovered several challenges that must be addressed in future iterations. Ensuring reliable communication and minimizing latency are critical in real-time remote assistance applications, as any delays can disrupt the flow of guidance and hinder the user’s ability to complete tasks efficiently. Additionally, creating an intuitive user interface for smart glasses remains a challenge, as users must interact with AR elements seamlessly without being overwhelmed by the technology. While the current implementation successfully tackled many of these issues, there is still room for improvement in making the system more robust, particularly in environments with variable network conditions. Beyond its immediate application in automotive emergencies, this thesis suggests that AR, when combined with smart glasses, has the potential to transform various industries where remote collaboration is essential. The ability to provide hands-free, real-time assistance opens new possibilities for innovation in different fields significantly enhancing productivity and efficiency .

Moving forward, there are several promising ways to expand and improve the current system. One important area is integrating the application with smart glasses, which couldn't be fully done because of hardware limitations. Using the system on more advanced smart glasses would give users a completely hands-free experience.

Another key improvement is switching from a local Wi-Fi connection to a global system using a dedicated server. Hosting the application on a server would allow devices to connect from anywhere in the world, making remote collaboration possible even when the user and the expert are in different locations. This would make the system more flexible and available for a wider range of scenarios.

Further enhancements could include adding QR code functionality to the first aid kit use case. By scanning QR codes on items like pill bottles, the system could instantly show important information, such as dosage instructions or warnings. This would give users quick access to necessary details during emergency situations, adding an extra level of guidance.

Additionally, the system could be improved by adding hand animations that show users how to perform key tasks. For example, the application could demonstrate how to apply ointment, place a bandage, or complete other steps with clear visual aids. This would make the instructions easier to understand, especially for tasks that are more complex or delicate.

The system could also be expanded to handle other types of automotive emergencies, not just tire changes and first aid. For example, it could provide instructions for addressing mechanical issues like diagnosing engine problems or fixing minor faults. This would make the system more versatile and helpful in a wider range of car troubles.
IoT (Internet of Things) devices could be integrated into the system to provide real-time data to the professional. For instance, thermometers or other sensors could connect to the application, delivering live information on engine temperatures during diagnostics. In the first aid scenario, IoT devices could monitor the patient's heart rate or other vital signs, giving the remote professional a better understanding of the situation and allowing them to offer more accurate guidance.

Integrating artificial intelligence (AI) into the system could greatly improve its functionality. AI could be used to recognize objects like tires or body parts, automatically placing AR elements like tools or medical equipment in the right spots. Speech recognition would allow the expert to give voice commands, making interaction faster and more natural, while gesture recognition would let users interact with virtual objects or use gestures to communicate with the professional and utilize the UI through simple hand movements. These AI features would make collaboration between the user and the remote expert smoother, quicker, and more accurate.

In addition to helping with remote collaboration, AI could also be used to create a system where the user doesn’t need an expert at all. In this case, the application would scan the environment and use AI to give real-time feedback and instructions based on what it detects. For example, if the application recognizes a flat tire, it could guide the user through the tire-changing process without any help from a professional. Similarly, in a first aid scenario, the system could detect an injury and provide step-by-step instructions for treatment, including helpful visuals and advice.
By turning the system into a fully AI-driven solution, the application would be able to assist users on its own, providing immediate help in situations where a remote expert might not be available. This would greatly increase the system's flexibility and usefulness, making it valuable for both expert-assisted and independent use.

In conclusion, using AR,MR, AI, and IoT in remote assistance systems has great potential to make difficult tasks to become easier and more efficient in important situations like car emergencies. As these technologies keep improving, the system from this project could be useful not just for cars, but in many different areas, helping experts guide people who need assistance from a remote distance.

Bibliography -References -Internet Sources

[1] Z. Makhataeva and H. A. Varol, Augmented reality for robotics: A review, 2020, p. 21.

[2] S. Ahmed, «Management, A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project,» 2019.

[3] K. Kim, M. Billinghurst, G. Bruder, H. B.-L. Duh, and G. F. Welch, «Revisiting trends in augmented reality research: A review of the 2nd decade of ISMAR (2008–2017),» *EEE Transactions on Visualization and Computer Graphics,* vol. 24, no. 11, pp. 2947-296, 2018.

[4] Abdullah M. Al-Ansi a Mohammed Jaboob, «Analyzing augmented reality (AR) and virtual reality (VR) recent development in education,» *Social Sciences & Humanities Open,* vol. 8, no. 1, p. 10, 2023.

[5] Leonor Adriana Cárdenas-Robledo Óscar Hernández-Uribe Carolina Reta Jose Antonio Cantoral-Ceballos , «Extended reality applications in industry 4.0. – A systematic literature review,» *Telematics and Informatics,* vol. 73, 2022.

[6] Hamad, Ayah ; Bochen Jia, «How Virtual Reality Technology Has Changed Our Lives: An Overview of the Current and Potential Applications and Limitations,» *International Journal of Environmental Research and Public Health,* vol. 19, 2022.

[7] A. B. Craig, «What Is Augmented Reality?,» in *Understanding Augmented Reality*, 2013, pp. 1-37.

[8] D. Ramoliya, «Improvisation in Spinal Surgery Using AR (Augmented Reality), MR (Mixed Reality), and VR (Virtual Reality),» σε *RAiSE-2023*, 2024.

[9] Rusnida Romli; Amir Firdhaus Razali1; Nur Hafizah Ghazali; Nik Adilah Hanin; Siti Zuraidah Ibrahim, «Mobile Augmented Reality (AR) Marker-based for,» in *1st International Symposium on Engineering and Technology*, 2020.

[10] Carlos E. Mendoza-Ramírez Juan C. Tudon-Martinez Luis C. Félix-Herrán Jorge de J. Lozoya-Santos Adriana Vargas-Martínez, «Augmented Reality: Survey,» *Virtual/Augmented Reality and Its Applications,* 2023.

[11] Arvind Ramtohul; Kavi K. Khedo, «Location-Based Mobile Augmented Reality Systems: A Systematic Review,» in *Immersive Technology in Smart Cities, Augmented and Virtual Reality in IoT*, 2021, pp. 41-65.

[12] A. Stork, O. Bimber and R. d. Amicis, «Projection-based Augmented Reality in Engineering Applications,» *Corporate Engineering Research,* 2002.

[13] Shuran Zheng; Jinling Wang; Chris Rizos; Weidong Ding; Ahmed El-Mowafy, «Simultaneous Localization and Mapping (SLAM) for Autonomous Driving: Concept and Analysis,» *Advanced Technologies for Position and Navigation under GNSS Signal Challenging or Denied Environments,* 2023.

[14] M. H. R. J. S. C. N. G. F. D. C. A. Venkatesan M, «Virtual and augmented reality for biomedical applications,» *Cell Rep Med,* 2021.

[15] Jacky Cao; Kit Yung; Lam Lik-Hang Lee; Xiaoli Liu, «Mobile Augmented Reality: User Interfaces, Frameworks, and Intelligence,» 2021.

[16] Jeremy Hartmann; Yen-Ting Yeh; Daniel Vogel, «AAR: Augmenting a Wearable Augmented Reality Display with an Actuated Head-Mounted Projector,» in *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, USA, 2020.

[17] G. Koutromanos και G. Kazakou, «Augmented reality smart glasses use and acceptance: A literature review,» vol. 2, 2023.

[18] Z. Xu, Z. Feng, M. B. Jelodar και B. H. Guo, «Augmented reality applications in construction productivity: A systematic literature review,» *Advanced Engineering Informatics,* vol. 62, 2024.

[19] «Unity,» [Online]. Available: https://unity.com/. [Accessed 06 08 2024].

[20] «Unreal Engine,» [Online]. Available: https://www.unrealengine.com/en-US. [Accessed 10 09 2024].

[21] «Godot,» [Online]. Available: https://forum.godotengine.org/. [Accessed 10 09 2024].

[22] Yasemin Bal; Nazlı Ece Bulgur, «Remote Work: A Paradigm Shift in the Modern Workplace and Its Impact on the Workforce,» in *Enhancing Employee Engagement and Productivity in the Post-Pandemic Multigenerational Workforce*, 2023, pp. 374-391.

[23] S. Haque, «THE IMPACT OF REMOTE WORK ON HR PRACTICES: NAVIGATING CHALLENGES, EMBRACING OPPORTUNITIES,» *European Journal of Human Resource Management Studies ,* 2023.

[24] He, Peng Wang Xiaoliang Bai Mark Billinghurst Shusheng Zhang Xiangyu Zhang Shuxia Wang Weiping, «AR/MR Remote Collaboration on Physical Tasks: A Review,» vol. 72, 2021.

[25] Oluwawapelumi Ola; Ebernezer Toba Adaramola; Bernice Oluwalanu Sanusi, «COMMUNICATION CHALLENGES AND STRATEGIES IN REMOTE WORK SETTINGS,» *International Journal of Management, Social Sciences, Peace and Conflict Studies (IJMSSPCS),,* vol. 6, no. 3, pp. 75-86, 2023.

[26] R. Azuma, «Location-Based Mixed and Augmented Reality Storytelling,» in *d Edition of Fundamentals of Wearable Computers and Augmented Reality*, 2 ed., W. Barfield, Ed., CRC Press, 2015, pp. 259-276.

[27] Augustus J. Rush, III; Nicholas Shepard; Michael Nolte; Krzysztof Siemionow; Frank Phillips, «Augmented Reality in Spine Surgery: Current State of the Art,» *Int J Spine Surg,* p. 22–S27, 2022.

[28] Michael H Kurniawan; Suharjito; Diana; Gunawan Witjaksono, «Human Anatomy Learning Systems Using Augmented Reality on Mobile Application,» in *3rd International Conference on Computer Science and Computational Intelligence 2018*, Jakarta, Indonesia 11480, 2018.

[29] P.-Y. Hsu, J. Singer and J. J. Keysor, «The evolution of augmented reality to augment physical therapy: A scoping review,» *Journal of Rehabilitation and Assistive Technologies Engineering ,* vol. 11, pp. 1-16, 2024.

[30] Dinh, Alana; Yin, Andrew Lukas; Estrin, Deborah; Greenwald, Peter; Fortenko, Alexander, «Augmented Reality in Real-time Telemedicine and Telementoring: Scoping Review,» *JMIR Mhealth Uhealth,* 2023.

[31] D. Kamińska, G. Zwoliński, A. Laska-Leśniewicz and R. Raposo, «Augmented Reality: Current and New Trends in Education,» 2023.

[32] M. B. Ibáñez and C. Delgado-Kloos, «Augmented reality for STEM learning: A systematic review,» *Computers & Education ,* vol. 123, 2018.

[33] Nesse van der Meer, Vivian van der Werf, Willem-Paul Brinkman, Marcus Specht1, «Virtual reality and collaborative learning: a systematic literature review,» *Virtual Reality and Human Behaviour,* vol. 4, 2023.

[34] Y. Koumpouros, «Revealing the true potential and prospects of augmented reality in education,» *Smart Learning Environments,* vol. 2, p. 11, 2024.

[35] Emanuele Marino, Loris Barbieri, Fabio Bruno, Maurizio Muzzupappa, «Assessing user performance in augmented reality assembly guidance for industry 4.0 operators,» *Computers in Industry,* vol. Volumes 157–158, 2024.

[36] David Breitkreuz; Maike Müller; Dirk Stegelmeyer; Rakesh Mishra, «Augmented Reality Remote Maintenance in Industry: A Systematic Literature Review,» in *XR Salento 2022, Lecture Notes in Computer Science*, Salento, Italy, 2022.

[37] Rupert Reif; Willibald A. Günthner, «Pick-by-vision: augmented reality supported order picking,» *The Visual Computer ,* vol. 25, pp. 461-467, 2009.

[38] Dušan Tatić; Bojan Tešić, «The application of augmented reality technologies for the improvement of occupational safety in an industrial environment,» *Computers in Industry,* vol. 85, pp. 1-10, 2017.

[39] Andrzej Szajna; Roman. Stryjski; Waldemar Woźniak; Norbert Chamier-Gliszczyński , «The Production Quality Control Process, Enhanced with Augmented Reality Glasses and the New Generation Computing Support System,» *Procedia Computer Science ,* vol. 176, 2020.

[40] D. Pickman, "The Use of Virtual Reality and Augmented Reality in Enhancing the Sports Viewing Experience," *International Journal of Arts Recreation and Sports,* vol. 1, pp. 39-49, 2023.

[41] Melanie Fernandes; Nicole Mallmann; Nicole Mallmann, «The Rise of Augmented Reality in Live Music Events: The Cases of Snapchat and Gorillaz,» *Business Communication Research and Practice ,* vol. 7, pp. 58-63, 2024.

[42] L. Jingjing, W. Wider, Y. Ochiai and M. A. Fauzi, «A bibliometric analysis of immersive technology in museum exhibitions: exploring user experience,» *Frontiers in Virtual Reality,* vol. 4, 2023.

[43] M. Ladunca, «New artistic experiences in the age of digital technologies,» in *THE IMPACT OF NEW TECHNOLOGIES IN CONTEMPORARY VISUAL ARTS*, Romania, Cluj-Napoca, 2024.

[44] K. Y. Thakkar, B. B. Joshi and P. Kachhela, «Consumer engagement with augmented reality (AR) in marketing: Exploring the use of ar technology in marketing campaigns and its impact on consumer engagement, brand experiences, and purchase decisions,» *Journal of Management Research and Analysis ,* vol. 10, pp. 99-105, 2023.

[45] J. M. D. Delgado, L. Oyedele, P. Demian and T. Beach, «A research agenda for augmented and virtual reality in architecture, engineering and construction,» *Advanced Engineering Informatics,* vol. 45, 2020.

[46] Zhidong Xu; Zhenan Feng; Mostafa Babaeian Jelodar; Brian H.W. Guo, «Augmented reality applications in construction productivity: A systematic literature review,» *Advanced Engineering Informatics,* vol. 62, 2024.

[47] H. Alavi, N. Forcada, S.-L. Fan and W. Ong, «BIM-based Augmented Reality for Facility Maintenance Management,» *Proceedings of the 2021 European Conference for Computing in Construction,* 2021.

[48] Zahrizan Bin Zakaria; M.A. Omardin; Rahimi A. Rahman; A.T. Haron, «Barriers to augmented reality application in construction: an exploratory study in Malaysia,» 2022.