Gaze-driven, Head-Worn Augmented Reality System for Firefighters in both Urban and Wild Fire Operations with the use of Thermal Imaging and Android Data

Theodoros Chalimas

Thesis Committee

Professor Katerina Mania

Professor Costas Balas

Professor Michail G. Lagoudakis

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Abstract

Despite recent advancements in technology and organizational measures, firefighting remains a perilous profession. To enhance safety and operational efficiency during firefighting operations, there has been a growing exploration of integrating sensors and technical systems. One notable technological advancement in this field is the utilization of augmented reality (AR) technology. AR technology has emerged as a promising tool for firefighters, offering various capabilities to augment their performance. By leveraging modern augmented reality head-mounted displays, equipped with an array of sensors, firefighters can gain enhanced situational awareness by sensing and understanding the environment around them.

This thesis introduces two systems developed using the Unity development engine, targeting distinct firefighting scenarios. The first system addresses fire and rescue operations, where thick smoke poses a significant challenge. By integrating a heat-wavelength infrared camera with the Microsoft HoloLens 2, thermal data can be streamed directly to the operator's field of view, enhancing their perception in smoke-filled environments. Unlike conventional handheld thermal cameras, this approach maintains the operator's ability to use their hands effectively.

The second system focuses on wildfire situations, enabling live tracking of each firefighting team member and displaying their locations on a 3D map, accessible remotely on a computer. Moreover, an augmented reality headset provides the team captain on the field with intuitive visual signals about their teams location. This setup facilitates real-time location representation of all members for both the team captain and those operating remotely, such as personnel in offices or headquarters.

By leveraging the advancements in AR technology and addressing the need for seamless communication, the proposed systems aim to augment firefighters' capabilities, improving their safety and operational effectiveness in challenging firefighting situations.

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Introduction

1.1 Motivation

Firefighters play a vital role in safeguarding lives, protecting property, and mitigating the devastating impacts of fires. As frontline responders to emergency situations, they face immense challenges and risks. In order to enhance their operational efficiency and maximize their effectiveness, it is crucial to equip firefighters with a comprehensive array of tools and provide them with the necessary support.

In 2021 alone the Hellenic Fire Service reported 9514 wildfire cases and 56699 urban operation events of which 19379 were urban fires [1]. In the last decade there have been multiple wildfires that have shocked the Nation with the most memorable ones in Mati Attica Greece in 2018 where 103 people lost their lives and 2021 where, after a historic heatwave for the country [2], 125.000 hectares of forest and arable land were burnt with over 50000 hectares burnt in northern Euboea alone.

The diverse nature of firefighting operations necessitates a wide range of tools and equipment. Firefighters encounter varying scenarios, from structural fires to wildland fires, hazardous materials incidents, and rescues. Each situation demands specialized tools tailored to the specific challenges faced. For instance, thermal imaging cameras aid in locating individuals in smoke-filled environments, while hydraulic tools enable the extrication of trapped victims from vehicles during rescue operations. By providing firefighters with a comprehensive suite of tools, authorities can enhance their ability to respond effectively to a multitude of emergency scenarios.

The provision of adequate support systems is paramount to firefighters' operational success. This support encompasses various aspects, including training, communication networks, and logistical assistance. Comprehensive training programs ensure that firefighters possess the necessary skills and knowledge to handle complex situations safely. Additionally, reliable communication systems, such as robust radio networks and advanced mobile technologies, enable seamless coordination and information sharing among personnel in high-stress environments. Furthermore, logistical support in the form of sufficient staffing, well-maintained vehicles, and readily available supplies and resources ensures operational readiness and timely response.

Moreover, firefighters often operate under extreme conditions, exposing them to physical and psychological stress. Thus, it is imperative to prioritize the well-being and safety of these frontline responders. Providing appropriate personal protective equipment (PPE), including flame-resistant clothing, helmets, gloves, and breathing apparatus, helps safeguard firefighters from potential hazards and reduces the risk of injuries. Furthermore, access to counseling services, peer support programs, and mental health resources is essential to address the psychological toll that firefighting operations can have on individuals. By prioritizing firefighter well-being, organizations can foster a resilient workforce capable of tackling the challenges they face.

This thesis aims to prove that Augmented Reality (AR) technology in combination with a communications network can assist the firefighters efforts in both urban and wildfire operations.

1.2 Brief Description

Rapid development of future technologies, such as Augmented Reality (AR) and Virtual Reality (VR) has enabled the creation of new and motivating tools based on these interactive technologies . Virtual Reality (VR) is gradually finding its way into firefighting training as it proves to be effective for simulation purposes [3],[4]. However, its practicality is limited by the inherent drawback of obstructing the operator's field of vision in real-world scenarios. Augmented Reality (AR) in turn is a technology that allows computer generated virtual imagery to exactly overlay physical objects in real time [5].This way, AR can superimpose layers of digital content to a real-world environment. This

feature is incredibly important in fire and rescue operations, where reliable and continuous communication between teams and individuals is crucial, even though it can become overwhelming in extreme situations. By leveraging AR technology, firefighters can have access to critical information and situational awareness while keeping their focus on the surroundings and tasks at hand.

Thermal Imaging Cameras (TIC) significantly improves the efficiency and safety of fire and rescue operations by providing crucial insights into heat sources and aiding in the rescue of trapped individuals [6]. Firefighters have incorporated TIC in a lot of their operations [7] mostly through hand held cameras that limit their hand movements. One other technology that is widely used in fire and rescue operations is GPS tracking. GPS tracking is highly valuable in fire and rescue operations due to its ability to provide precise location information. GPS tracking provides real-time situational awareness, allowing incident commanders to monitor the location of their teams and make informed decisions. It helps maintain personnel accountability, ensuring the safety of all team members during large-scale operations [8]. Additionally, GPS tracking data serves as valuable documentation for incident analysis, evaluating strategies and improving future response planning [9].

This thesis presents the implementation of two systems, namely **Thermal Imaging System** and **Live Tracking System**, with the use of AR technology. Thermal imaging and GPS Live Tracking hold significant potential in advancing the objectives of fire and rescue operations. The integration of these technologies into the systems is executed in a user-friendly manner, where the necessary data is displayed on an AR headset. By incorporating GPS tracking, the systems enable accurate location tracking of individual firefighters, ensuring their safety and facilitating effective team coordination. Additionally, the integration of thermal imaging provides firefighters with enhanced visibility in low-visibility conditions, enabling them to identify hotspots, victims, and potential hazards.

The **Thermal Imaging System** consists of two applications, one application runs on a laptop and another on the Hololens 2. For this system a small Thermal Imaging Camera (FLIR Lepton 3.5) was mounted on top of the Hololens 2 and it streams its content on the headsets display. Due to lack of ports on the Hololens 2 device the camera could not be connected directly to it. Therefore the camera is connected on the laptop which is responcible for streaming its content on the Hololens 2.

1. INTRODUCTION

The **Live Tracking System** consists of three applications, one application runs on a PC and acts as a server and two client applications, one for an Android smartphone and another for the Hololens 2. This system provides live tracking for the Android phones connected to the server and a visual representation of their location on the PC application. Lastly the Hololens 2 operator can see the direction and distance of every connected device in respect to them.

This thesis aim to contribute in the research needed for future development of an Augmented Reality helmet that could greatly aid in fire and rescue operations in the future. The specific contributions of this thesis include:

- Users interact with the AR interactive experience through hand gestures and gaze-based interaction, and the user interface is designed to be user-friendly and intuitive.

- The applications of each system communicate and share data, allowing for seamless integration and a comprehensive overview of the operational environment.

- The systems presented are intended for both wild fire and urban cases, addressing the diverse needs and challenges faced by firefighters in different scenarios.

- The systems increase firefighter safety through the use of individual emergency signals and location tracking, enabling rapid response and assistance in critical situations.

- The AR experience incorporates thermal vision and digital elements superimposed on the real world, providing firefighters with valuable information and enhancing their situational awareness.

Finally, the proposed systems underwent testing conducted by professional firefighters, who examined the effectiveness, strengths, and weaknesses of the systems. Following this evaluation process, the conclusions of this thesis are being deliberated upon, along with potential avenues for future work and research aimed at optimizing these systems or similar ones, ultimately improving the effectiveness and safety of fire and rescue operations.

1.3   Structure of the Thesis

Chapter 1 introduces the motivational reasons for the object of this research and a brief description of the project's purpose and contributions.

Chapter 2 analyzes the background needed in order to establish a framework for understanding the methods used to implement the systems described in this thesis. In the first sections, the protocols and services, software and hardware that are used in the implementation process of this thesis are mentioned. Next related work done using similar hardware and firefighting tools utilizing AR technology are discussed.

Chapter 3 presents the user requirements' gathering and use cases illustrating the possible interactions between the firefighters and the platforms. In this chapter the use cases in which the systems will be of service are analyzed. This chapter also offers the design of the systems presented in this thesis.

Chapter 4 describes the user experience of the systems. In this chapter the User Interface (UI) of each application is presented and its functionality explained. The chapter presents the two distinct systems implemented and the applications that encompass them. This chapter functions as a users manual of the systems and explains the user interface functionality.

Chapter 5 describes in detail the technical implementation of the systems presented in this thesis. The chapter is divided in the two distinct systems created (namely: Thermal Imaging System and Tracker System). In this chapter the software development of the applications as well as their connectivity is analyzed. The utilization of the tools presented in chapter 2 is also presented and explained.

Chapter 6 describes the Evaluation process that took place. The systems developed were tested by professional firefighters who highlighted their effectiveness.This testing is presented in two distinct sections for each system respectively. This chapter also offers the highlighted strengths and weaknesses of the proposed systems.

Chapter 7 offers a summary of the systems of this thesis as well as future work and research that can be looked into.

Chapter 2

Background/Research Overview

2.1 Introduction

This chapter provides the background necessary to establish a framework for understanding the methods used to develop and implement the systems described in this thesis.

It is also essential to study the attempts and approaches regarding firefighting and the use of AR, relative work is analyzed and presented in this chapter.

The concept of this thesis requires a specific set of network protocols and services as well as the use of some software tools and hardware to be able to function the way it was envisioned.

2.2 Protocols and Services

The following protocols and services were used in the implementation process in order to create the systems presented in this thesis.

2.2.1 Global Positioning System (GPS)

Global Positioning System (GPS) is a global navigation satellite system that provides location and time information in all weather conditions, anywhere on or near the Earth's surface. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

GPS works by using a network of satellites that orbit the Earth and transmit signals to GPS receivers on the ground. The receivers use these signals to calculate their exact position, speed, and direction. The GPS system consists of three segments: the space segment, the control segment, and the user segment. The space segment is composed of the GPS satellites, the control segment consists of ground stations that monitor and control the satellites, and the user segment is made up of the GPS receivers.

GPS is used for a wide range of applications, including navigation, geolocation, mapping, surveying, and asset tracking, among others. The system provides a high level of accuracy, with the ability to determine a location to within a few meters in some cases. GPS is also widely used in military and government applications, as well as in many civilian sectors such as agriculture, transportation, and emergency services [10].

In this thesis GPS was used in order to obtain the location of an android phone, by using the built in receiver that most smartphones have. This way the location of each member of a firefighting operation can be tracked. Tracking down every member of a firefighting operation is crucial to this thesis. By knowing the location of everyone involved, a clear picture of the unfolding of an operation can be achieved and the safety of every member is immediately increased.

2.2.2 Transmission Control Protocol (TCP)

Transmission Control Protocol (TCP) is one of the main protocols of the Internet protocol suite (TCP/IP) that is used to ensure the reliable delivery of data over a network. It is a transport layer protocol, which means it provides reliable end-to-end data transfer services to applications running on different hosts.

TCP is responsible for breaking down data into manageable packets, transmitting the packets to the recipient, and reassembling the packets into the original data at the receiving end. It also provides flow control and congestion control, which ensures that data is transmitted at a rate that the recipient can handle and prevents network overload.

TCP is widely used in many applications that require reliable data transfer, such as email, file transfers, and web browsing. It is designed to provide a reliable, error-free data transfer, even over unreliable networks. When a packet is lost or corrupted, TCP will detect the error and retransmit the packet, ensuring that the data is delivered correctly [11] [12].

In this thesis TCP was used to send packets of data between applications via Internet connection. This method was used because of the reliability it provides. Reliable communication between the platforms and applications developed is needed for the systems to exchange data and achieve the requirements set.

2.3   Software

In order to implement the systems presented in this thesis that implement the protocols mentioned above, these programming platforms and libraries are combined.

2.3.1   Unity

Unity3D (Figure 2.1) is a cross-platform game engine and integrated development environment (IDE) for building video games, simulation, and other interactive 3D content. It is a powerful tool for game development, offering a wide range of features and capabilities to help developers create high-quality, engaging games and interactive experiences. Unity3D is used to create a variety of applications, including 2D and 3D games, AR and VR experiences, educational and training simulations, architectural visualizations, and more. The engine supports a wide range of platforms, including Windows, macOS, Linux, iOS, Android, and many more.

Figure 2.1: Unity logo

With Unity3D, developers have access to a large number of built-in tools and features, such as a flexible and intuitive scripting API, physics engine, animation system, audio pipeline, and more. Additionally, the Unity Asset Store offers a wealth of resources and tools for developers, including pre-built assets, plugins, and tools to help streamline development and reduce the time and effort required to bring a project to completion [13].

In this thesis, the technical implementation of the applications created on all platforms (Windows, Android, Hololens 2) is based on the advanced libraries offered by the Unity engine, employed through C♯.

In this thesis Unity3D was used in order to implement all applications in all 3 platforms used (Windows, Android and Hololens 2).

2.3.2 Microsoft Mixed Reality Toolkit (MRTK)

Figure 2.2: Windows Mixed Reality Toolkit (MRTK) for Unity logo

Microsoft Mixed Reality Toolkit (MRTK) (Figure 2.2) is a toolkit developed by Microsoft for Unity game engine, which provides a set of components and features to accelerate the development of mixed reality applications. MRTK enables developers to create experiences for Microsoft HoloLens, Windows Mixed Reality immersive (VR) headsets, and OpenVR platform.

MRTK simplifies the process of creating mixed reality apps by providing a set of pre-built components for common interaction patterns, input handling, and spatial understanding. These components can be easily integrated into a Unity project and can be customized to meet the specific needs of a project. The toolkit also provides design guidelines and best practices for developing mixed reality experiences, ensuring a consistent and optimized user experience across different mixed reality devices [14].

In this Thesis MRTK was used in the implementation process of the Hololens applications. The integration of this toolkit in the Unity 3D project allowed for setting up the Headsets inputs and spatial understanding according to this particular applications needs.
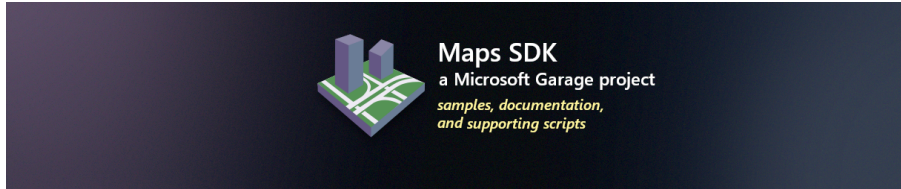
Figure 2.3: Maps SDK Logo

2.3.3 Maps SDK

The Maps SDK (Figure 2.3) for Unity is a set of tools and resources for building maps and geospatial applications using the Unity game engine. This Maps SDK is provided by Microsoft as part of its Bing Maps platform, and it allows developers to create interactive maps and 3D visualizations for games, simulations, and other applications. The Maps SDK for Unity is available on GitHub, and it provides access to a range of features and functionalities, including support for custom styles, spatial data, and advanced map controls. The Maps SDK for Unity can be used to create applications for various platforms, including iOS, Android, and Windows, and it provides a seamless way for developers to integrate maps into their Unity projects [15].

In this thesis Maps SDK was used to visualise the location data sent to the server in a 3D map. This development kit simplified the process of 3D map rendering as well as pinning the location of given coordinates on the map.

2.3.4 Android Studio

Android Studio (Figure 2.4) is an Integrated Development Environment (IDE) for building Android applications. It is the official IDE for Android app development, and it provides a comprehensive set of tools for developing, testing, and debugging Android apps.

Android Studio is used by developers to create and manage Android projects, design user interfaces, write code, and debug applications. It provides a code editor with advanced features such as syntax highlighting, code completion, and refactoring tools. Android Studio also includes a layout editor for designing user interfaces visually, as well as tools for testing and debugging applications on emulators or physical devices.

Figure 2.4: Android Studio logo

Android Studio is a powerful tool for building Android applications, and it provides many features and tools that simplify the development process. Its official documentation and user guide provide comprehensive guidance for using its features and functions, and it is regularly updated to support the latest Android development frameworks and technologies [16].

In this thesis Android Studio was used in order to implement a plugin for Unity that provides native measurements of the devices magnetometer and other sensors.

2.4   Hardware

The following devices were used in the process and development of the systems proposed in this thesis.

2.4.1   Thermographic Cameras

Thermographic cameras, also known as thermal imaging cameras, are devices that capture thermal energy (heat) emitted by objects and convert it into an image that can be displayed on a screen. The image produced by a thermographic camera is called a thermal image (Figure 2.5), and it shows the temperature distribution of objects in the field of view.

Thermographic cameras use infrared (IR) technology to detect the amount of thermal radiation emitted by objects. This radiation is invisible to the naked eye, but it can be
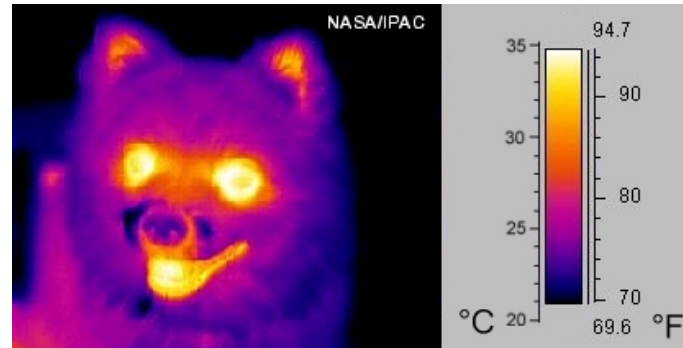
Figure 2.5: Image of a Pomeranian taken in mid-infrared ("thermal") light (false-color)

detected by specialized sensors and converted into an image that displays the temperature differences between objects. Thermographic cameras are useful for a wide range of applications, including building and industrial inspections, medical imaging, search and rescue, and military surveillance, among others [17].

FLIR Lepton 3.5

Figure 2.6: FLIR Lepton 3.5

FLIR Lepton 3.5 is a thermal imaging camera module produced by FLIR Systems, Inc. It is a compact, lightweight, and low-power device that can be integrated into

various systems and devices to provide thermal imaging capabilities. The Lepton 3.5 uses microbolometer technology to detect infrared radiation and produce thermal images, and it can be used in a range of applications, such as building automation, security, and surveillance, industrial inspection, and scientific research. The FLIR Lepton 3.5 is known for its high thermal resolution, fast response time, and low noise, and it offers advanced features, such as temperature measurement and adjustable radiometry. With its small form factor and low power consumption, the FLIR Lepton 3.5 is well-suited for use in portable and battery-powered devices [18].

In this thesis the FLIR Lepton was chosen due to its small factor and the fact that it can be easily mounted on top of an AR Headset. The 3.5 was chosen because it offers a 160x120 pixel resolution compared to Lepton 2 and increased dynamic range +400 degrees(C) compared to Lepton 3. Because the application the proposed system is designed for is very demanding these extra features of the Lepton 3.5 made it ideal for the concept of this thesis.

2.4.2 Augmented Reality

Augmented Reality (AR) is a technology that enhances the physical world with virtual elements. AR blends real-world and computer-generated data, allowing users to interact with digital information in the real world. In AR, virtual objects are superimposed onto the real world, creating a combined view of the physical and digital worlds. AR can be experienced through various devices such as smartphones, tablets, head-mounted displays, and smart glasses.

Augmented Reality has a wide range of applications in various industries such as education, gaming, advertising, e-commerce, entertainment, and more. In education, AR is used to enhance learning experiences by providing interactive, visual, and engaging information. In gaming, AR adds a new dimension to traditional video games by incorporating the real world into gameplay. In advertising, AR provides an immersive brand experience by blending digital content with the physical environment [19].

Hololens 2

Microsoft Hololens 2 (Figure 2.7) is a mixed reality headset designed for use in enterprise and commercial settings. It allows users to see and interact with virtual objects in the

Figure 2.7: Microsoft Hololens 2

real world by projecting holograms into the user's field of view. It runs on Windows Mixed Reality, a platform that supports mixed reality experiences and applications. The Hololens 2 is equipped with a range of sensors, including cameras, microphones, and depth sensors, which allow it to sense the environment and the user's movements. It also features hand tracking, enabling users to interact with virtual objects in a natural and intuitive way.

The device is designed to be used for a range of purposes, including training, collaboration, design and visualization, field service, and remote assistance. For example, it can be used by engineers and technicians to view and interact with 3D designs, by medical professionals to view and manipulate virtual anatomy, or by military personnel to view and interact with virtual maps and tactical displays [20].

In this thesis Microsoft Hololens 2 was used to implement the AR aspect of the proposed systems. The AR headset is the most critical part of the design of the system. Although the Hololens 2 has a lot of limitations and is not built for firefighters, it is capable enough for the proof of concept of this thesis.

2.5 Related Work

2.5.1 Expanding the Hololens 2

The Hololens 2 offers advanced hardware specifications and it is a popular developer choice for a reason. Nonetheless many have tried expanding the headsets capabilities by connecting other hardware to it. In [21] an external camera live streams on the Hololens in order to bring text closer to people with impaired vision which shows how easy it is to expand the Hololens capabilities by simply connecting an external camera. They investigate an AR-based magnification solution that combines a small finger-worn camera with a transparent augmented reality display (the Microsoft Hololens). The image from the camera is processed and projected on the Hololens to magnify visible content below the user's finger such as text and images.

Related work regarding thermal cameras and the Hololens has already been the focus of researches. A setup consisted of a Microsoft HoloLens with two FLIR Lepton 3.5 Radiometric infrared thermal cameras (housed in PureThermal 2 I/O modules) mounted to the top has already been implemented in [22]. The researchers have extended the Hololens capabilities by mounting two heat-wavelength infrared cameras to a Microsoft HoloLens, facilitating the acquisition of thermal data and enabling stereoscopic thermal overlays in the user's augmented view. They present a human-subject study, in which they simulated different temperature shifts using either heat vision overlays or 3D AR virtual effects associated with thermal cause-effect relationships (e.g., flames burn and ice cools). They also did further investigation regarding differences in estimated temperatures when the stimuli were applied to either the user's body or their environment. In this thesis a similar setup could be implemented that utilizes one of these cameras to capture the thermal properties of the headset operators view.

In [6] they propose using a thermal imaging camera with a deep learning model as an intelligent human detection approach during emergency evacuations in a low-visibility smokey fire scenarios. Thermal imaging cameras can provide the necessary data to distinct human figures in smokey scenarios. In this thesis a thermal imaging camera can be mounted on the Hololens 2 headset like in [22] and stream its content to the Hololens 2 display like in [21]. This configuration should allow the operator to see better in smokey environments and thus assist firefighters see through smoke without using their hands.

2.5.2 AR and GPS

Unity 3D offers a lot of tools to develop a complete augmented reality project using GPS data like they did in [23].

In [24] a smartphone is running a server application developed in unity that feeds the location data to a Hololens 2 client application also developed in unity. A navigation route is then generated using Google GPS and the smartphone GPS data. The application creates a route graph for the operator and uses the smartphone data to locate itself. The Hololens application then computes the difference between the position of the Hololens and the next position node and generates a line that connects these two coordinates.

In this thesis smartphone GPS data could be used to track the firefighters in operation and feed these locations to a central server. After these locations can be forwarded to the Hololens 2 so that a signal regarding their location could be visualized on the Hololens 2 display.

2.5.3 Systems for Firefighters

ENGAGE IMS/CAD System

ENGAGE IMS/CAD, a software system developed by Satways, has been specifically designed for emergency response management and is currently employed by the Greek firefighters. The acronym IMS stands for Incident Management System, while CAD represents Computer-Aided Dispatch. ENGAGE IMS/CAD serves as a vital tool for

Figure 2.8: ENGAGE IMS/CAD system desktop screenshots

furnishing real-time information and assistance to emergency response teams during incidents or crises. This system enables emergency operators to swiftly acquire information pertaining to the incident at hand and dispatch the appropriate resources to the location.

ENGAGE IMS/CAD encompasses a comprehensive range of tools meticulously crafted for effective management of emergency situations. These tools encompass incident reporting and tracking, resource management and allocation, mapping and visualization features for enhanced situational awareness, communication and collaboration capabilities for both field teams and command centers, as well as analytics and reporting functionalities facilitating post-incident analysis and planning.

The versatility of ENGAGE IMS/CAD ensures its suitability for employment by diverse entities, including emergency response agencies such as police, fire, and medical services, public safety organizations, government agencies, and private companies necessitating robust incident management capabilities. Moreover, the system can be tailored to align with the unique requirements of different organizations and seamlessly integrated with other platforms and systems.[8]

In this Thesis a the Live Tracker System should present the locations of each operating firefighter in a 3D Map visualizing their positions. The system should have a solid data flow and handling so that accurate representation is established.

VR in Firefighting Simulation

Figure 2.9: BRIDGES: Firefighters training simulation.

The Firefighters Training Simulation [4] shown in (Figure 2.9), is a simulation platform designed for training firefighters in a virtual environment. The simulation provides realistic scenarios that mimic real-life firefighting situations and allows firefighters to practice their skills and techniques in a controlled and safe environment. The goal of the simulation is to enhance the training experience of firefighters, improving their preparedness and proficiency in responding to actual fire emergencies. The simulation can also be used to test and evaluate new firefighting strategies, techniques, and equipment before they are used in real-life situations.

AR firefighter helmet

Figure 2.10: Qwake Technologies C-THRU

C-THRU is a product developed by Qwake Technologies [25]. C-THRU is a firefighter helmet equipped with augmented reality technology (Figure 2.10). The helmet provides firefighters with real-time information and visualization overlaid onto their actual view, allowing them to see through smoke, navigate through structures, and access critical information in low visibility environments. The helmet also has thermal imaging capabilities, which can help firefighters locate hot spots and victims in the fire scene.

Chapter 3

Requirements

3.1 Introduction

This chapter delves into the general requirements and system design considerations for optimizing firefighting operations through the integration of emerging technologies like Augmented Reality. The proposed system aims to enhance the efficiency, safety, and effectiveness of firefighting operations, and to achieve this goal, it is crucial to identify and address the specific requirements that govern its development. Additionally, the system design plays a pivotal role in determining the feasibility and functionality of the proposed solution.

Thermal imaging technology has revolutionized firefighting practices by providing real-time assessment and monitoring capabilities in smoke-filled environments. These cameras detect heat, allowing firefighters to navigate through darkness and locate individuals with enhanced safety and rescue possibilities. However, the current handheld nature of thermal cameras restricts operators' movement and operational efficiency. Augmented reality headsets offer a potential solution by providing a hands-free interface for delivering powerful thermal data to firefighters.

In addition to improving visibility, effective communication is crucial during firefighting operations, particularly in collaborative scenarios like forest fires. The use of radios, smartphones, and Computer-Aided Dispatch (CAD) systems can become overwhelming due to the scale of operations and the number of individuals involved. To address this challenge, a comprehensive system can be developed that integrates location-based data,

emergency signaling, and visualization technologies. By gathering real-time location information and displaying it on maps accessible to officials and augmented reality headsets worn by team captains, the system optimizes coordination, minimizes radio congestion, and enhances situational awareness.

In the subsequent sections of this chapter, we will discuss in detail the specific requirements that must be met by the proposed system and delve into the intricacies of its design. By examining these aspects, we aim to provide a comprehensive understanding of how the proposed system can address the challenges faced by firefighters and pave the way for more efficient and effective firefighting operations.

3.2 General Requirements

The primary objective of the proposed system is to optimize firefighting operations through the utilization of emerging technologies. To ensure the efficacy of the system, it is imperative to satisfy various general requirements. These requirements encompass diverse aspects, including use case scenarios, system performance, user interface and experience, data management, and communication. Adherence to these requirements is crucial for the development of a reliable, efficient, and user-friendly system that can augment firefighting operations. This section delineates the general requirements that the proposed system must meet.

1. The augmented reality (AR) application should offer a hands-free user interface. An interface must be implemented to enable operators to control different aspects of the application, such as the thermal view and visual signal settings.

2. The project should enhance the operators' ability to visualize through smoke by presenting infrared data in the visible spectrum. Given that firefighting environments often suffer from reduced visibility due to smoke, thermographic cameras are already utilized. Incorporating such capabilities into the AR application would be highly beneficial.

3. The AR application should display relevant information to the operator's field of view without impeding their vision. Consequently, the interface should be dynamic, allowing operators to activate or deactivate visual elements based on their preferences.

4. Maintaining awareness of each team member's precise location is critical during fire-fighting operations. Hence, the system should display visual signals to enable operators to easily ascertain the whereabouts of individual team members. Additionally, a visual representation of these locations should be provided to the communication headquarters, such as the fire station, to ensure a comprehensive understanding of the operation by all involved parties.

5. To bolster the safety of all individuals engaged in firefighting operations, the system should incorporate an individual firefighter emergency signal. Since firefighters are constantly on the move within dynamic environments, the emergency signal should be readily accessible to each team member, allowing them to transmit their location and communicate their situation to all involved in the operation.

6. The system should aim to alleviate radio channel congestion by minimizing the necessity for vocal communication between the Hololens 2 operator and their team. This approach will mitigate the likelihood of human error or misunderstanding while communicating critical information.

3.3 System Design
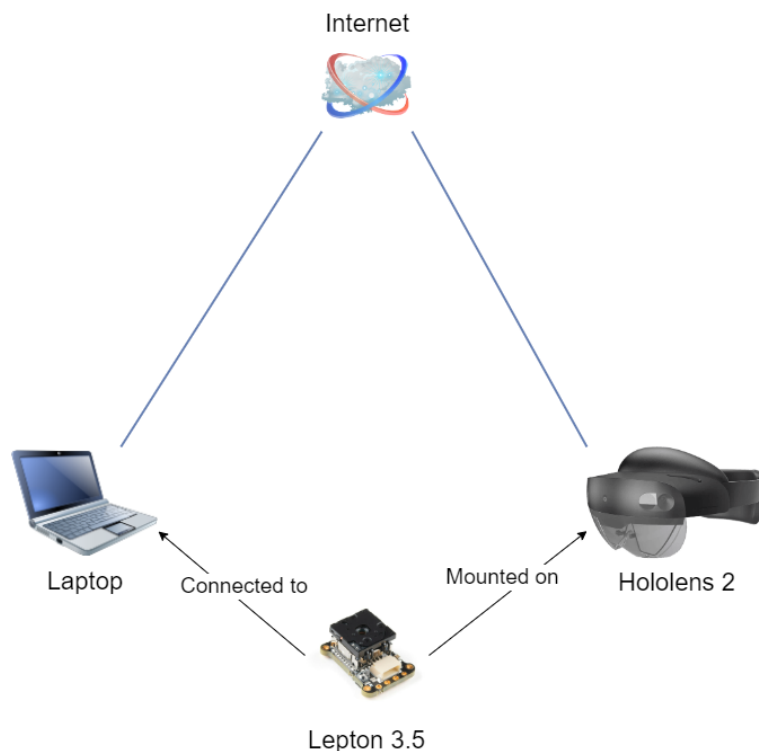
3.3.1 Thermal Imaging System

Figure 3.1: Thermal Imaging System connections diagram

(Figure 3.1) presents the connections diagram for the thermal imaging system, which addresses the first and second requirements by providing thermal imaging on an Augmented Reality Headset such as the Hololens 2. To achieve this, a thermal imaging sensor is mounted on the headset, as demonstrated in prior works (Erickson et al., 2019; Stearns et al., 2017). Considering the limited I/O ports of the Hololens 2 device, it becomes apparent that directly connecting an external camera via USB is not feasible. Therefore, a proposed method involves connecting the camera to a separate device and streaming its content to the Hololens 2 headset using a WiFi connection, as depicted in (Figure 3.1).

Although the Hololens 2 offers multiple input sensors that satisfy the first requirement, hand gestures and speech recognition will not be utilized in the planned application

environment. Speech-driven interfaces would prove inefficient due to constant radio communication during operations, while hand gestures would compromise the hands-free aspect and diminish operational efficiency. Therefore, eye-tracking has been selected as the preferred user interface for the Hololens 2.

The system design necessitates a server-client connection, with a laptop serving as the server and the camera-equipped Hololens 2 device serving as the client. The camera is mounted on the client device and connected to the server device via a USB cable. Consequently, the distance between the server and client is restricted to the length of the USB cable.

3.3.2 Live Tracker System

To satisfy the fourth, fifth, and sixth requirements, the system must also capture the firefighters' locations using their smartphones, transmit this data to a server located at the firefighters' headquarters, and subsequently forward the information to the Hololens 2 device. This communication process is illustrated in (Figure 3.2).
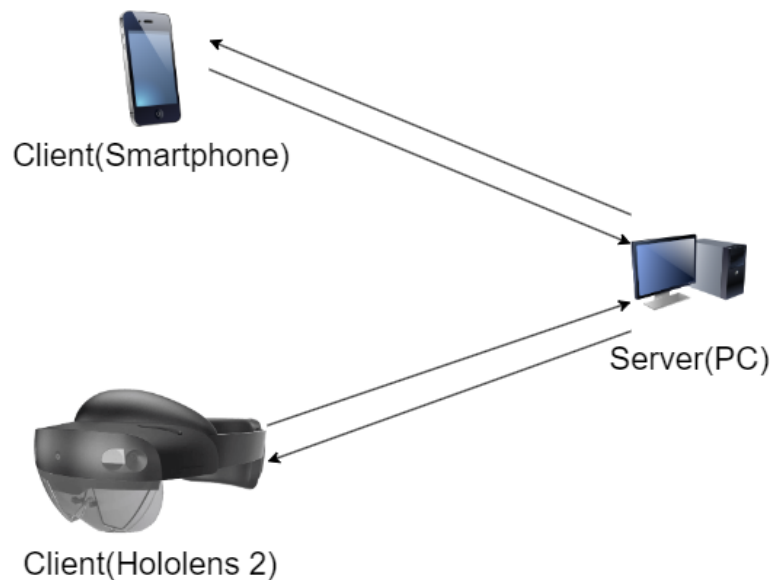

Figure 3.2: Live Tracker System communications diagram

Since this system necessitates the operational functionality of the server regardless of the distance to the clients, a decision has been made to implement two distinct systems:

the Thermal Imaging System and the Live Tracker System. Both systems should adhere to the third requirement when designing the user interface.

Chapter 4

End User Experience

4.1 Introduction

The whole project is divided into 2 distinct systems. the first is a hands free thermal vision system, designed for operating in scenarios where vision is limited due to thick smoke, while the second one is a live tracking system designed for wild fire or rescue operations.

4.2 Thermal Imaging System

The Thermal Imaging System described in this section is specifically designed for urban firefighting operations, where thick smoke often hinders the visual assessment of the environment. To address this limitation, the system incorporates a FLIR Radiometric infrared camera mounted on top of a Microsoft HoloLens 2 device. This configuration enables the real-time capture of thermal data, which is then streamed directly to the headset.

One notable feature of the system is its user interface, which uses eye tracking technology for seamless control. By utilizing eye movements, the operator can conveniently open or close the thermal data stream, allowing for on-demand visualization of the thermal properties of the environment. Importantly, this hands-free functionality ensures that the operator's hands remain available for other critical tasks during firefighting operations.
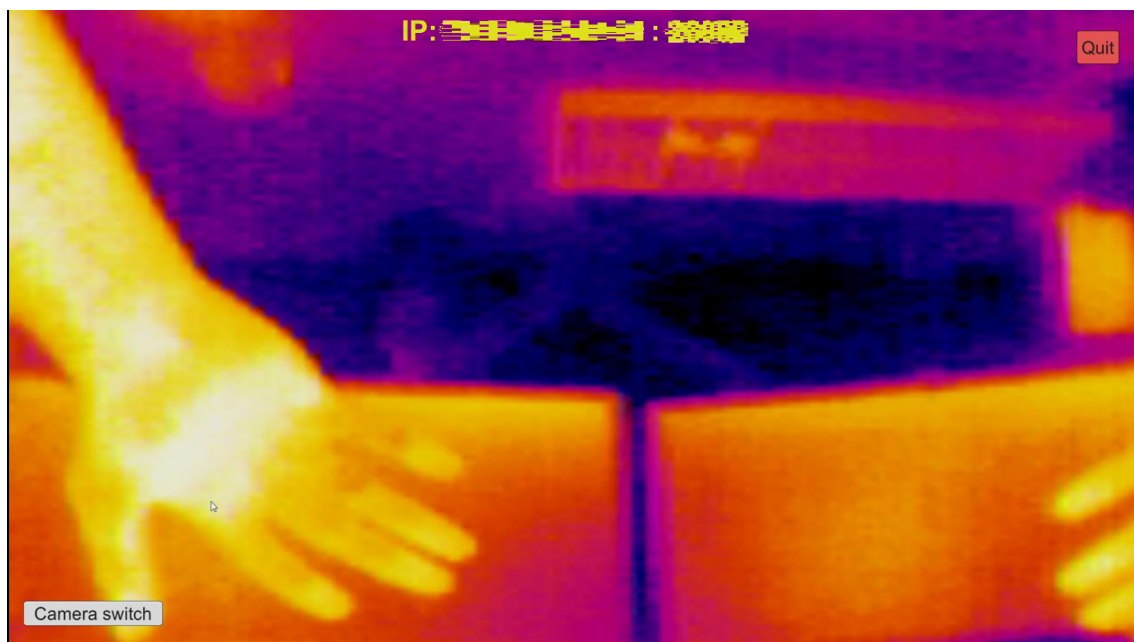
4.2.1   Server (PC application)

Figure 4.1: Laptop Thermal Application screenshot (Server)

In order to establish the thermal data stream on the Hololens 2 device, it is necessary to transmit the captured data from the camera to the headset. However, due to the limited hardware ports on the device, an alternative approach was implemented. A laptop is connected to the camera via a USB cable, serving as an intermediary to stream the thermal data to the headset, which is connected to the internet via WiFi.

The laptop application, as depicted in (Figure 4.1), provides the user with the ability to select from available cameras and stream their feed to a connected device. To establish this connection, the receiving device (client) must connect to the laptop (host) using the IP address and a designated port set by the user upon opening the host application. Once the host application is configured and running, the captured video feed is displayed along with the necessary connection information (IP, Port) for the client device.

4.2.2 Client (Hololens 2 application)

Upon launching the client application on the Hololens 2 device, an input panel is displayed, requesting the input of the IP address and port information to establish a connection with the host.
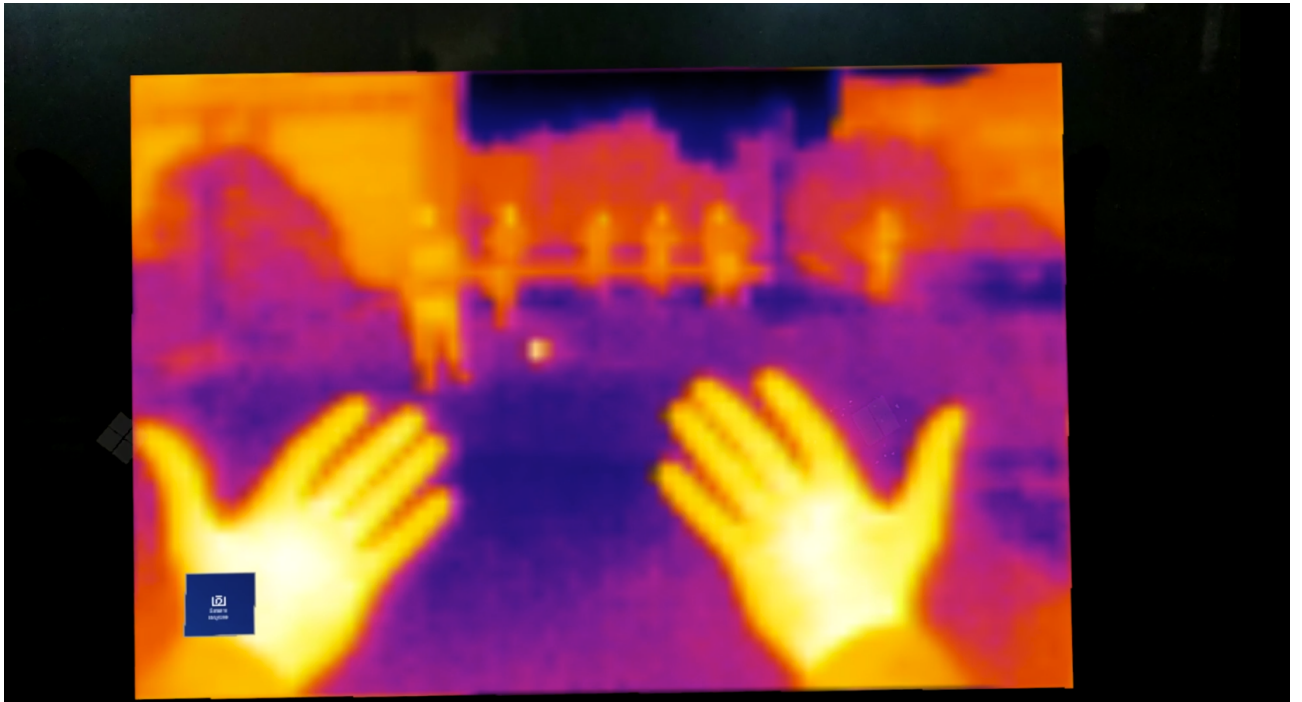
Figure 4.2: Hololens 2 Thermal Application

Figure 4.2 illustrates the Hololens 2 Thermal Application, showcasing the user interface and functionalities of the client application. Upon successful connection with the host, the operator will observe a small button positioned at the bottom left corner of the display. Utilizing the eye-tracking technology provided by the headset, the operator can activate the button by maintaining their gaze on it for a duration of 2 seconds. This deliberate activation process helps minimize unintended button selection. The purpose of this button is to toggle the opening or closing of the thermal data stream received from the host, allowing the user to choose between viewing the stream or observing the physical environment.

4.3 Live Tracker System

The Live Tracker System comprises three interconnected applications designed to facilitate the transmission of each team member's location from their mobile phones (clients) to a PC server application. The server application serves as a centralized hub for client devices, including Android devices and Hololens headsets, enabling them to sign in and access the transmitted location data. Subsequently, these location coordinates are forwarded to the Hololens device worn by the captain of each operating team. The overall connection scheme is illustrated in the high-level diagram depicted in Figure 5.6.

4.3.1 Android Application (Client)

The Android application (Figure 4.3) serves the purpose of capturing and transmitting the user's location data to the PC application. Upon launching the application, the initial screen prompts the user to select their role, distinguishing between a member and an operator, where the operator additionally wears the Hololens 2 headset.

The subsequent screen is the connection interface, where the user is required to input the IP address and port of the PC hosting the "server" application, along with a designated username for data association. After providing these details, the user proceeds by selecting the "Connect" button to establish a connection with the host PC.

Upon successful connection, the application presents the Home Screen, displaying the information sent to the server application, including longitude, latitude, accuracy, and altitude. A console screen is positioned at the bottom, serving both debugging purposes and as a display for verifying the establishment of the connection. Additionally, the user has the option to activate the Emergency Button to send an emergency signal to the server application, which includes the location of the button press. Pressing the "Emergency Signal" button again ceases the broadcasting of the emergency signal to the PC application.

4.3.2 PC Application (Server)

The PC application works as a host for the rest of the devices(clients) to connect to. When started the user must enter an open port in the network for the clients to connect through and press the "initialize Server" button.
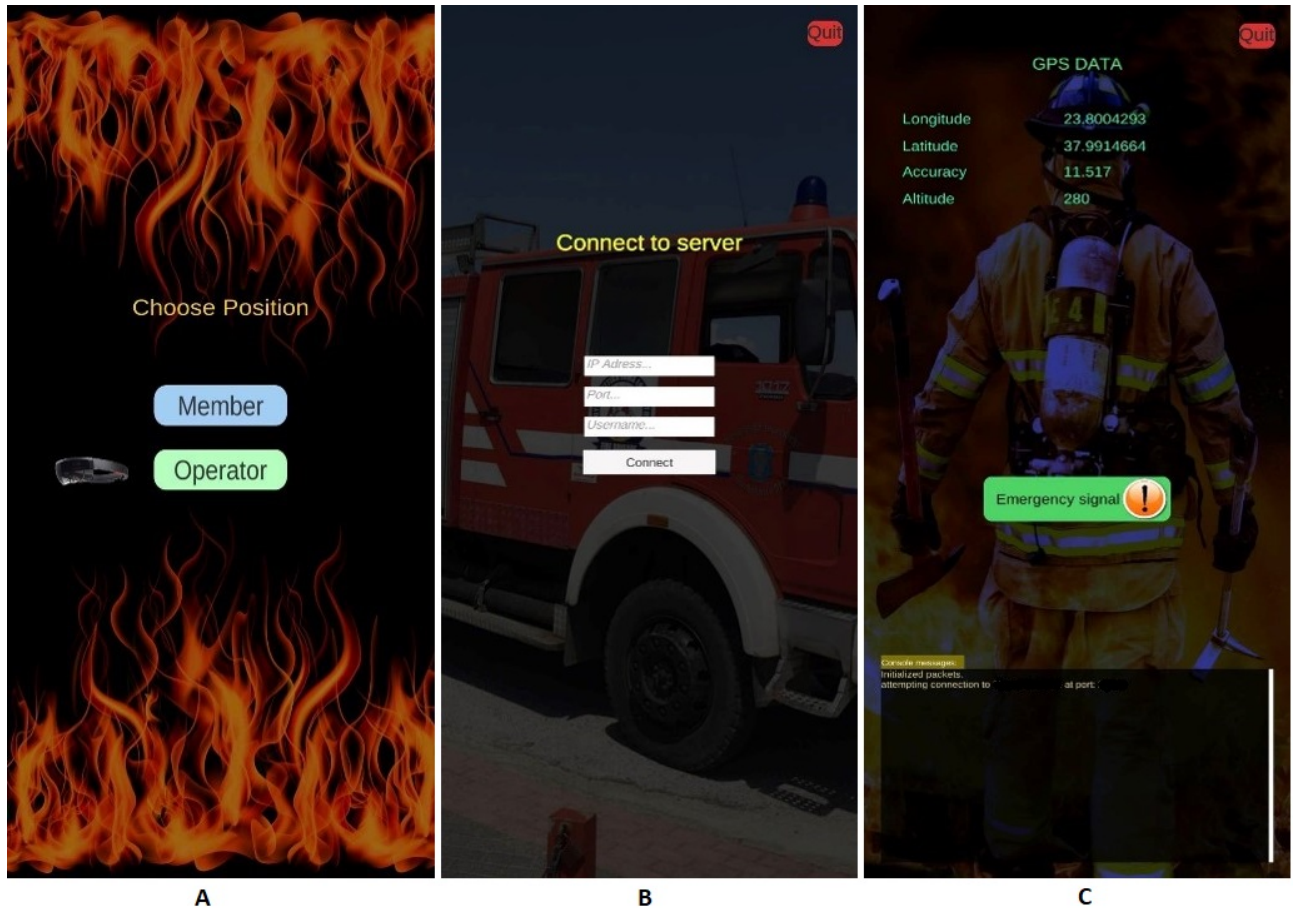
Figure 4.3: Android application screenshots

When the server is initialized the console on the bottom left corner of the display will show the IP address and port needed by the clients to connect to the application. When a client is connected their username will be shown on this console as well as all the emergency signals pressed during this session. The operator has the option to hide this console when the "Show/Hide Console" button, located in the bottom right corner, is pressed. Next to this button there is another one that reads "Reset Map" which is used to re-align the map to the north if the user makes any unwanted movements to the Map object on the display.

The main focus of the display is the Map object which simulates the real world using 3D Mapping of the real world in a rectangular based object. When an Android client

Figure 4.4: PC application screenshot

connects to the host their location data are calculated in order to place a pin representing their location on the map object. Furthermore when a connection of an Android client is established a new button appears on the right top of the screen that reads the username the Android user used to connect to the host. When this button is pressed the Map objects focuses smoothly to the current location of the client with the corresponding username. The Map object can be rotated and the map can zoom in or out with the use of the mouse, which because is 3D represented can offer a better representation of the environment the firefighter is located, to the PC operator.

4.3.3   Hololens 2 Application (Client)

The Hololens 2 application establishes a connection with the host application in a similar manner to the Android application, albeit with a distinction that the headset operator is not required to input a username. Instead, only the IP address and port need to be

Figure 4.5: Hololens 2 application

provided.

Upon launching the application, a panel is presented to the operator, prompting them to enter the host's IP address and port. Subsequently, the operator selects the "Connect" button, allowing the host to match this information with the location and username sent by the Android application associated with the "Operator" role.

Once the connection to the PC application is established, a virtual phone appears in front of the Hololens 2 operator, accompanied by a new button on the operator's Android application labeled "Align to north". The operator is required to position their phone at the location indicated by the virtual phone displayed on the Hololens and press the "Align to north" button. This procedure enables the acquisition of the angle from true north. Consequently, the Hololens 2 device can present the operator with the direction of true north, while a virtual compass materializes at the top of the display, dynamically updating based on the operator's orientation.

Figure 4.6: Hololens 2 application

The Hololens application also features a mini-map situated at the bottom right corner, perpetually facing the operator. After a successful connection, the host application forwards all location data from the Android devices, along with their corresponding identifiers. Utilizing this data, the application can illustrate the location of each member on the mini-map.

Utilizing the true north direction and the locations of all members, including the operator, the Hololens device generates virtual green arrow holograms that indicate the direction of each member relative to the operator's position. The username of each member, together with their distance from the "Operator's" Android device, is displayed beneath the arrow holograms. In the case of numerous connected members, the abundance of arrow holograms may become overwhelming. Consequently, the operator has the option to hide them. Similar to the thermal imaging system Hololens applicaiton, the Hololens application presents a button in the bottom left corner, which can be selected

by the operator using eye-tracking. By toggling this button, the operator can choose to display or hide the arrow holograms. If an emergency signal is received by the host, the arrows assume a red color, and the operator is unable to hide them.

Chapter 5

Implementation

5.1 Introduction

The implementation of the systems presented in this thesis was executed using the Unity 3D engine, in order to build applications that can run on the Android and Windows platforms as well as the Hololens 2 device.

The first system 5.2 mainly focuses on urban firefighting operations, where thermal imaging is often used to visualize the environment when smoke doesn't allow to do so. For this to happen a thermal camera was mounted onto the Hololens 2 device, so that it captures the same area that the operator is facing. The camera feed is then sent to a laptop through a USB cable (due to limitations on the Hololens 2 connectivity ports) and finally streamed to the Hololens device via WiFi connection.

The second system 5.3 is intended to be used in Wildfire operations and offers live tracking service, for each individual team member operating outdoors. For this to happen an android application was built to send the GPS location data of the phone, to a server hosted in a personal computer application. Lastly the server forwards these data to the Hololens 2 application running on the headset worn by the operator.

In both systems the communication between apps is established through TCP packet streams flowing between devices.

5.2   Thermal Imaging System

For the camera to capture the same direction the operator is facing, a mount had to be designed and 3D printed. This mount should house the camera and hold it in place while also screwed to the Hololens 2 headset.

Due to the fact that the Hololens 2 headset has limited I/O ports, the camera cannot be connected to the device directly. For this reason a system was implemented, so that the camera can be connected to a PC and the video feed from the camera can then be streamed to the headset to be displayed.

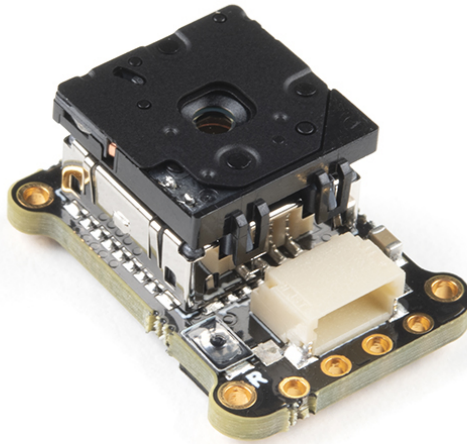### 5.2.1   Sensor and 3D Print

Figure 5.1: FLIR Lepton 3.5 with PureThermal Mini Pro JST-SR

For the thermal stream to work the first thing to do is to acquire the thermal data, using an infrared sensor and a module that can offer connectivity for digital data transfer such as USB connection. The thermal camera used is the FLIR Lepton 3.5 mounted on a PureThermal Mini Pro JST0-SR (Figure 5.1).

The FLIR Lepton 3.5 is a radiometric-capable Long-wave infrared (LWIR) camera solution that is smaller than a dime. It uses focal plane arrays of 160x120 active pixels on a 57 degree field of view.

The PureThermal Mini Pro JST-SR module with Thermal by FLIR is a hackable thermal camera for the FLIR Lepton thermal imaging camera core. It is pre-configured to operate as a plug-and-play UVC 1.0 USB thermal webcam. It has multiple connection options such as solder straight to the board or a custom cable using the JST-SR port.

Figure 5.2: FLIR thermal camera mounted on top of the Hololens 2

For the sensor to face the same way as the Hololens 2 operator, a 3D printed mount was designed using SolidWorks and then 3D printed. When the print was available the camera was placed in the 3D printed case and mounted on the Hololens2 using screws as shown in (Figure: 5.2). The connection was established using a custom JST-SR to USB cable connected to a laptop USB port.

5.2.2 Server (PC Application)

This PC application is used to choose between available cameras connected to the computer and stream the desired capture feed to a Hololens 2 device using internet connection.

Webcam access

In Unity, a webcam texture refers to a texture that is generated from the video feed of a webcam device. The webcam texture can be used as a source for a material that is applied to a game object, allowing the live video feed to be displayed in the game/application.

Webcam textures are created using the Unity WebCamTexture class, which provides access to the video feed from a selected webcam device. The webcam texture can be updated in real-time, so the game object will display the latest frame from the video feed.

Available webcam devices are listed in WebCamTexture.devices. With the use of a button that scrolls through this list, the user can choose the desired webcam video feed to be applied to the webcam texture.

Connection and streaming

For the PC application to connect and send data to the Hololens 2 device, a client-server communication was implemented using the TCP protocol.

After the webcam texture is obtained, each frame needs to be converted to a byte array. This array will first contain an integer representing its length, that the client can use to read the whole texture data of the frame.

The server uses the TcpListener class to wait for connections. After a new connection is established it begins the streaming process frame by frame.

5.2.3 Client (Hololens 2 Application)

This Hololens 2 application is used to connect to the laptop that is cable-connected to the thermal camera and display the thermal data streamed by the laptop.

Connection

The Hololens application connects to the PC application using the TCP protocol.

For the Hololens Application to connect to the server that is waiting for connections, the IP address and port are required from the operator. The application uses TcpClient.Connect with the inputs given by the operator. After the connection is established the application starts receiving the byte array containing the data of each frame.

The frame data are received in a stream of bytes that need to be converted back to an array. For this reason the first 4 bytes sent include the length of that array and thus the end of each frame data. The applicaiton uses that length in a loop to completely read the camera stream from the server.
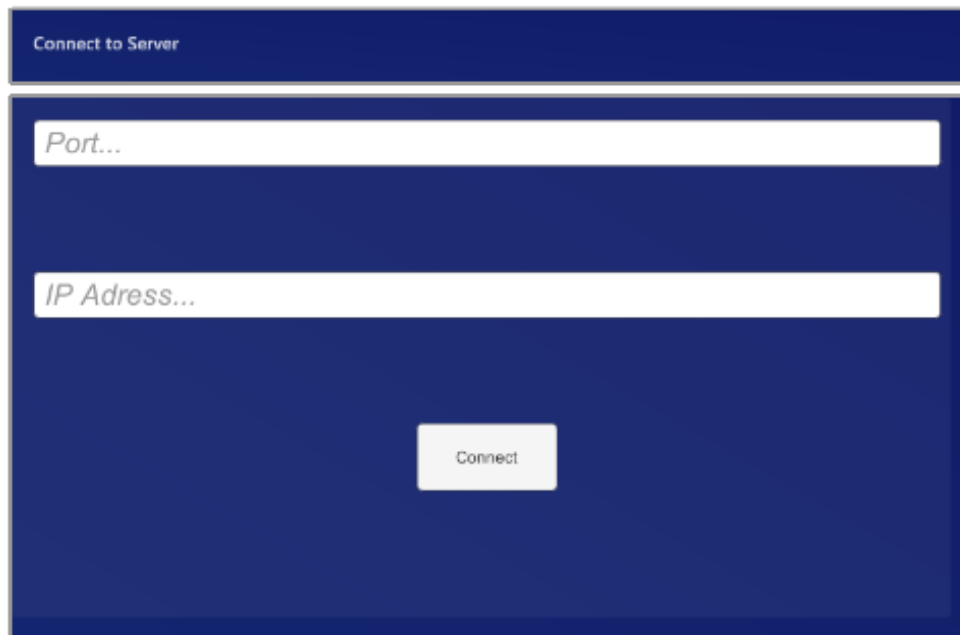

Figure 5.3: Hololens App-Connect to Server UI

User Interface

After each frame is received it is used as a source for the material of a GameObject which is always positioned in front of the operator. This GameObject is attached to the Main

Camera in the Unity space, meaning the Hololens 2 device in real life. That way it stays in front of the operator no matter their movement in the real world.

The GameObject containing the streamed frames can be deactivated and reactivated using a small button on the left of the screen. This allows the operator to choose if they want to see the thermal properties of the environment or not.
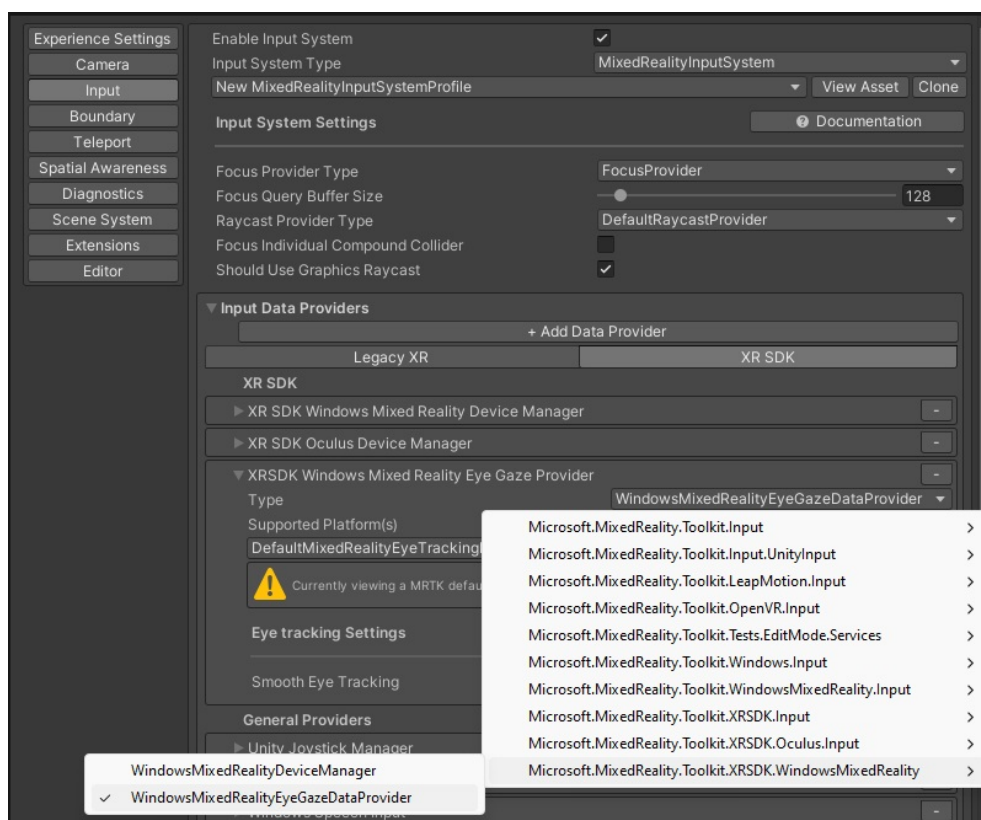
MRTK Settings

Figure 5.4: MRTK settings eye gaze data provider

MRTK was used to set up the Hololens 2 application to use eye tracking. To configure this the WindowsMixedRealityEyeGazeDataProvider was added in the Input tab of the MRTK profile (Figure: 5.4). Also in the Pointers section of the same tab the Use Eye Tracking Data selection was enabled.

MRTK was also configured in a way that the spatial awareness system was disabled. This was done to avoid the spacial mesh appearing in the display and because the use case of the application would involve a lot of smoke and so the spacial awareness feature would not be efficient.

Eye Tracking
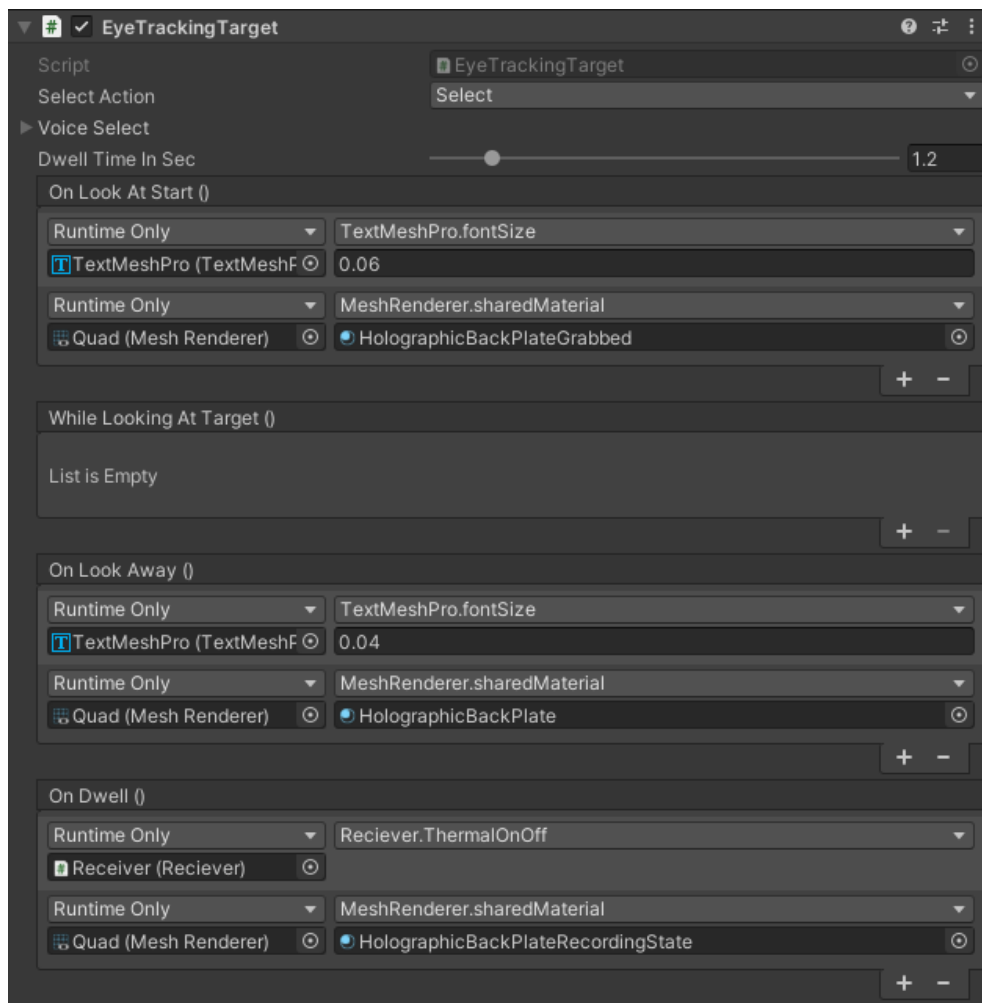
Figure 5.5: EyeTrackingTarget script

For the button to work with eye tracking the "EyeTrackingTarget" component was added to the object. A game object with the "EyeTrackingTarget" script attached reacts

to being looked at independent of other available inputs. This script allows for events to happen when the operator looks at the object, looks away or stare at it.

For this button to be selected the operator should dwell on the button for 2 seconds and so the settings where set as shown in (Figure 5.5). Also when the LookAt is activated the Objects properties are slightly changed to give a visual signal to the operator that the device recognized the gaze. These changes are reverted when the operator looks away.

5.3 Live Tracker System
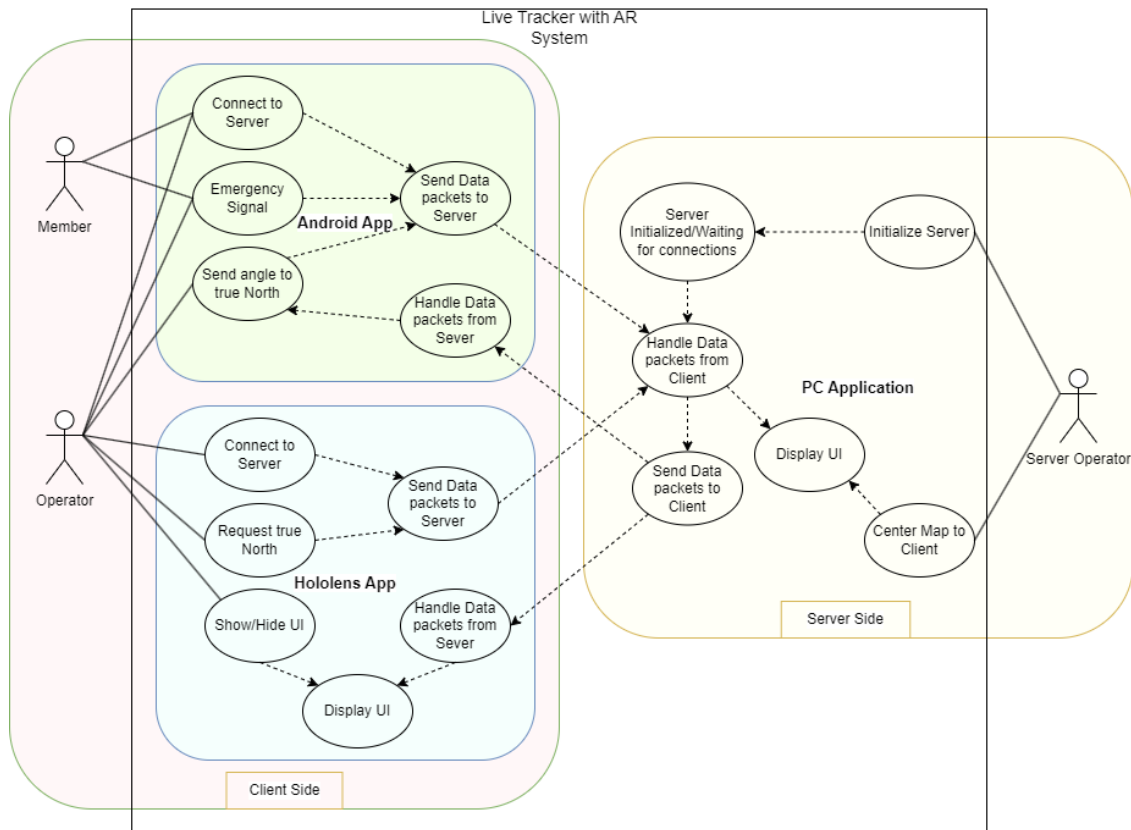
Figure 5.6: Live Tracker System use case diagram

Looking at the High Level use case diagram (Figure 5.6) it is clear that, for the system to work in its full potential there need be at least three users represented by the three actors in the diagram. On the client side the member and operator both use the android application to connect to the server, while the operator also uses the Hololens 2 application which is also connected to the server. On the server side the user is operating the PC Application and monitoring all connections.

The handle and send data use cases are present in all 3 applications and their communication is established through the server, meaning that the Android Application cannot send data directly to the Hololens 2 Application.

5.3.1   PC Application (Server)

Handle Connections

For the PC application to receive and send data to both client applications(Android, Hololens2), a client-server communication was implemented using the TCP protocol. TCP is connection-oriented, and a connection between client and server is established before data can be sent. The server must be listening (passive open) for connection requests from clients before a connection is established. To do this the TcpListener Class was used (System.Net.Sockets) to listen for connections on a specified port, with the help of the AsyncCallback delegate in order to asynchronously process incoming connection attempts. Accepting connections asynchronously offers the ability to send and receive data within a separate execution thread. Once a new connection is established the server assigns an id to the client and stores its information on a Client class. A Dictionary<TKey,TValue>helps track the Clients, using the id as a key and each Client as a value.

The data exchange between the Server (PC Application) and the clients is implemented using various different packets. These packets contain an integer representing their byte length and the data to be sent in the form of a byte array. The packets defined and used for the server to send data are:

Server Packets

1. Welcome. This packet is the welcome packet sent by the server to a new client to verify that a new connection has been established.

2. SendMemberData. This packet is used to forward the location and id of a firefighter to the Hololens client.

3. SendNewMemberData. This packet is used to forward the location and id of a firefighter for the first time to the Hololens client.

4. RequestNorthAngle. This packet is sent to the Operators android phone to activate the button that measures the angle to true north.

5. SendNorthAngle. After the Operator has sent the angle to true north this packet forwards this angle from the server to the Hololens device.

6. FirefighterDisconnected. This packet is used to signal the Hololens device that an Android client has been disconected.
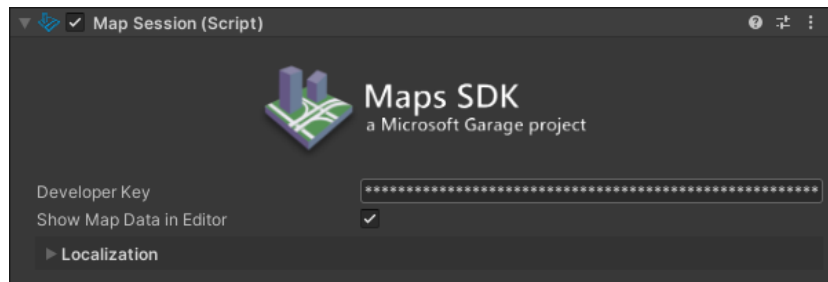
Microsoft Maps SDK

Figure 5.7: Map Session (Script)

Maps SDK is a Microsoft Garage project that provides the ability to visualize a 3D map within Unity-based projects. The SDK handles streaming and rendering of 3D terrain data with world-wide coverage.

Maps SDK can be setup once the package is included in the unity project. A new GameObject was added to the scene and a Map Renderer (Script) component, which also includes the Map Session (Script), provided by the SDK was added to the GameObject. To configure the Map Renderer a valid Bing Maps Key was required which can be provided by Bing Maps Dev Center. Once a valid key had been provided in the Map Session (Script) (Figure 5.7) Settings, the map would render the Location and zoom level provided in the Map Renderer (Script) (Figure 5.8) Location section. The MapLayout section was used to configure the shape dimention and colider type of the map GameObject. The visuals of the map can be configured in the render settings. The map terrain consists of either elevation data, high resolution 3D models or neither of those implementing a flat terrain. The last components of the Map Render (Script) are Quallity settings and Texture Tile Layers where the texture source to use for the map tiles is specified.

To position GameObjects on the Map by location, the SDK provides the MapPin component (Figure 5.9) which can place an object on the Map GameObject in a corresponding geo-location. This component, combined with a new script that updates the
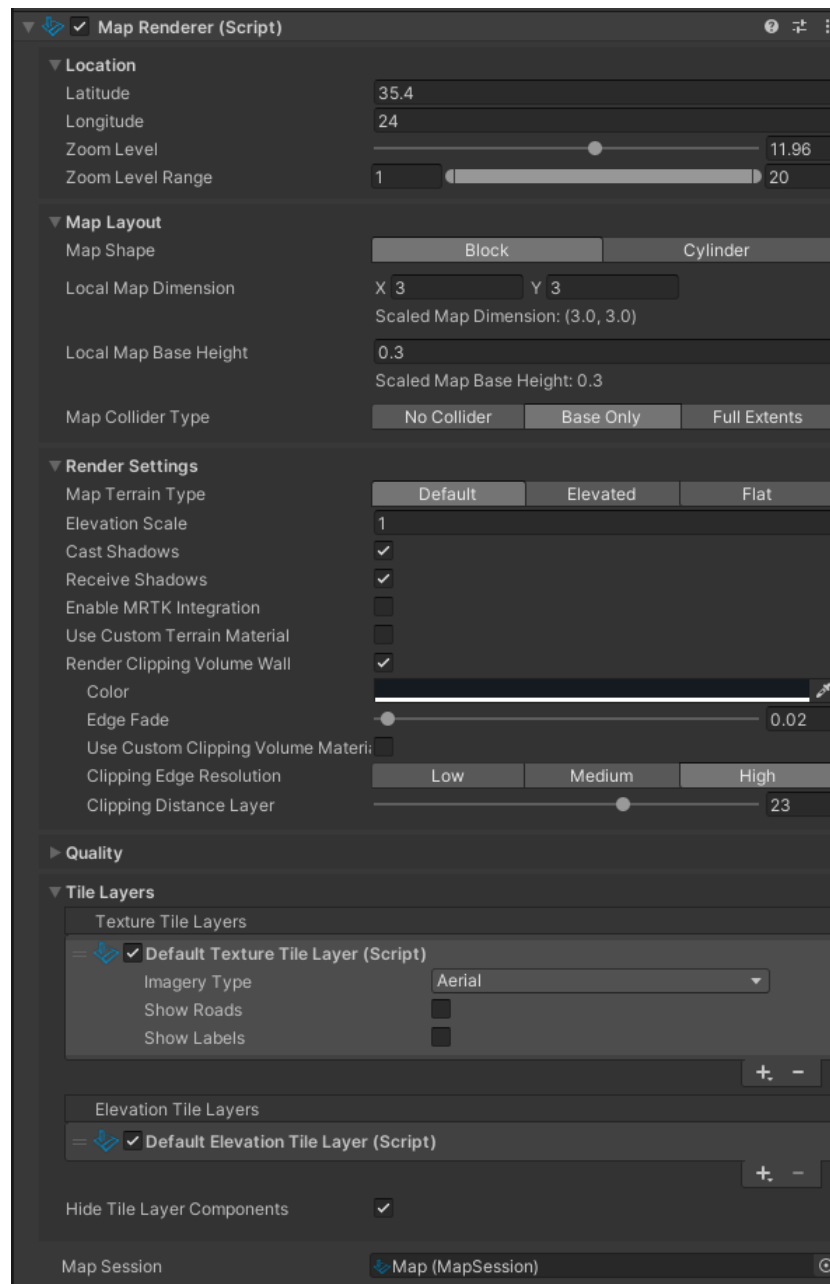
Figure 5.8: Map Renderer (Script)

transform of each MapPin GameObject each frame and synchronizing it to the corresponding location of each firefighter, was used to position the firefighters locations on the map GameObject according to the location transmitted by their android phone.
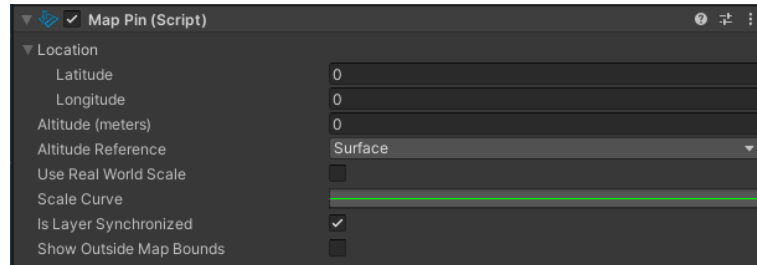
Figure 5.9: Map Pin Component (Script)

For this purpose a MapPin GameObject prefab was created (Figure 5.10) with the coresponding components which is spawned when a new Android client connects to the server. The Text that contains the clients username is set to always rotate and look at the camera with a script and the color/material of the MapPin is automatically adjusted depending on the clients role and emergency signal.

Figure 5.10: MapPin GameObject (prefab)

5.3.2 Android Application (client)

Android GPS Data

For the application to acquire the GPS data from the android devices GPS receiver, a plugin for Unity was made using Android Studio. The resason for this is that the LocationInfo.latitude that Unity provides, returns the latitude as a float and not a double, thus providing worse precision. Also the location update frequency is not ideal for live tracking.The plugin can access native android data and thus is more reliable.

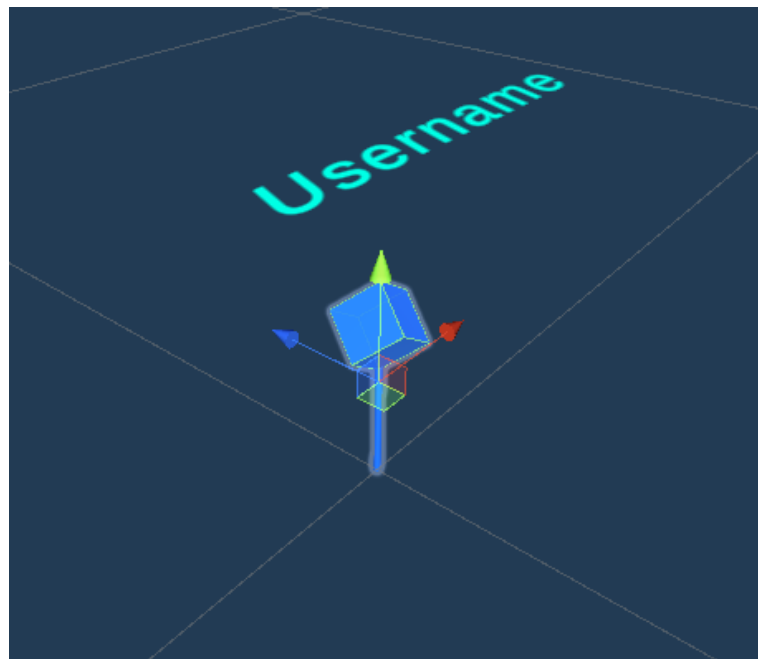For this plugin two classes were created, Main.java and Location.java. Main.java is only used to call the GPS init method and get the properties. In Location.java there are two functions. Init location service and update values on change. In the init method permission for location was added in the .xml file. After building the file the .arr file was added to the unity assets folder.

To use the plugin the Start method has to check if location permission is true and if so, call StartLocation. If it is not, the Application will ask the user for permission.

Connecting to the server and data exchange

For the Android application to connect to the PC Application the Socket.BeginConnect method was used to begin a request for a connection.

After the connection has been established, the communication is established, as mentioned in the PC Application, through packets. The packets defined and used, for the Android application (Client) to send data to the server are:

Android Application Client Packets

1. WelcomeReceived. This packet is sent to the server after the welcome packet has been received. If the WelcomeReceived packet reaches the server the connection is successful.

2. Location. This packet is used by the Android application to send the users current location (longtitude, latitude, accuracy, altitude) as well as their role and credentials.

3. EmergencySignal. This packet is used by the android device to send an emergency signal to the server.

4. NorthAngle. After the Android device receives the RequestNorthAngle packet from the server and the operator presses the coresponding button, this packet contains the angle to true north and the server forwards it using the SendNorthAngle packet.

User Interface

The Android Application UI shown in (Figure 4.3) consists of three screens.

- Role Screen.

  In this Screen the UI consists of 2 buttons that indicate the role of the user. If the user chooses to be the operator the Server will forward the location of the user to the Hololens Application with the boolean Op as true, meaning that the Hololens Application will consider this as the location of the Hololens.

- Connect Screen.

  In this screen the UI consists of 3 input fields and a connect button. After the user inputs their username and the IP address and port of the server and presses the connect button, the application begins a connection to the server and if successful sends a packet of data including their username.

- Main Screen. If the android device establishes a connection with the server then it begins to transmit its location in packets of data that are displayed in the top half of the main screen. Together with the data sent the Android application sends a Boolean called emergency which is set to false. In this screen there is an Emergency button, which when pressed changes the value of the emergency Boolean to trues. To make it back to false the user needs to press the same button to close the emergency signal. If the application is running in operator role then the operator can send a North Request through the Hololens device which will make the Home screen of the android application change, a new button appears that sends the angle to north of the android phone orientation when pressed, to the Server and forwarded to the Hololens for calibration. Lastly there is an red Quit button on the top right of the screen, which when pressed disconnects the client from the server and quits the application.

5.3.3 Hololens 2 Application (Client)

Connecting to the server

The connection to the server is established using the same method, as the one mentioned in the Android application (Client). The operator can input the Port and IP Adress through the UI shown in (Figure 5.3).The packets defined and used for the Hololens 2 Application (Client) to send data to the server are:

Hololens 2 Application Client Packets

1. WelcomeReceivedHolo. This packet serves the same purpose as the WelcomeReceived packet (Android Application Client Packets: 1) but indicates that the Hololens device has been connected.

2. NorthAngleRequestHolo. This packet is sent by the Hololens Application to the server, to indicate a request for the angle to true north from the operators android device and to activate the RequestNorthAngle packet.

User Interface

The Hololens User Interface consists of four main parts

- Virtual Compass.
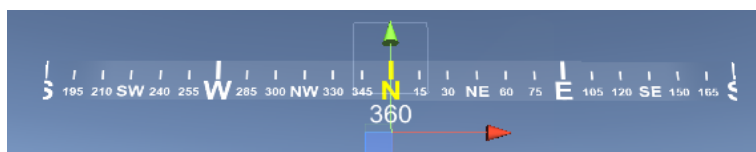
Figure 5.11: Virtual Compass UI

The virtual compass (Figure 5.11) object consists of two textures, compass background and compass which are both 2D sprites that are positioned on top of each other, and a Text UI object that displays the corresponding username and distance in meters. The compass object includes a script that is responsible for rotating the compass texture according to the operators localEulerAngles, using RawImage.uvRect.

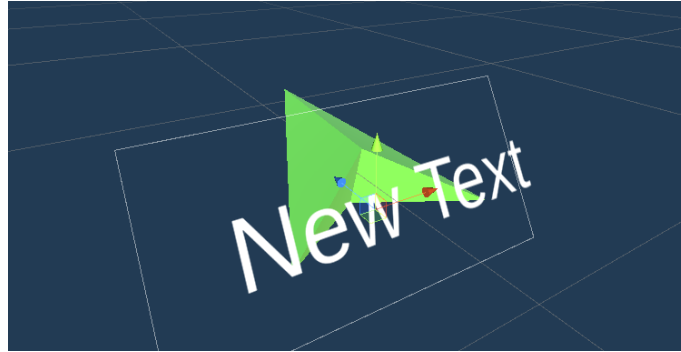- Virtual indicators that show direction and distance of each member.

Figure 5.12: Virtual Indicator Prefab

The arrow prefab shown in (Figure 5.12) is contained in the FirefighterSpawner.cs script. This script instantiates a GameObject with this prefab for each member android client. Then the application updates the coordinates of each android device and computes the direction and distance from the operator's position to each member position. The arrows are contained in a ring around operator, positioned facing the angle to north of each android device in respect to the Hololens position and Virtual north. Bellow the arrow the username of each device and their distance are displayed.

- Mini Map.

The Mini Map is a GameObject that contains the MapSession and MapRenderer scripts (Figure 5.7) (Figure 5.8) similar to the one described in the PC Application (Server). The only difference is that the MiniMap is rendered in 2D and is configured in a way that always faces the Operator.

- Eye Tracking button to show/hide virtual indicators.

This button is implemented using the same methods described in 5.2.3 and when it is pressed it activates or deactivates the prefab arrows.

North alignment

Once visualised, even though the compass and arrows are virtually pointing to the correct position, the north is pointed to an arbitrary direction, based on the direction the user

was facing when the application was started. In order to position them accordingly to the real analogous points in space, e.g. placing the virtual north according to true north, a rotational transformation is required. In this fashion, the necessary rotation is equivalent to an angle, which represents the number of degrees this direction is divergent from the factual north. By receiving the magnetic north heading in degrees available from the smartphone magnetometer, a good starting point measurement is already available to find the angle. Such device, however, needs to be pointed exactly at the same direction the user was facing previously. On top of that, the magnetic declination, i.e. the deviation between the true north pole of the Earth and its magnetic equivalent is not constant across the Earth. Since this deviation angle does not change drastically in less than a couple of hundred kilometers and in order to proceed with the development and tests of the present work, a transient design choice was made to keep this value stable, using the angle of 4.49 degrees, which pertains to the city of Chania, Greece. As to facilitate with the particular position the user has to hold the phone for the magnetometer to present an optimal reading, a hologram in the form of a phone pointing to the virtual north is placed in the scene, as showed in (Figure 5.13). The user is prompted to position the phone in the position of this hologram. This process has to be done once every time the application is run, since the HoloLens embedded accelerometers and gyroscope ensure that all object positions and rotations will be kept untouched unless otherwise commanded via code.

Figure 5.13: Hololens 2 App Interface

Chapter 6

Evaluation

6.1 Introduction

This section describes the evaluation process followed in order to establish the proof of concept and demonstrate the feasibility of the projects described in this thesis. For this reason a group of firefighters from the 1st fire station of Chania, offered to help test and evaluate the practicality of the project described in this thesis. For the evaluation process of the Thermal Imaging system a smokey environment with limited vision was simulated while the Live Tracking system was tested in the Technical University of Crete campus area.

6.2 Thermal Imaging System Evaluation

6.2.1 Simulation and Testing

In order to simulate a scenario where smoke doesn't allow the human vision to see the environment and the people within it, a smoke grenade was activated on the outdoors landscape of the technical university of Crete campus. The system was started and configured so that a connection between the server (PC) and client (Hololens 2) applications was established and the stream successful. The Hololens 2 operator was able to recognize the human figures on the landscape, through the thick smoke produced by the smoke grenade as well as the environment and the buildings surrounding them.

Figure 6.1: Firefighters testing the Thermal Vision System in the surreal team lab

6.2.2 Effectiveness of the System

The results of the simulated firefighting scenarios indicate that the system is effective in providing thermal data to the operator. As shown in (Figure 6.2) and (Figure 4.2) the smokey environment makes it difficult for the firefighter to see, but when the thermal stream is operational the operator can clearly understand the structure of the environment as well as locate other people in it.

6.2.3 Strengths of the System

One of the strengths of the system is the ability to provide thermal imaging of the view of the headset operator directly to the headset's display. Another strength of the system is the ability to display the thermal imaging data whenever deemed necessary in a hands
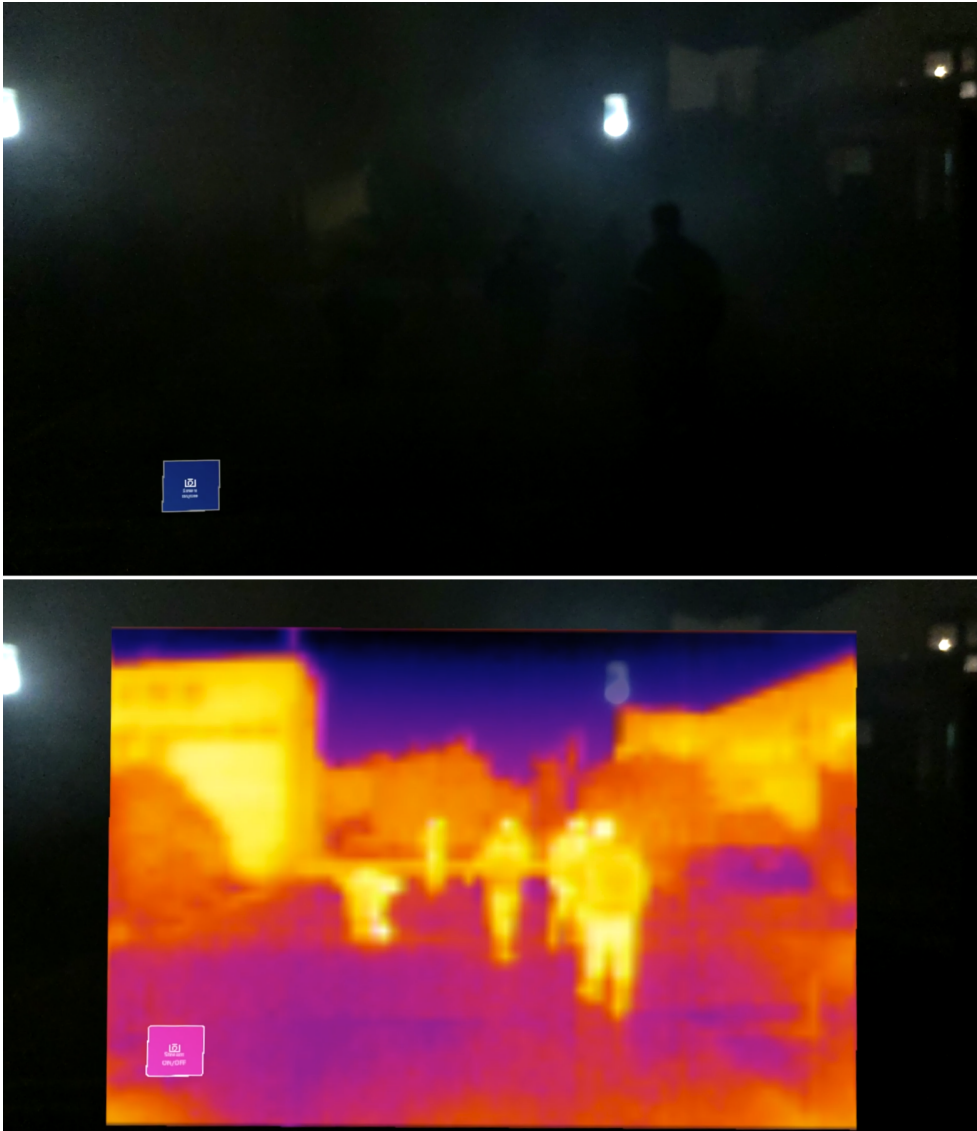
Figure 6.2: Hololens 2 Thermal Application interface during a test in a smokey environment with thermal stream OFF and ON

free implementation, which is made possible with the use an of eye-tracking controlled user interface. Another advantage is that the thermal data, except limiting the visual impairment factor due to the smoke, also provide the operator with important thermal properties of the environment and the material surrounding the operation.

6.2.4 Weaknesses of the System

The main weakness of the system is that there need be a solid internet connection for the applications to work properly. This is a problem because there can be no guarantee for good connection in firefighting and rescue operations. Also the stream latency that occurs with sending data through the internet is also a weakness, especially when the operator is moving and the thermal stream is slightly delayed. Another weakness of the system is the sensor image quality that limits the distance a human person is distinguishable. Also the Hololens 2 headset has its limitations in environment lighting conditions, that impact the contrast of virtual imagery displayed to the operator.

6.3   Live Tracker System Evaluation

Figure 6.3: Firefighters project presentation/evaluation

6.3.1   Simulation and Testing

The location the Tracker System was configured and tested was the wider campus area of Technical University of Crete in Chania. For the testing of this system the firefighters downloaded the android application in their phones and were connected to the Server which was configured in a Laptop at the Surreal team Lab(Figure 6.3). Then a group got in a car and went around the university area while being connected to the server with their android phones. The firefighters took turns in wearing the Hololens 2 headset which was running the Live Tracker system application and was also connected to the server. The headset operator should be able to see the car group moving through the campus as well as control some of the virtual objects displayed in the headset display.

Figure 6.4: Firefighters testing the Hololens 2 application

6.3.2 Effectiveness of the System

The system was able to detect the location of the car group members and send the corresponding data to the server, which in turn operated successfully in visualizing the received locations on a digital map and forwarding them to the Hololens 2 device. The AR headset was effective in indicating the location of the moving firefighters with low latency and was helpful in showing the orientation the operator was facing. In essence the results of the testing indicate that the system is effective in tracking moving targets in real time and displaying the direction and distance, in respect to the operator, on an AR headset. Also the server user interface was very helpful in giving the members operating remotely a clear view of the operation and the geographical qualities of the environment.

6.3.3 Strengths of the System

One of the main strengths of the system is its ability to provide real-time location data between devices and then present them in a visual manner. The user interface of the server was very useful in presenting the data in a way that the server operator immediately had a clear view of the location of each member operating. The system was able to provide accurate information, which helped visualize the operation as it unfolds. All aspects of the system were also easy and intuitive to use and did not require any specialized training.

6.3.4 Weaknesses of the System

One of the weaknesses of the system is that the headset hardware doesn't meet the requirements needed in order to function in a real-life firefighting operation, as mentioned in the weaknesses of the thermal imaging system above. The headset was only able to provide the Hololens 2 operator with visual data if the lighting was correct, for example it is difficult to see the holographic display while outside in a sunny day. Another weakness of the system is its dependency on the availability of internet connection and the fact that in most rescue missions connection is limited. If the connection is lost, the system would not be able to function. Another weakness regarding the network connections is that if one android application changes its IP address during a session by changing connection from a WiFi hot spot to cellular data or vice versa, then the server adds a new client with the new IP and keeps the previous connection of the same application with their last location as static. One more limitation to the current system is the accuracy that single frequency GPS provides which is not ideal for urban firefighting scenarios.

Chapter 7

Conclusion and future work

7.1 Introduction

In this thesis, two firefighting systems that employ advanced technologies and innovative approaches to enhance the efficiency and effectiveness of firefighting operations were presented. Throughout this thesis, the key components and features of of the design and implementation of these systems have been discussed, and experimental results were presented to demonstrate their proof of effectiveness in various scenarios.

However, there is still critical work and research that has to be done if a similar system is going to be used someday in real life scenarios. In this concluding chapter, the key findings and contributions of the work done are summarized and the potential avenues for future research and development in the field of augmented reality firefighting systems is discussed. Some of the limitations and challenges that need to be addressed in order to fully realize the potential of the systems and ensure its practical implementation in real-world firefighting operations are also highlighted. By identifying these areas for future work, this thesis also aims to inspire further research and development in the field of firefighting systems, and ultimately contribute to the enhancement of public safety.

7.2 Conclusions

In conclusion this Thesis aims at bringing AR technology to the field of firefighting operations in order to assist everyone involved. The systems presented in this thesis are

designed to offer assistance in both urban and wild fire case operations. The approach was to design two distinct systems mostly due to hardware limitations in one of the two. In the end both systems were tested and were able to prove their effectiveness in firefighting and rescue operations.

The evaluation of the Thermal Imaging System and Live Tracker System for firefighting operations has demonstrated their potential to enhance the efficiency, safety, and effectiveness of firefighting operations. The Thermal Imaging System successfully provided thermal data to the operator, allowing for improved visibility in smoke-filled environments. The system's strengths included its ability to display thermal imaging directly on the augmented reality headset, a hands-free user interface, and the provision of important thermal properties of the environment. However, weaknesses such as the dependency on a solid internet connection, stream latency, and limitations in sensor image quality and headset lighting conditions were identified.

The Live Tracker System effectively tracked moving targets in real-time, providing location data to both the server and the operator wearing the augmented reality headset. The system's strengths included its real-time location data visualization, accurate information presentation, and ease of use. However, limitations related to the headset hardware, dependence on internet connectivity, and the accuracy of single-frequency GPS were identified.

The proposed systems have the potential to significantly improve firefighting operations by integrating emerging technologies such as augmented reality, thermal imaging, and location tracking. By addressing the specific requirements identified, including hands-free user interfaces, enhanced visibility in smoke-filled environments, dynamic and non-intrusive information display, precise location awareness, and efficient communication, the systems can optimize coordination, minimize radio congestion, and enhance situational awareness among firefighting teams.

However if similar systems to the ones described in this thesis, are sometime going to be put to use in real life firefighting and rescue operations, there is still a lot of research and work to be made in all of its aspects (protocols and services, hardware, software).

7.3 Future Work

In this section, several future work directions are outlined that could further enhance the capabilities and functionality of this or similar projects.

7.3.1 Protocols and Services

Dual frequency GPS

Dual frequency GPS, also known as L1/L5 GPS, is a newer version of GPS technology that uses two different frequency signals from satellites to determine a receiver's location. The L1 frequency is the same one used in traditional GPS, while the L5 frequency is a newer signal that provides more precise positioning information.

Compared to traditional single frequency GPS, dual frequency GPS has several advantages. The L5 signal is less prone to interference and multipath errors, which can cause inaccuracies in positioning. Additionally, the dual frequency system allows for more accurate determination of the ionospheric delay, which can improve the accuracy of the GPS location fix.

While dual frequency GPS has some advantages over traditional single frequency GPS, such as improved accuracy and resistance to interference, it is currently limited by the availability of hardware and satellite coverage, and may be more expensive to implement. However when the satellite infrastructure is in place, this technology could provide centimeter accuracy to GPS devices.

Network infrastructure

The current Tracker system (5.3) requires internet connection in order to work properly. Unfortunately good internet connection is not always guaranteed in rural areas where most fire and rescue operations are located.

7.3.2 Hardware

Specialized AR Headset

Current Augmented Reality Headsets are not created to withstand the harsh conditions that accompany a firefighting or rescue operation. For the systems to be used in real life

a new AR Headset has to be designed and constructed, that meets the requirements of firefighters and to be able to operate in harsh conditions.

Such a headset could be designed to include a thermal camera and thus eliminate the current thermal imaging system (5.2) limitations regarding the need for internet connection. Also the design should take into account the firefighters helmet which is designed in such a way that offers different layers of insulation and protection.

Smart watch

With the utilization of a smart watch in the Tracker system (5.3) replacing the Android application, the system could not only send the GPS location of each member but also monitor their oxygen and heart rate levels. This way the emergency signal could be triggered if those levels exceed a specified threshold.

7.3.3   Software

More Information on Hololens 2 display

In terms of software the systems could offer a wider range of controls in the user interface and allow the AR headset to change aspects of the virtual components and the information displayed on the headset.

Systems database

Also for the system to keep a record of the operation a database should be implemented that tracks all data being transferred for later analysis of the operation as well as training and optimisation of response strategies.

Thermal Image edge detection

The thermal imaging system (5.2) could benefit from edge detection image processing algorithms as it can offer great object detection.

7.4   Closing Note

While the firefighting profession has made tremendous strides over the years, there is always room for improvement. One area that deserves our unwavering attention and investment is the research and development of firefighting operations and the equipment and tools used by firefighters. By prioritizing advancements in this field, we can enhance the effectiveness and safety of firefighting efforts, ultimately saving more lives and minimizing property damage. We owe it to all firefighters to equip them with the best resources available, ensuring they have every advantage possible when battling the destructive force of fire.

Furthermore, research in firefighting has broader implications for our society. Fire safety affects everyone, it impacts residential areas, workplaces, public spaces, and the natural environment. The knowledge and advancements gained through research can be shared and applied across various industries and disciplines, leading to improved fire prevention, emergency response, and disaster management practices. Ultimately, this can enhance public safety and reduce the devastating impact of fires on our communities.

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