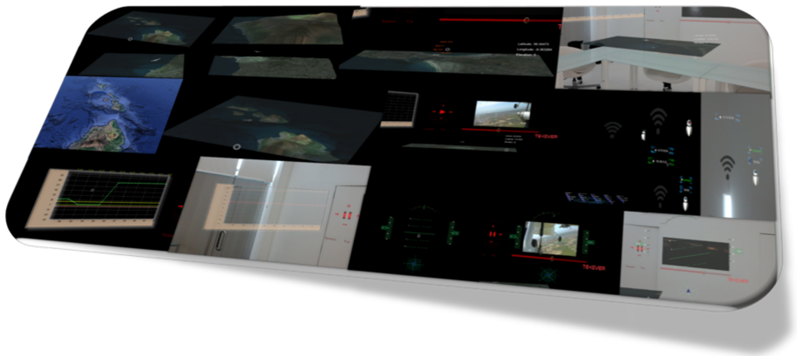

GoAR: Augmented Reality drone navigation from multiple spatial sensors

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Thesis to obtain the Master of Science Degree in

Information Systems and Computer Engineering

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Abstract

Drones and Augmented Reality (AR) have been gradually increasing their position in the future. Over the years scientific publications were testing and basing the central role of what augmented reality can bring to this branch. Throughout the project, we had different examples of how the combination of everything that had already been done can increment results in our final goal and key problem.

This project had as the main goal to present an implemented solution for the analysis of missions with drones, using augmented reality technology, and with this achieve better planning for future missions. With this prototype, we tried to aim to bigger cooperation between the participants, allowing the share of different analysis in a constant way. Thus, it was possible to generate a greater data dispersion in this 360-degree surrounding environment.

Resumo

Este projeto tem como principal objetivo apresentar uma solução para a análise de missões com drones, recorrendo a tecnologias de realidade aumentada, provando a utilidade destas ferramentas para um melhor planeamento de missões.

Publicações científicas ao longo dos anos, foram testando e fundamentando o papel fulcral que a realidade aumentada pode apresentar para o ramo. Em todo o projeto temos exemplificadas as mais diferentes provas disso mesmo, e de como a junção de tudo o que já possa eventualmente ter sido feito, em produtos distintos combinados, poderá incrementar resultados no nosso objetivo e problema chave.

Esta nova ferramenta visava criar uma maior cooperação entre os interessados, permitindo a partilha de analises distintas, de forma constante, e sendo assim possível gerar uma maior dispersão dos dados no ambiente envolvente, em 360º.

Acknowledgments

We are put to the test every day whether it's in work, in studies, in a game, or even in a simple crosswalk. However, are those obstacles that give us a goal, a purpose to live, a sense of achievement and fulfillment of dreams.

This path is long and full of setbacks, but along with the right entities and people, everything becomes easier. To begin with a big thanks to TEKEVER, and especially to Luís Simão for inviting me to be part of this fantastic team (Jorge Mimoso, Bruno Galveia and Pedro Constantino) and for helping me in the realization of this project. He always tried the impossible so that nothing was lacking.

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Then thank all my friends who accompanied me during this course, for making me see that the college is not only a place for studies and training, but also for experiencing unique moments.

To my family, Father, Mother, Sister, Grandfather and Brother-in-law who, throughout my life, were my pillar, my best friends. Who guided me throughout my training to the person I am today.

To finish my big thanks to my best friend, companion, girlfriend, Patrícia Marques. She is the reason why this work is finished and by which every day I strive to be a better person. Thanks for the patience, the help, the joys, the friendly words, but also more harsh in the right moments, deep down for making the best of me stand out. Thank you.

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List of Acronyms

AR	Augmented Reality
MR	Mission Replay
UAV	Unmanned Aerial Vehicle
UV	Unmanned Vehicle
UXV	Unmanned and autonomous vehicles
DRI	Detection, Recognition and Identification
HUD	Heads-Up-Display
XML	Extensible Markup Language
AUVW	Autonomous Unmanned Vehicle Workbench
IMC	Inter-Module Communication
PED	Processing, Exploitation and Dissemination
ISR	Intelligence Surveillance and Reconnaissance
HMD	Head Mounted Display
DDF	Decentralized Data Fusion
VSDPSim	Vision Sensor Detection Performance Simulation
KLV	Key-Length-Value
MVC	Model View Controller
SRTM	Shuttle Radar Topography Mission
UI	User Interface
C2	Command and Control
IMPACT	Intelligent Multi-UxV Planner with Adaptive Collaborative Control Technologies
C2-CST	Command and Controler Collaboration Sand Table
CTA	Computed Tomography Angiography

1. Introduction

Drones are more and more playing a fundamental role in the recent world driven by the technology advance. These UAVs has been used to capture different types of data in the most diverse application areas. Using a drone to operate a mission has fewer costs than if we had, for instance, a helicopter to execute the same mission. It is possible to enumerate more advantages like the dimensions, where we can now access locations not possible before, the fuel, flight time, security, easy to use and more. In a near future, drones will be responsible to assist in detection missions, in recognition and identification (DRI), in firefighting, in traffic monitoring, in event coverage, among multiple other applications. In this sense, this dissertation was carried out in collaboration with the TEKEVER business group, which, in turn, was the main driver of this augmented reality project.

The TEKEVER main focus is mostly on technology development, products and services in information and communication technologies areas, space and defense and security. It has as well a huge experience in aeronautics, where already has a wide drone’s fleet. These drones have the most different applications such as maritime surveillance, refugee tracking in the Mediterranean, and more.

Augmented Reality is often confused with Virtual Reality, yet both have a pivotal point that distinguishes them easily. Virtual Reality passes into a created and imagined "world", while Augmented Reality brings the opportunity for objects to be "transposed" into the real "world".

1.1. Motivation

One of the major motivations was to help, using augmented reality (AR), the growth in mission analysis (mission replay), through the provision of other forms of interaction, as well as the increase of data and its organization driving to new meetings dynamics. It would be motivating as well, in the future to improve this technology to a point where it could be possible to interact with the objects that leads to a change in the course of events.

In today's mission replay application, TEKEVER finds a way to gauge the success or failure of a mission that has already taken place. In this application, we can see in a single monitor different types of data such as a map of the terrain where the mission occurred and what decisions were taken. An area where is possible to selected data and visualize its evolution over time and another area with the different streams captured. Both of these areas have information captured by the airplane payloads (All components inside the drone).

It is through this program and in a meeting room that several collaborators meet and discuss the various points of the mission and, in the end, they can perceive which aspects they must maintain, need to be improved and/or difficulties encountered so that in a future mission can be corrected.

Augmented Reality is a technology that enables us a merge between the virtual world and the real world, allowing a greater correlation between the two. This area is not only in a great rise in the current panorama but has still much to give. Being able to bring to our reality this form of innovation is undoubtedly one of the main motivations for the development of this project. The fact that other areas already do it and demonstrate promising results also becomes a motivating factor.

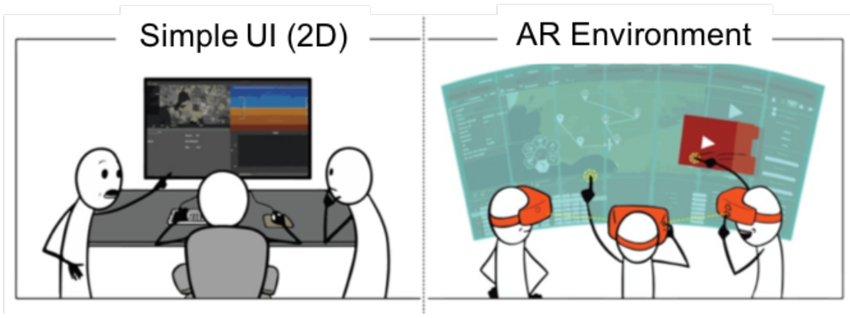


Figure 1 - Mission Replay Illustration

1.2. Problem Description

After a brief description of the current model in the motivation subtopic, we were able to identify some points to improve. Nowadays it is fairly easy to understand a video, but we can’t go further from what it is passed to us and realize in real time all the information that is made available to us and in a personalized way to our real needs. In short, that’s the problem.

Given the amount of information displayed on a single monitor and the need to switch between different views using the keyboard and mouse, we can quickly see several points as a distracting focus. Going into more detail, due to the high volume of information and its condensation into one monitor it is possible to see that our focus it will disperse frequently to other parameters than the essential, as well as the heap of views, overlaying each other almost making it impossible to observe the two views simultaneously (map and camera of the drone, for example), if necessary. It is still visible the effort that we have to provide to move near to our mouse or keyboard only to change between menus.

An example of a problem is when someone intends to offer a description of what is currently happening on the mission and, at the same time, we have a graphical analysis of another parameter running that might catch our attention. It is highly probable that we will lose part of the current discussion about the course of the mission at that time.

Following this reasoning, we observed that in a meeting scenario multiple collaborator try to discuss the critical points of the mission, but since only the application moderator controls the application, whether we like it or not, it manages the course of the presentation and so inevitably it is not possible to access all requests from all employees. In this way, it is impossible for all to make their contribution, for instance, evaluating important characteristics and presenting these same data in real time in a schematic and perceptible way or exploring a mission based on different parameters.

The fact that information is all agglomerated and concentrated in a single user is highlighted as one of the main focuses of the problem since in a discussion of ideas people cannot all interact in the same way in the conversation. Therefore, does not exist an environment so emerging, which in the end, results in a user very susceptible to other inputs from abroad.

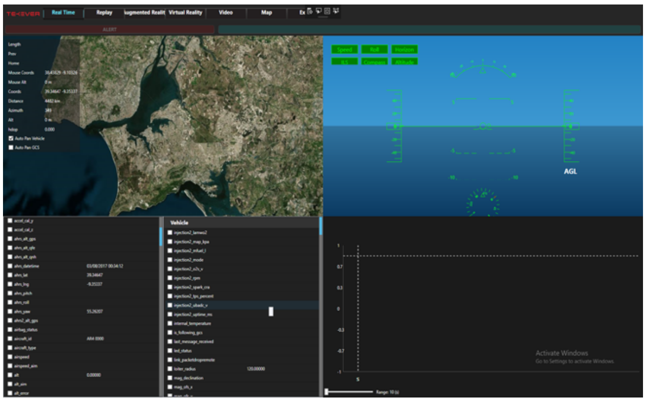


Figure 2 - Actual Mission Replay Illustation

1.3. Objectives

With the use of AR, it is possible to move from a monitor to a much larger viewing area, for example, where our entire room or whatever we want from it can be part of this projection and thus obtain a 180 or 360-degree view, depending on the necessities. Since, as we now have a larger area with which we can work, many of the problems described above were quickly resolved. Thus, it is possible to **abstract the different views of the mission replay in multiple viewing areas, arranged around the room**, such as the map, video player and some graphics. Access to these is then very easy because with a simple move of the head we can quickly view the content.

Through interaction with simple drag and drop gestures, we can manipulate the order or even which video we want to watch at the moment, whether or not it is in the preview pane. There also exists a mapping of a table, which function as an alternative to gestural interaction, since some types of more specific and detailed interactions may eventually require the use of the table because it is simpler to handle and requires less effort in terms of positioning the superior members. After a few minutes of use eventually becomes exhausting to be all the time with the arms up in the air. The table is where you will find the selection panel of data captured by the drone's sensors, where other graphics will be created, among other features that are considered necessary.

Some of these features can later be launched in the preview pane to perform other types of analysis.

With this work, **we aim to prove that with the expertise** of the latest augmented reality technologies will bring **much less room for errors and failures** and is advantageous at many levels like **portability, setup time, tasks speed, terrain realism as well as airplane behavior, the collaboration between stakeholders, reduce mission costs and stimulation to the use of new technologies**.

With this system, we intend to validate if we can achieve a **better future planning of the missions**, through a systematic analysis of them.

1.4. GoAR

To ensure the effectiveness and efficiency of control missions is necessary to assure that the drone pilot operates in an augmented reality environment capable of retaining all the information necessary for decision support, such as target selection and route definition.

In order to keep up with the points presented above, technology progression and correct some flaws from the current mission replay system, it appears the GoAR prototype.

In the first stage, this prototype is responsible for the analysis of missions that were already completed using augmented reality. Through a video player, a map and graphics built with data captured by the drone’s components it is possible to have an overview of what was done on a mission and what went wrong. That way, a future mission can have a much better plan and with that achieve better results, being more efficient and with superior performance.

For a second stage, but out of the scope, was discussed that in a near future it would be possible to control the drones during the mission, detecting real-time threats and sending constant information to the pilot.

So far, our solution works only as a mission replay. Currently, this tool has a video player with all the respective commands of a normal video player, such as a play button, pause button, speed control, timeline, and more. Contains as well, a terrain with real-world images and elevations at a small scale, a plot area where we can check how the information fluctuates over time and a place where we can select what data to visualize. The GoAR supports voice inputs to activate one more hidden area, the HUD. When we interact with the application to activate the HUD, is possible as well to receive feedback from what actions occurred.

1.5. Document structure

First, in section 2, we will identify some projects with similar purposes. These are divided into three categories: Drone Control and Missions Visualization, AR Applications for command and control and finally Others. In this section, we intend to explore the most diverse problems and realize how augmented reality can help in solving them. In section 3, we will explain our approach to these problems and how other augmented reality projects have influenced our solution. In section 4, we discuss how the tests will be performed and what the evaluation parameters are. Finally, in section 5 we present our final result and how it can help and/or be carried out in the future.

2. Related work

Below we start describing information obtained in works and articles, which we considered relevant for the development of this project.

To organize the information, we decided to divide works and articles into three main subsections. The first one concerns the control of drones and visualization of missions. Here we only talk about 2D solutions that have been implemented, some of which are still active in the real world. From these, we can learn about what data to extract, how the views are organized and what solutions are used to implement the software behind this type of business. These types of implementations have already been investigated and, with all that knowledge it is possible to take advantage of what they have best and understand the errors or limitations to improve our own solution. After 2D solutions on drones, the next is about command and control AR applications. In this case, we decided to include all applications of this type by increasing the sample and not restricting only to the drones. In this way, we can observe how to move from a 2D interface to a 3D and, once again, how to organize the data. In the last group, we've included some global AR projects grouped by different areas, where we can finally see all the capabilities of AR applications. It is a way of adapting to this new technology and thinking of unison with it. Know what to do, how to do it and when to do it.

2.1. Drone Control and Missions Visualization

Many systems that involve multiple remote sensors or machines require that a single operator control more than one device or monitor simultaneously. Thus, it is important that good interface design exists to avoid multiple problems because the inherent complexity of multi-platform control can cause confusion and operator overload.

In order to avoid the problems presented by 2D interfaces and improve them passing to AR, we studied some early examples of applications that were used to control drones, review or planning missions.

Over the years various tools have been developed and presented in articles. "The Autonomous unmanned vehicle workbench: mission planning, mission rehearsal, and mission replay tool for physics-based X3D visualization" [1] is an example of this. This tool published in 2005 allows the planning, testing and replay of missions for arbitrary (UV) unmanned vehicles. It was designed based on the features of the Autonomous Vehicle Control Language, having an extensible markup language (XML) vocabulary for task-level mission specification, vehicle telemetry, control orders, and sensor data. The tool developed, AUVW, has a number of features including 3D visualization of mission progress during testing and playback through the use of X3D - a standardized ISO format for web-enabled 3D graphics. AUVW also provides an appropriate planning tool for arbitrary UVs with innumerous utilities available to facilitate operations with real vehicles, including automated data format translations, support for AUVW-to-Vehicles communications and data transfer.

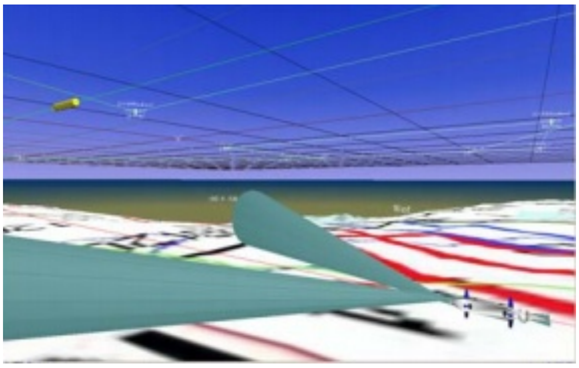


Figure 3 - ARIES and Seahorse autonomous underwater vehicles operating in the same virtual environment as seen in the Autonomous Unmanned Vehicle Workbench Xj3D viewer. [1]

That same year a pilot control experiment was carried out on a number of unmanned aerial vehicles to a group of pilots and published in “Mission control of multiple unmanned aerial vehicles: A workload analysis” [2]. Results revealed that both the AutoAlert and the autopilot automation improved overall performance by reducing task interference and alleviating workload. Practical implications for the study included the suggestion that reliable automation can help alleviate task interference and reduce workload, thus allowing pilots to better handle simultaneous tasks during single and multiple UAV flight control.

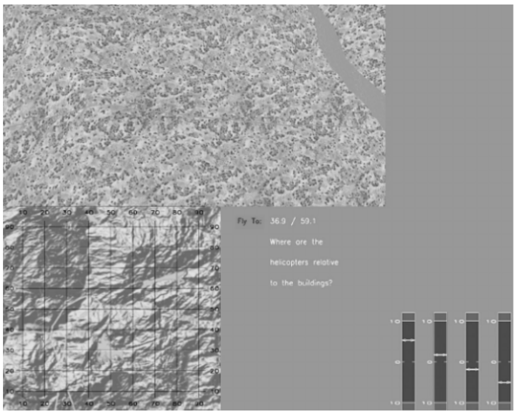


Figure 4 - UAV display. [2]

In 2009, the implementation of an advanced interface is presented for a UAV ground control station based on a touch screen, a 3D virtual viewer and an audio feedback message generator. This article, titled "A first implementation of an advanced 3D interface to control and supervise UAV (uninhabited aerial vehicles) missions" [3] refers to a workspace that considers mainly the operator's posture and the visibility of the 3D virtual display. The interface includes a mouse to navigate the synthetic environment on the virtual 3D monitor while monitoring the active mission The touch-screen display area contains in the center a north-facing navigation map giving a 2D view of the operator's mission area and two key side panels: the command-key panel on the left side of the map and the manipulation keypad on the right side of the map. The keypad panel is designed to allow the operator to send high-level commands. Each command consists of three substructures: "what task to perform", "where to execute it" and "how to execute it". That is, by analogy, the command keys are divided into three different blocks. Using the keys in the first block, the operator can define the specific mission type. Then, using the keys in the middle block, the operator activates the functions to interact with the map on the screen in order to select the points where the vehicle is forced to fly, called primary points, and the mission targets. The operator can also, by means of a text box, define the exact coordinates of the primary points or the target. The interface architecture includes a planning algorithm and a generic vehicle model, being a tool to study the interaction between the operator and the vehicle with different models and automation capabilities. The most important result of the tests was the semiautomatic activation of the replanning command, which allowed the operator to have the highest level of awareness of the situation and an acceptable level of workload during mission supervision.

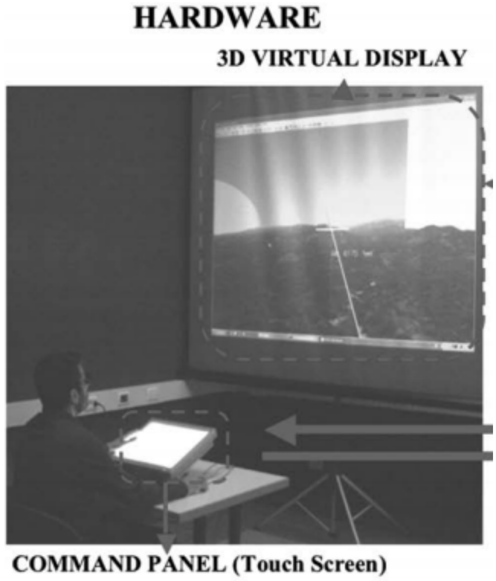


Figure 5 - Interface for UAV ground control station. [3]

Other control systems have been developed and improved over the years, with the Neptus control system being discussed in “Tools for UAV operations” [4] as an example of that. This system, published in 2011, is described as a flexible system in terms of planning and situational awareness, functioning as a messaging system that has interoperability capability (IMC) and also has an integrated software system (Dune) that interacts with several sensors. Neptus includes the Mission Planner application, which is intended exclusively for these tasks. In the Neptus Mission Planner, the map editor interface allows you to map the world in 2D and 3D views. The IMC protocol comprises different logical message groups for UAV operations. It defines an infrastructure that is modular and provides different layers for control and detection.

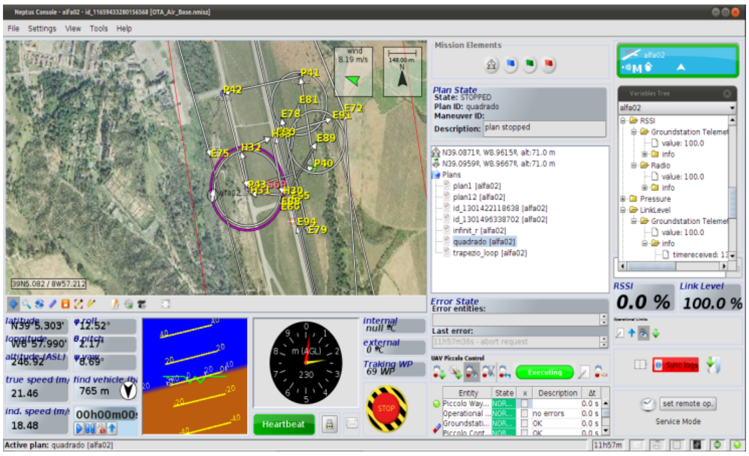


Figure 6 - Neptus Operation Console. [4]

In order to mitigate concerns about the natural increase of the operator's workload and the reduction of situational awareness, the change in the way information was transmitted to the operator in 2013 was tested. The article entitled “Adaptive Consoles for Supervisory Control of Multiple Unmanned Aerial Vehicles” [5] demonstrated the results of this study, based on an established framework that supports operating scenarios with multiple UAVs, where a series of changes were made to the interface of the existing operating consoles. After the test sessions, in a simulated environment, with human participants of different levels of operational certification, the results and feedbacks were analyzed. Operator feedback demonstrated an overwhelming preference for the consoles developed and the results showed improved situational awareness as well as reduced workload.

The creation of one more Framework has been another milestone this year. The article "High-level Mission Specification and Planning for Collaborative Unmanned Aircraft Systems using Delegation" [6] describes a new formal framework with an architecture based on the concept of delegation, which can be used for specification, generation, and execution of high-level collaboration missions, involving various vehicle platforms and human operators. These agents form a collaborative system where all participants cooperate to accomplish the mission. An agent-based software architecture, a mission language specification based on temporal logic, a distributed temporal glider, and a task language specification are described which, when integrated, provide a basis for the generation, instantiation, and execution of complex collaborative missions in heterogeneous air vehicle systems. Through the prerequisites, consequences of available actions and the current state of the surrounding environment it is possible to create an automatic task planner to combine actions in a plan to achieve objectives.

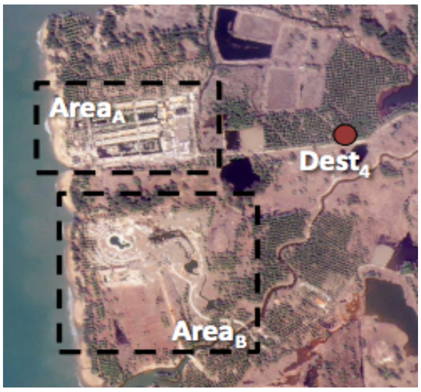


Figure 7 – Mission area map [6]

In 2017, the 'Ground Replay Station' system was developed by SAAB [7]. This software allows, through a two-dimensional interface, the review of missions performed by aerial platforms through the visualization of multiple video streams.

Figure 8 - MR Systems: (A) SAAB 'Ground Replay Station' [7]

Similar tools to 'Ground Replay Station' were developed by other entities, namely: the company Simulyze that presents the 'Mission Insight' [8], which in addition to the capabilities for planning and processing of data, also has a post-mission phase, with review capability.

With the advancement of time, a more complex system is presented by the company General Dynamics. They developed the TAC-MAAS tool [9], which includes several distinct capabilities of interest for Intelligence Surveillance and Reconnaissance operations, especially the post-mission 'Ground-based video replay' analysis and replication service. The TAC-MAAS is an advanced processing, exploration and dissemination of motion images (PED) software, which provides significant productivity and intelligence benefits for Intelligence Surveillance and Recognition (ISR) operations. TAC-MAAS has an operationally proven track record and has plug and play interoperability demonstrated with both manned and unmanned ISR platforms.

Provides an economical solution to leverage the intelligence of airborne sensor images. TAC-MAAS supports flexible deployment options from single user tablets and laptops through to scalable multi-user systems. Thus, this service acts as an add-on of the mission system and allows the visualization of multiple streams of video simultaneously through a two-dimensional interface. The TAC-MAAS allows, for example, the graphics provision of multiple data collected and processed during and / or after the mission, georeferencing them and making them available on a terrain map, as well as generating mission reports, which facilitates a review of the most relevant parts by the users, in a fast and efficient way.

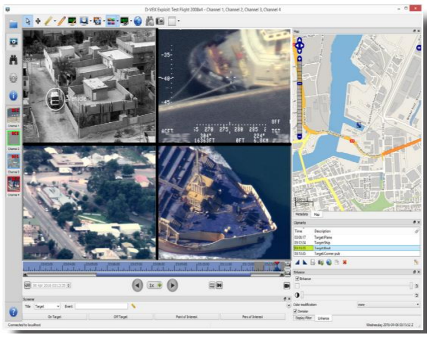


Figure 9 - General Dynamics 'Ground-based video replay' [9]

2.2. AR Applications for command and control

It was in 1991, presented in "Marker tracking and HMD calibration for a video-based augmented reality conferencing system" [10] a conference system in augmented reality, that used the overlay of virtual images in the real world.

Users remotely were represented on virtual monitors and could freely position themselves about a user in space. This tool allowed the user to interact and view virtual objects through a shared white screen. This interaction was performed by recording accurate virtual images using HMD visualization and calibration techniques. The results were positive when close to the user, however, accuracy was affected as the objects were further away from the camera.

Figure 10 - Virtual white shared screen. [10]

Over the years, in 2002, it is featured in "A collaborative tangible augmented reality system" [11], an augmented reality system (AR), MagicMeeting. This system now allowed multiple participants to interact with 2D and 3D data using "user interfaces". The system features face-to-face communication, collaborative visualization, and manipulation of 3D models, and seamless access to 2D desktop applications within shared 3D space. All virtual content, including 3D models and 2D desktop windows, is attached to tracked physical objects to take advantage of the efficiencies of natural two-handed manipulation. The presence of 2D desktop space in 3D facilitates the exchange of data between the two domains, allows control of 3D information by 2D applications and generally increases productivity by providing access to familiar tools. It was thus witnessed an augmented reality system with multiple users that allowed four users to have a zone of mission review design.

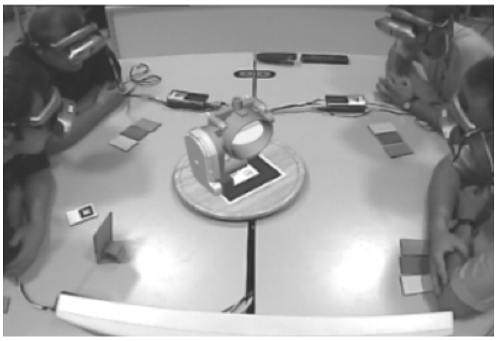


Figure 11 - Four User observe a common module. [11]

It is in 2005, in the article "An augmented reality system for multi-UAV missions" [12], presented a new approach in the use of AR technology in multiple missions of unmanned aerial vehicles (UAV). A tool to augment UAV sensor systems with decentralized data fusion sensors (DDF), running multimodal logging sensors and cooperative control experiments. The RMUS (multi-UAV simulator) began to be used in many multi-UAV simulations and also in actual flight tests like Control System missions. It was concluded that the AR system allows executing multi-UAV missions in which real or simulated UAVs or other heterogeneous agents interact with each other in real time.

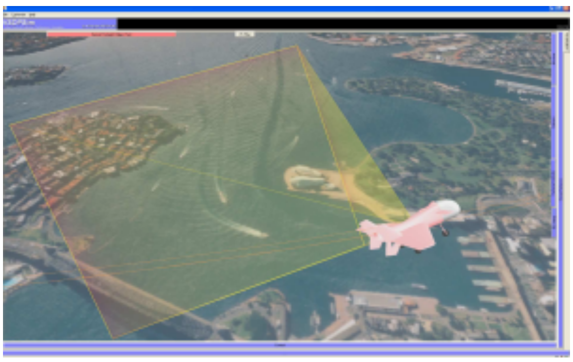


Figure 12 - RMUS Vision Sensor Detection Performance Simulation (VSDPSim) performance. [12]

Regarding the automatic planning of the flight path, although it is frequently applied, it is not possible to replace human beings in the circuit to date. In this sense, several problems have arisen such as the perception of depth of objects, the need to mentally transfer the position of the air vehicle between 2D map positions and the physical environment. In “Augmented Reality Supported Micro Aerial Vehicle Navigation” [13], dated to 2014, Augmented Reality is presented with navigation support and flight planning, enhancing the user's vision with information relevant to flight planning and live feedback for its supervision.

Figure 13 - Visualization of the enriched flight plan path with additional graphical clues showing the heights and distances between the singular waypoints [13]

A year later, in 2015, immersive viewers and the way they build spatial knowledge in multi-UAV operations will once again become a topic. This article, titled "Immersive displays for building spatial knowledge in multi-UAV operations" [14], presents an experience in which the operator needs to understand not only the 3D spatial relationships between UAVs but also how the UAV behaves in relation to obstacles. The objective of the research presented in this scientific article was to draw attention to the integration of immersive displays in UAV operations. From the researches, it was possible to conclude that a gradual increase of immersion improved the spatial understanding of the UAV operator. The virtual reality display and the Rift Glasses have performed better than a monitor solution.

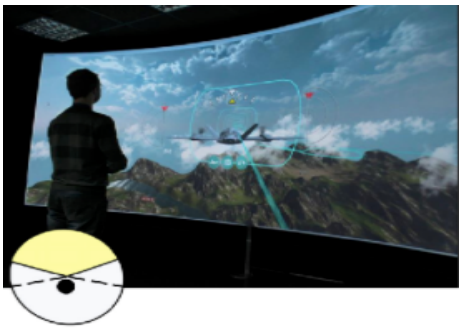


Figure 14 - Standard monitor solution in orthogonal display mode, VR Screen of CATEC installations in egocentric viewing mode and Oculus Rift. [14]

In 2018 a Command and Control (C2) display system using the Microsoft HoloLens and the Intelligent Multi-UxV Planner with Adaptive Collaborative Control Technologies (IMPACT) has been developed as a demonstration of a new advanced user interface and that's the theme of "Command and Control Collaboration Sand Table (C2-CST)" [15] article.

With this system it is possible for human-to-human-to-machine collaboration for situational awareness, decision making, and C2 planning and execution of simulated multiunmanned heterogeneous autonomous vehicles. The advanced user interface allows multiple operators to collaborate across a shared holographic sand table and control multiple vehicles. Multiple networking frameworks were used to offload the computation of vehicle autonomy and planning algorithms to allow the HoloLens to run efficiently for an improved user experience.

Results showed that human interface improvements in the presentation, understanding, and collaboration for C2 systems can achieve better situational awareness, decision making and effective interaction.

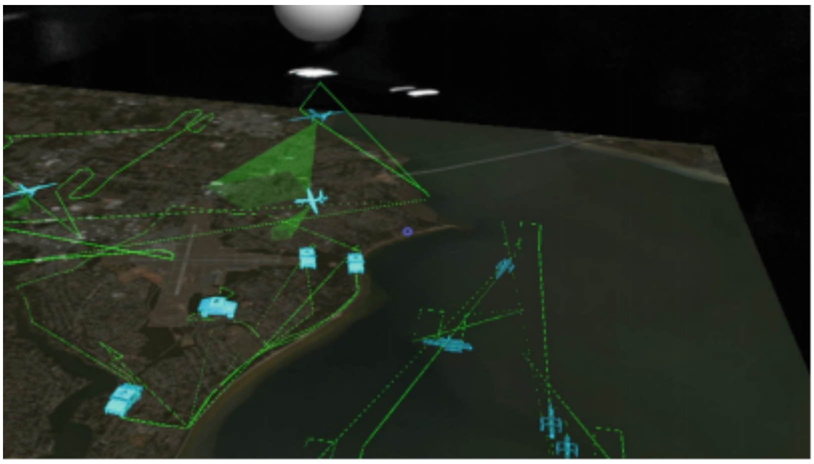


Figure 15 – C2-CST sand table display within the HoloLens [15]

2.3. Others

In this subsection, we will now talk about other projects that were very useful for the development of this prototype. In here we explore all the AR capabilities and see some examples of what it is possible to do. This way, we achieved a better adaptation to this kind of technology as well as some ideas for some developments.

In order for AR to be more used, it is necessary to implement new techniques that allow people a more intuitive form of interaction, concludes "Advanced Interaction Techniques for Augmented Reality Applications" [16] in 2009. New forms of interaction are described, among tangible user interfaces, multimodal input and mobile interface. MagicCup shows you how to use tangible AR design principles to produce a more intuitive interface - combine gestures and speech, to create efficient multimodal interfaces - and finally how to apply tangible AR to AR mobile interfaces.

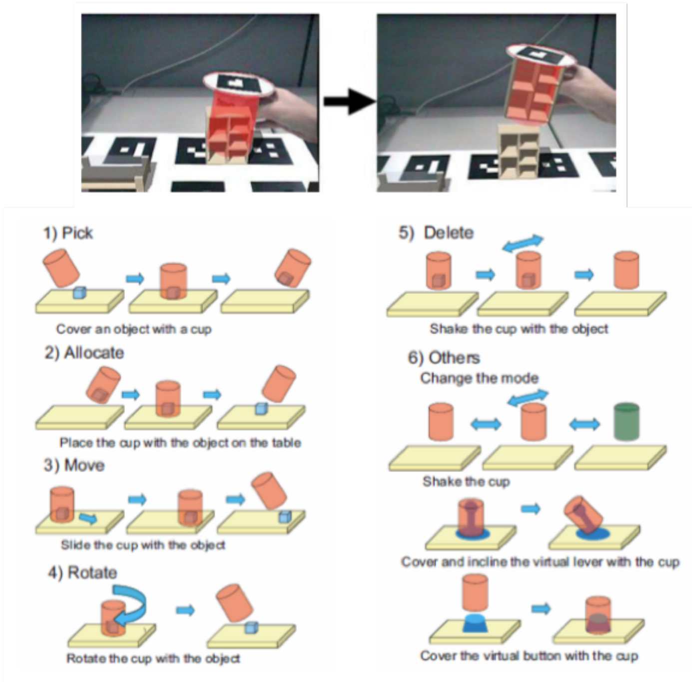


Figure 16 - Magic Cup manipulation methods [16]

Studies were also done in different areas of interest that add volume to the literature that is being published about this subject. "Simulation and augmented reality in endovascular neurosurgery: lessons from aviation.", Published in 2013 [17], does mirror this. The learning in an improved image environment, with simulation embedding. Evidence of how to do certain tasks can improve the safety of procedures and give the interventionists and trainees the opportunity to study or perform simulated procedures before the intervention, as well as in the case of aviation, always being a parallel between the two areas of study.

Endovascular neurosurgery is a strong image dependent discipline. Therefore, a technology that improves the amount of useful information we can get from a single image has the potential to assist in making decisions during endovascular procedures. Relevant data on the utility of augmented reality in education and learning of surgical and/or aviation techniques are discussed in the article. Finally, the benefit of augmented reality during endovascular procedures, along with future computerized image enhancement techniques, is evaluated.

Still in this health area emerged a new publication “Through the HoloLens™ looking glass: augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels” in 2018 [18].

This work has demonstrated that AR can assist the accurate identification, dissection and execution during reconstructive surgery. Biologicals structures were delineated from preoperative CTA scans to generate three-dimensional images using two complementary segmentation software packages. These were converted to polygonal models and rendered by means of a custom application the HoloLens™ stereo head-mounted display.

Intraoperatively, the models were registered manually by the surgeon using a combination of tracked hand gestures and voice commands. AR was used to aid navigation and accurate dissection.

The HoloLens proved to be a powerful tool that has the potential to reduce anesthetic time and morbidity associated with surgery as well as to improve training and provide remote support for the operating surgeon.

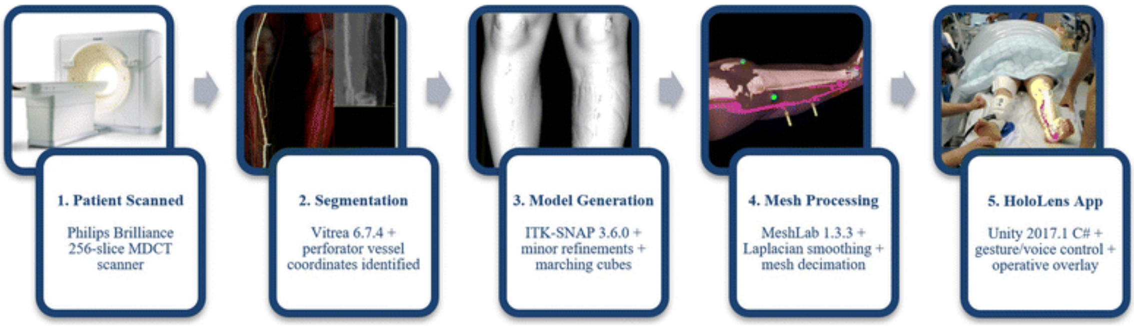


Figure 17 – Workflow diagram showing the processes involved in AR content production [18]

Passing now to the automobile industry we have Toyota trying to establish as a leader in the commercial augmented and virtual reality (AR/VR). Utilizing HoloLens and Microsoft dynamics 365 suite of AR apps they intend to begin to fill an integral niche in doing things such as coating finish inspection. As a result of this implementation, they were able to reduce eight of the labor hours previously required. It is possible to observe that they see AR as the future, and that way they want this technology to also play a role in optimizing and factory planning and space allocation. That way designers can easily visualize whether pieces of manufacturing equipment will fit in various locations.

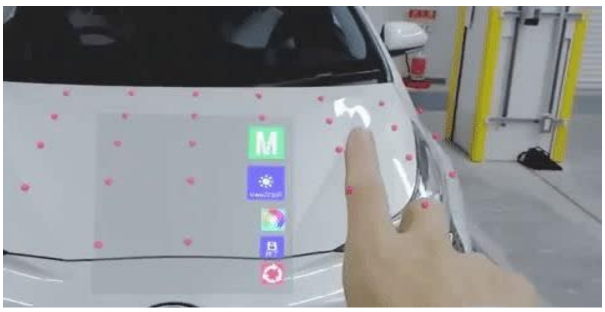


Figure 18 – Toyota Augmented Reality HoloLens project [19]

In terms of space, NASA is using Hololens to build its spacecraft faster. At the moment they use it to see holograms displaying models that are created through engineering design software. Models of parts and labels are overlaid on already assembled pieces of spacecraft. Information like torquing instructions can be displayed right on top of the holes to which they are relevant, and workers can see what the finished product will look like.

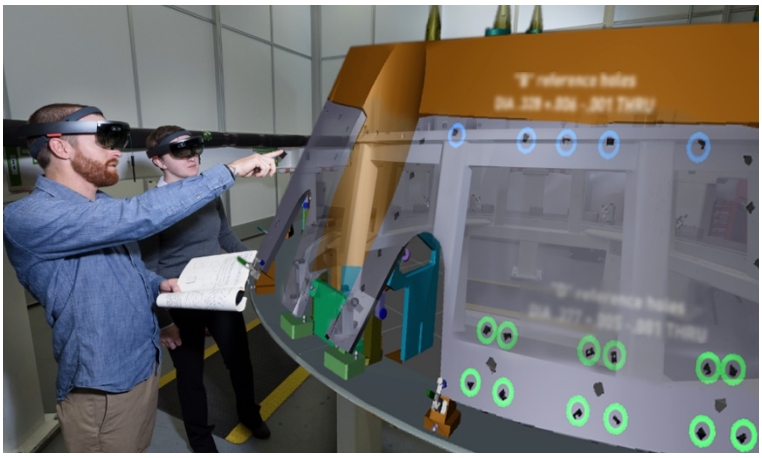


Figure 19 – NASA HoloLens spacecraft [20]

After showing some other areas that implement successful solutions, Microsoft itself offered a set of projects that helps developers to get accustomed to the technology and where a lot of capabilities are shown. Projects like Galaxy Explorer, wanted to take full advantage of the ability of HoloLens to render 3D objects directly in your living space, so was decided to create a realistic looking galaxy where people would be able to zoom in close and see individual stars, each on their own trajectories. It had to have some specifications like depth, movement, and feel volumetric—full of stars that would help create the shape of the galaxy.

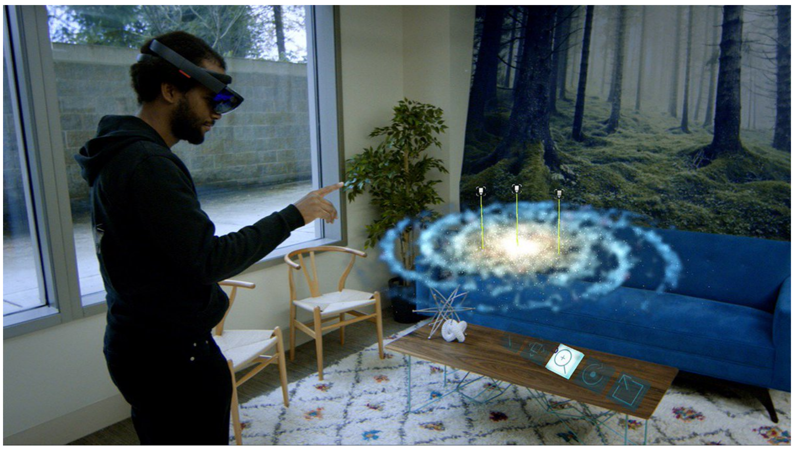


Figure 20 - Microsoft HoloLens - Galaxy Explorer [21]

Then we have the Periodic Table of the Elements where we can visualize the chemical elements and each of their properties in a 3D space. It incorporates the basic interactions of HoloLens such as gaze and air tap. Through this project, one big purpose is to learn how to lay out an array of objects in 3D space with various surface types using an object collection. Also learn how to create interactable objects that respond to standard inputs from HoloLens.

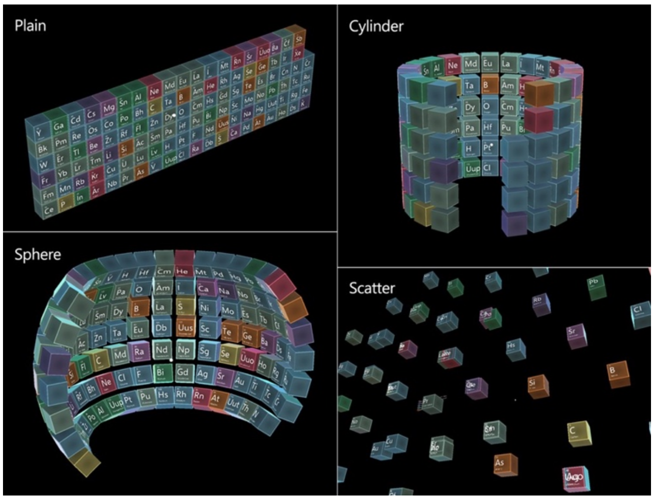


Figure 21 - Microsoft HoloLens - Periodic Table of the Elements - Object Collection in various shapes [22]

The next two projects concern to games and they were clearly useful to understand how spatial mapping works, from the topology to the placement of objects. The first one lunar module, where a player is controlling a space ship and has to land it into a safe place. In this case obviously a learning to withdraw is how to extend HoloLens' base gestures with two-handed tracking and Xbox controller input, create objects that are reactive to surface mapping and plane finding and implement simple menu systems.

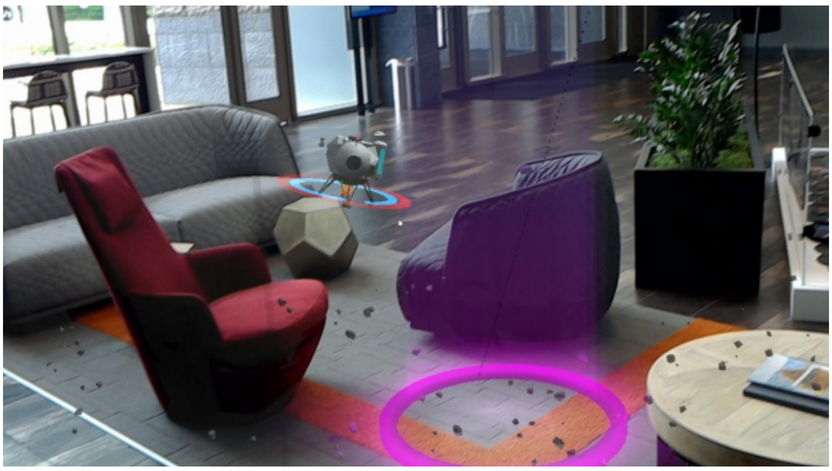


Figure 22 - Microsoft HoloLens - Flying the lunar module [23]

The second refers to the fragments. Where you are investigating a crime scene and it is important to follow the clues to solve a mystery that takes place in your real-world space. Because we are at the heart of action talking to characters or interacting with the whole environment, this leads to a very immersive experience.

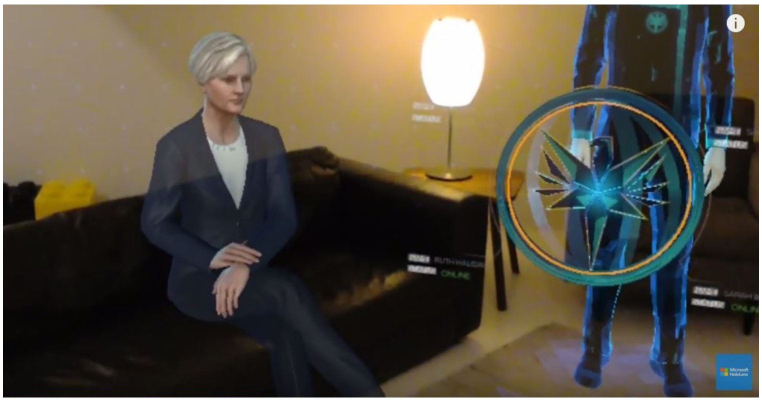


Figure 23 - Microsoft HoloLens - Fragments [24]

2.4. Analysis

After analyzing the articles and works presented below, table 1, we found different types of visualizations, interactions, and applications. It was possible to verify different types of prototypes, some that relate to UAVs and others distributed in the different areas of knowledge. Studies have been done on different types of technology, including 2D, 3D, VR and AR and where different themes are discussed such as simulators for planning, missions' reviews and Real-time applications for mission's execution. In all, the results were very conclusive, because it was verified that through the separation and automation of concepts, it is possible to reduce the operator's work, improve the planning of missions and also improve the mitigation of failures. We have also looked at the work that has been done in RA, in other areas, where unmanned vehicles are not protagonists, but other capabilities and ideas can be acquired.

Article	Dimension	Environment	UAV	Interaction	Audio	Voice	Collaboration	Spatial Mapping	Devices	Time	Studies
1	2D/3D	Virtual	Yes	XML	-	-	-	-	-	Non Real Time	-
2	-	Desktop	Yes	Peripheral	-	-	-	-	>1	Real Time	Reduce Task Interference
3	2D/3D	Virtual	Yes	Peripheral	Yes	-	-	-	-	Non Real Time/Real Time	Workload Reduction
4	2D/3D	Desktop	Yes	Peripheral/Messages	-	-	-	-	-	Non Real Time/Real Time	-
5	2D	Desktop	Yes	Consoles	-	-	-	-	>1	Non Real Time/Real Time	Situation Awareness
6	-	Desktop	Yes	Interface/Actions	-	-	Yes	-	>1	Non Real Time/Real Time	-
7	2D	Desktop	Yes	Peripheral	Yes	-	-	-	1	Non Real Time	-
8	2D	Desktop	Yes	Peripheral	-	-	-	-	1	Non Real Time/Real Time	-
9	2D	Desktop	Yes	Peripheral	Yes	-	-	-	>1	Non Real Time/Real Time	-
10	3D	AR	No	Gestual	-	-	Yes	Yes	>1	-	Fully Imersive
11	2D/3D	AR	No	Gestual	-	-	Yes	Yes	>1	Real Time	-
12	3D	AR	Yes	-	-	-	-	-	1	Real Time	Navigation
13	2D/3D	AR	Yes	Gestual	Yes	-	-	Yes	1	Non Real Time/Real Time	Navigation System Improved
14	2D/3D	AR	Yes	Touch Screens	Yes	-	-	Yes	>1	Non Real Time	Immersive Environment
15	3D	AR	Yes	Gestual	-	-	Yes	-	1	Non Real Time/Real Time	Better situational awareness, decision making and effective interaction
16	2D/3D	AR	No	Gestual/Multimodal Interaction/Mobile Interaction	-	Yes	Yes	Yes	>1	Real Time	-
17	3D	AR	No	Gestual	-	-	-	Yes	-	Non Real Time	Dramatically Assist decision making
18	3D	AR	No	Gestual	-	Yes	-	Yes	1	Real Time	Accurate identification, dissection and execution during reconstructive surgery.
19	3D	AR	No	Gestual	-	-	Yes	Yes	>1	Real Time	Optimizing and factory planning and space allocation
20	3D	AR	No	Gestual	-	-	Yes	Yes	>1	Real Time	SpaceCraft optimization
21	3D	AR	No	Gestual	Yes	Yes	Yes	-	1	Non Real TIme	-
22	3D	AR	No	Gestual	-	-	-	Yes	1	Real Time	-
23	3D	AR	No	Gestual	Yes	-	-	Yes	1	Real Time	-
24	3D	AR	No	Gestual	Yes	-	-	Yes	1	Real Time	-

Table 1 – Resume Board

From the articles analyzed, and outlined above in the table.1, it is possible to make a separation into two types: those related to studies carried out on the topics to be explored and those related to developed software. Entering the branch of articles that reported developed software, it was possible to verify that much already has 2D and 3D features, simultaneously, since the inclusion of 2D brings the user closer to what is used today in the interactions with the application interfaces, which facilitates the mode of interaction with the program. Conversion to 3D menus is thus more easily accomplished and accepted since the user has the opportunity to work in both 2D and 3D environments. This ability to bring innovation leaving familiarity points with technologies more known to the public is a focal point in acceptance and conversion. However not all applications have followed this direction, and some of them have only been launched using 3D technology. Although 3D requires a stage of ambiance, its advantages are enormous because it adds value in visual terms, that is, we get a more realistic view of the models and still adds great value with respect to the interaction with the platform, being possible a closer contact with what is generated/displayed in the tool.

In the field of interaction with the application, the most varied existing methods are demonstrated, with the most representative being gestures, followed by peripherals. It is important to include two or more interaction methods, so that end users have the opportunity to choose. For example, if the application only has gesture interaction available, it is possible for the user to feel fatigued by keeping members up and/or in the same position for long periods of time.

It is also worth mentioning that there are few articles that present voice recognition, a fundamental tool for basic aspects, such as for processing video commands or activating an overlay. In this way, we facilitate interaction and processing speed of actions.

Of the articles of augmented reality analyzed almost all, if not all, present HMD devices and spatial mapping, much also due to the inherent capabilities of this hardware.

Collaboration among users is presented and discussed in all articles as one of the main focuses in the development of augmented reality applications. Dynamic interaction between the various players is one of the main points that this technology can offer, namely the sharing of content in real time.

It is also possible to analyze, based on the documentation, that with the decoupling of views the workload of the operators has reduced and therefore, the Situation Awareness increases, and thus, the success of the mission increases accordingly.

Many articles focus on both Real-Time tasks and non-Real-Time tasks. The ability to control multiple devices is also a constant, and one of the main focuses of analysis.

Specifying how we operated in relation to the application, object mapping and interactions are performed both in 2D (in the spatial mapping of the table) and in 3D. This approach is critical to manipulating data and monitors present in the *Mission Replay* application. Concerning the interactions, some voice commands and their audio feedback are possible as a result of some actions. The study is mostly in non-Real-Time since it has a great focus on the analysis of a posteriori missions and, therefore, better planning for future missions.

It is noteworthy that several studies mention collaboration between the mission actors as the object of study and as a great improvement. It has therefore been taken into account as a focal point for implementation since it is intended to provide a great deal of freedom for users to be able to analyze the data they want and then be able to share any relevant information.

Currently, the 2D interaction component is not active in the table mapping, and we still resort to gestures and look to control this view. However, efforts are being made to make this interaction work in 2D, through sensors present on the table, so that later it is necessary only to click on the corresponding place in the table to activate the information that one wishes to observe.

3. GoAR

In this chapter, we will talk about the implementation of the GoAR prototype. It has been designed in AR and projected to bridge some of the current 2D application flaws, but also provide another more dynamic and optimized form of mission analysis with a strong collaborative component.

For the construction of this AR new capability being added to the actual MR, we used HoloLens glasses technology to reproduce an augmented reality environment. Not only because it was the device available by the company, but also due to the optical see-through system. These glasses have the technology for voice recognition, audio and countless sensors with different capacities, such as spatial mapping, gesture detection, among others.

Through some glasses functions, it is possible to create common endpoints that will serve as a communication portal for all collaborators. In this way, it is possible to take into account one or more points of observation common to all. The room will be mapped and will function as a 180º or 360º viewer, where the tables will be another way of interacting with the surrounding environment. The tables will have some commands, such as the selection of metadata supplied by the UAVS payloads, the manipulation of videos, among others.

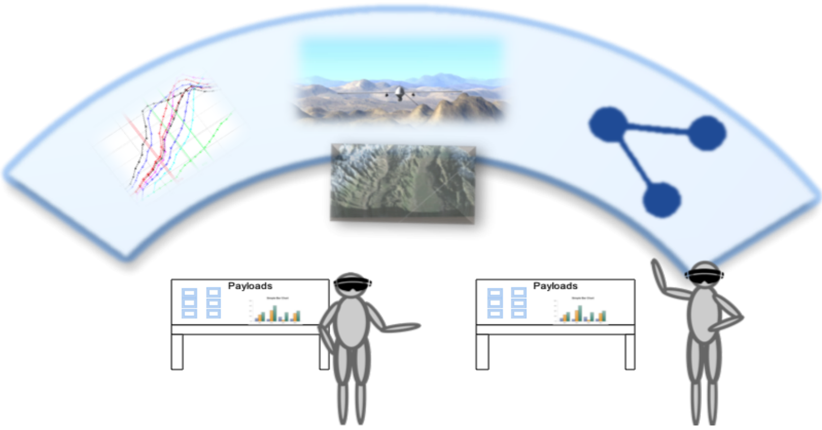


Figure 24 - Mission Replay Conference Room Project

To validate whether this AR component is feasible to be used or to perceive its strongest points has been defined a set of parameters that we consider fundamental to evaluate the success of mission review meetings.

Taking into account the 2D version and the RA, we chose as time factors the portability, the setup time of the Setup and the execution time of the tasks. Time factors were considered fundamental because they often influence the dynamics of work.

As factors for the minimization of errors and failures, I emphasize, among others, the realism of the terrain and the airplane and the arrangement of the different views. By reducing this critical factor, we can not only improve software and hardware but also achieve better planning of future missions. For example, by presenting a 3D model of the mission site, it is possible to better recognize space, possible trajectories, and many other details. Through the dispositions of the views we can increase the situational awareness and with that also reduce the failures.

With regard to the cost reduction factor, the goal is always the same, to increase the quality and reduce the number of resources to achieve it.

Collaboration among users is highlighted as one of the most important factors, as it calls for the participation of all stakeholders in a mission review, in which everyone analyzes and makes their own contribution.

We also consider the stimulus for the use of new technologies as one of the factors, because the desire to use will be greater consequently will lead to further reviews by users, which inevitably leads to improvements.

3.1. Architecture

After a brief discussion of our approach and what technology we will be working on, it's important to observe the entire flow of the application and how each module works with each other.

The architecture below [25] shows the actual Mission Replay capabilities. Actually, there is an implemented 2D application that is used to review missions. Now two more features will be added to that application like Virtual Reality and Augmented Reality technology. In this thesis, we talk about the AR implementation.

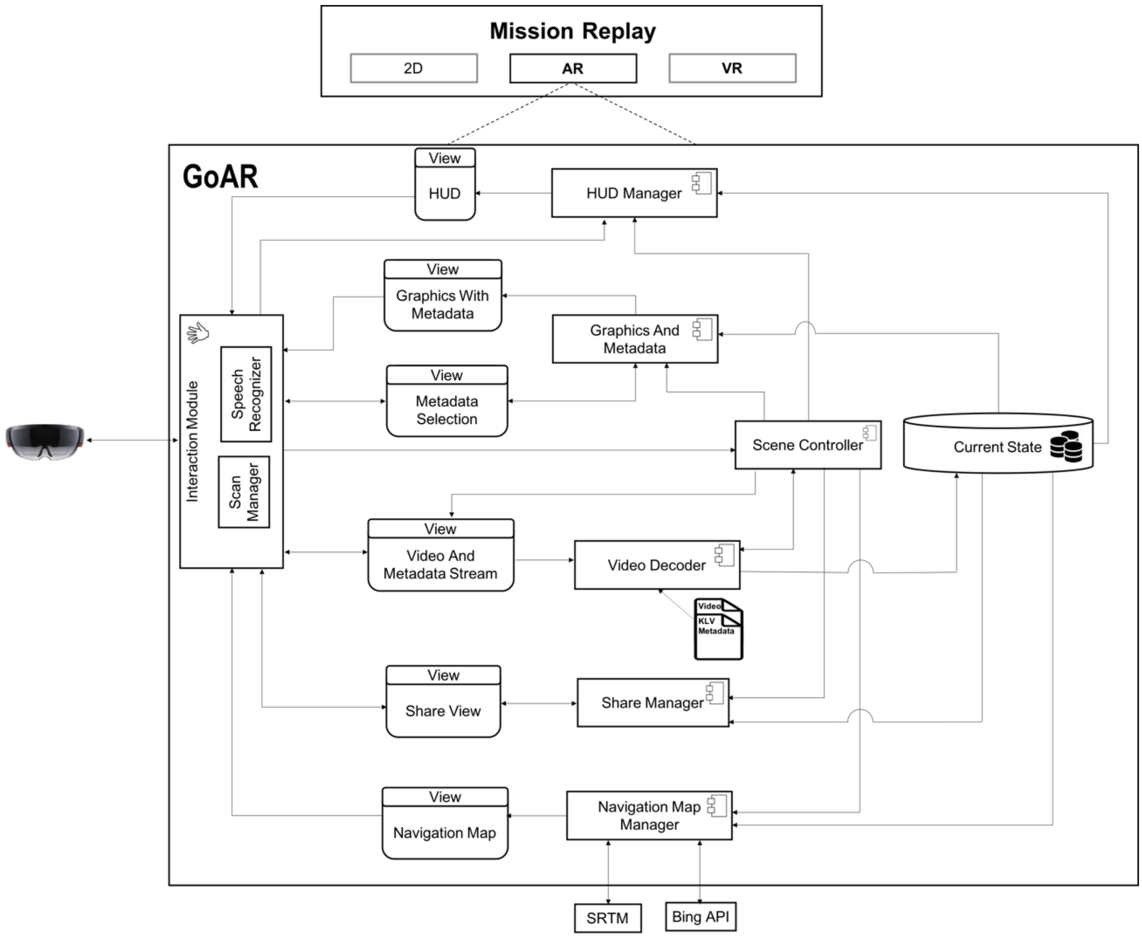


Figure 25 - Mission Replay Architecture

In a first analysis, we adopted an MVC approach. Where after a scan, a module is created to control the whole scene, what objects to create, what actions to do next, summarizing monitor the full pace of the application. Then two important module, Video & Metadata Streams and Metadata Selection, are placed in the world. The first one that supplied the current state, our data model, with information extracted from the drone's components like described below and the second one that mapped the data of the current model in a view for the user to select what that he wished to observe.

The video of the mission that we are analysing had to be synchronized with the provided metadata so that we could explore the different parameters exhaustively and in detail. This point above was one of the challenges explored, being able to associate the data with the exact moments and integrate them as if they were part of the video itself. This implementation was performed using the *FFmpeg* framework. After synchronization and data extraction from the KLV stream, they will be stored in a data model, called Current State. Thus, any data that is needed will be readily available. From the moment that data exists in the data model, other modules can now consume the model.

All modules have different forms of interaction with each other. Mostly throughout events, but two more forms were utilized like http requests and voice recognition with a speech dictionary. Below each component is described in more detail.

3.1.1. Scene Controller

This unit [26] is responsible for controlling, creating and starting the other modules. We can say that is the engine of the application. Although the modules may function independently of each other, this is the bridge between the user interface and the different other parts of the prototype. For example, it ensures control of the flow of metadata or perform actions that went to a dispatcher from other components and more. It is through this module that the main thread is update. So, when a different component requires an update in the main thread sends an action to a dispatcher and it is then up to the controller to know when to run. Also, sends messages to all the current state subscribers when occurs a change in the model.

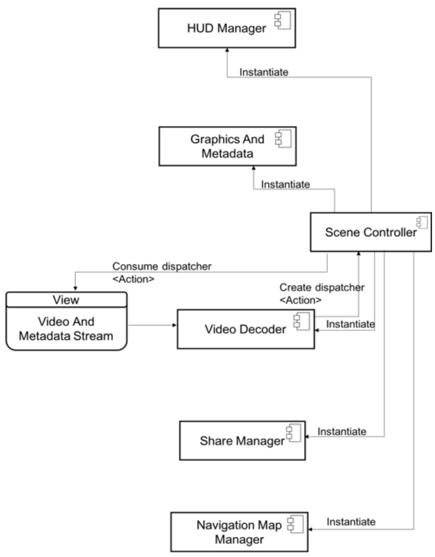


Figure 26 - Scene Controller flow

3.1.2. Interaction Module

The Interaction Module [27] makes the connection between the AR glasses and the different views. This interaction is triggered via events. They can be gestures, gaze or voice events. At the beginning and through HoloLens technology is responsible for the spatial mapping of a wall and a table that, when completed, triggers scene control to begin processing the scene. One important note is the creation of a speech manager, that can be activated or deactivated in the share view, with a dictionary of available words, so that our voice commands can be recognized.

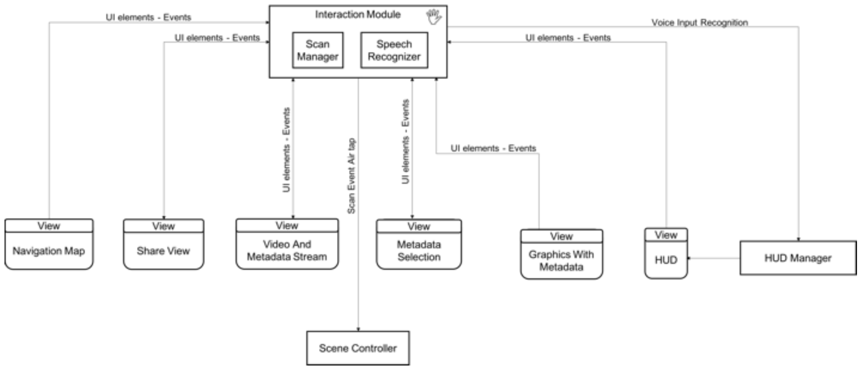


Figure 27 - Interaction Module flow

3.1.3. Video Decoder

Once everything has been mapped and the objects placed in the right place with a simple click of the play button, it is time for this module to work [28]. Mission Replay features a ".ts" extension video with hidden data. Then, in the beginning, with the help of *FFmpeg*, the module will separate the different streams presented in the video. Having obtained the streams, we are likely to have three different types, the video stream (.h264), the audio stream, and a KLV stream. The next phase is then to start the assembly of our video player. It is important to determine the frame rate of the video and thereby show the correct frame at the correct time. At the same time, the decoded data, klvs, are being saved in the current state. As we can see, our video is nothing more than a sequence of frames shown at the right moment.

It is important to note that this module will be running on a different thread and sending, to the scene controller by means of a dispatcher, an action of when it should show the next frame. In this way, we can increase the performance of our application, not slowing down the other modules. This way the main thread will almost always be available for work that really matters.

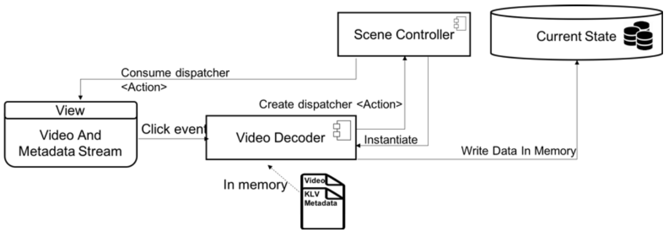


Figure 28 - Video Decoder flow

3.1.4. HUD Manager

This module [29] is triggered by voice events. In this case, we construct a speech manager that includes a dictionary with all the words to be recognized. After that, and with the help of *Holotoolkit*, the dictionary is passed to a Keyword Recognizer that is active throughout the lifetime of the application, capturing the specific words to activate that area. These events only change the visibility of some components within the HUD. These components were previously created and registered in the current state to be informed about changes. This way, when they are visible, they can start receiving data. This module is powered by the current state.

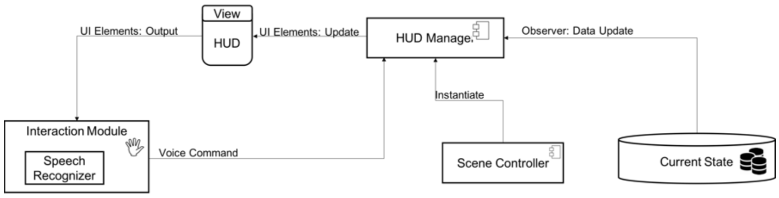


Figure 29 - HUD flow

3.1.5. Graphics and Metadata

With the need to analyse the data over time, this component appears [30]. When created by the scene controller at the beginning of the application, it is soon registered in the current state to be notified when it is updated. It has a list of active data selected by means of an event, from the fields displayed on the mapped table represented by the "Metadata Selection View". Then is only a question of a match between the data that is in the current state and the data that is active to show in the plot. It still has an important function like updating the "Metadata Selection View" with new fields encountered in the data embedded in the video.

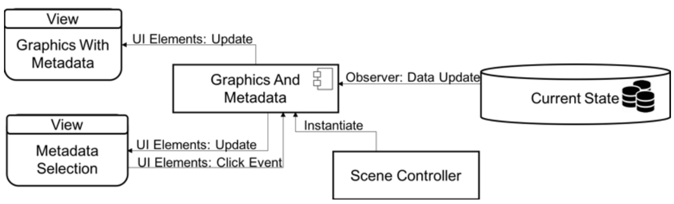


Figure 30 - Graphics&Metadata flow

3.1.6. Navigation Map Manager

The navigation map [31] is one more that, when created, registers in the current state and receives updates. It consists of two components. One being the model of a drone and the other the terrain area, whose plane is flying overhead. It is possible to observe in the airplane through the data extracted from the application model the behaviour of this one. In it are represented some data like raw, pitch, yaw. The center map will make use of different technologies, such as SRTM to capture elevations, and the Bing API to extract the Tiles, which will work as textures. These two requests are made via a unity class whose name is WWW. WWW class is important so we can retrieve contents of URLS. In the present situation both request symbolize a GET. One to get an SRTM zip file, which subsequently is unzip and saved in the “StreamingAssets\SrtmDataFiles” folder. Whenever one of the files is necessary just go to the folder indicated. Otherwise another request is made. To extract the Tiles from the Bing API, the process is similar. In this case, and because the operation is faster, it is not necessary to save the result of the request to a folder. After all it is only a matter of mapping everything on the terrain.

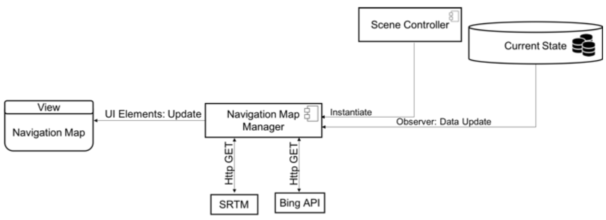


Figure 31 - Navigation flow

3.1.7. Current State

This module is nothing more than our data model, built as an object-oriented database (OODB) [32]. This is where all the information is stored and where almost all the modules are fed. This data model is filled as the video passes in "video decoder" when the KLV stream is encountered. When some modules need information, can simply request for data inside this model, but for most of the cases the current state allows subscribers and after they are notified about all the changes.

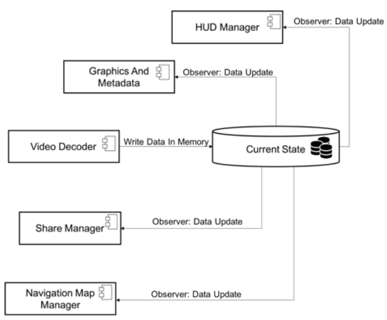


Figure 32 – Current State flow

3.1.8. Share Manager

In order to achieve collaboration between all users, this module [33] appears, which is created simultaneously with the video player in a common point to all participants. Its function is to save the list of users, shared information over time, but also to create all the necessary data for a user to be able to share their view. In this sense, an object was created responsible for storing the user's IP, the active metadata and the instant of the corresponding video. Through this information collected in the Current State, it is possible to later feed the views common to all users with this information. The sharing objects, as well as the user list feed, are created through events sent by the share button.

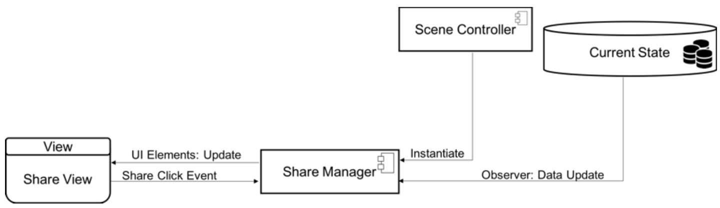


Figure 33 - Share flow

3.2. UI

In terms of the user interface, it is important to note that the prototype offers many ways for the user to communicate with the application. The user interface has many forms of interaction, being the gaze, gestures, and voice. The first two options are the best. With them, you can click the UI buttons that control the video player, for example, the play/pause, forward, rewind, and speed control buttons. With a simple combination, we can control the timeline using a click gesture and then looking to the right or left depending on whether we want to move forward or backward. One more option to manipulate the timeline is clicking at the correct time. And finally, for a first approach, choose which metadata we want to analyze over time. With voice input, you can enable an overlay view, the HUD. The HUD also has different components, and all of them can be turned on or off by voice input.

The surrounding environment will consist of several panels [34]. One more to the left responsible for the visualization of graphics, a central one for the reproduction of the video of the mission (with an anchor point, making it visible to every participant in the room) and still one more to the right that will be the panel of interaction between the collaborators. More panels can be allocated, block or sorted lately if necessary. Also, to be highlighted is the inclusion in the middle of the field of view, below the central panel, the placement of a 3D map of the world with the respective elevations and also a drone model. Both will be in accordance with the data embedded in the video. Different additional information can be entered, such as mission waypoints, or other relevant factors. We would also like to point out a view mapped in a table for users to interact with the graphics views.

Some of the software will be based on the *Holotoolkit* Framework, which provides tools for user interaction with the application (both voice and gesture), spatial mapping components, user collaboration, and more.

In order to approach the subject described in the previous points, let's explore a simple use case with the possibility of individual analysis or in a joint environment with the interaction of several users of an aeronautical mission. So as an initial point, the conference master will do the scan of the room. After that, he will place a video in one of the room walls, common to everyone, and each player can visualize different parameters, through characteristic graphs of a mission, or activating a head-up display and/or other menus where it is possible to select or standardize according to the personal preferences of each user.

All selections, choices, or changes are user-to-user independent (for example, one user can simulate a variation in wind speed, and the other user a variation in altitude) as well as any other interaction with the video. It is also possible that any graphics, parameters or other factors are shared through a sharing dashboard accessible to all users, or even using a meeting moderator who would also be responsible for some mandatory tasks.

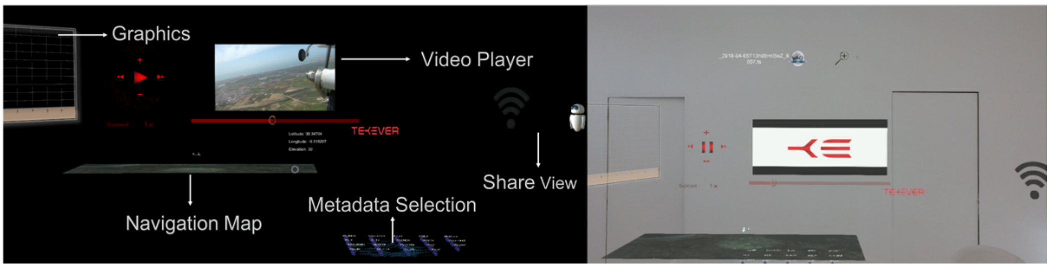


Figure 34 - AR Mission Replay Geral View in HoloLens

3.2.1. Interaction Module

The interaction module is what brings to life all the objects animation. It's through this that the user is able to interact with the interface, not only by gaze and gestures but by voice as well. The majority of these user inputs are made with the help of a framework called *Holotoolkit*. This component has a connection to "video & metadata streams" through the buttons and to the HUD with voice inputs. Still, with the aid of that framework, we have the spatial mapping [35]. At the beginning of the interaction with the application, is asked for the user to map a wall for the video projection, common to all collaborators, and a table where all the data is listed. It's on this table that the user can choose which ones are activated in each moment.

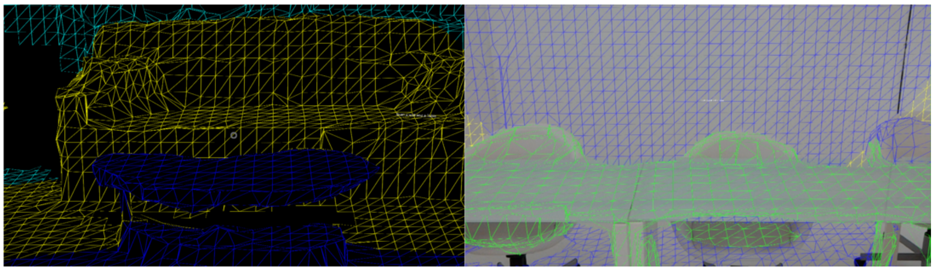


Figure 35 - Spatial Mapping in HoloLens

3.2.2. Video & Metadata Streams

The view represented by this subtopic is in the middle of the screen, above the navigation map, because it is the mission main point. It has multiple ways of interacting with the user, especially using buttons [36]. In the center left has the play button responsible for starting the video and all the work behind. After the click, the button changes and a pause button is displayed. Just below the user are presented two buttons, one button forward and another button back. These two add or decrease 3 seconds to the video time respectively. In the center on the right, the view has more buttons, responsible for controlling the video speed. Like all video players, a timeline is required and, this is shown just below the video. Its usability is very simple. To go ahead in time is only necessary to click where you want to go on the timeline. But there is another possibility by clicking on the timeline and looking at the side to where you want to move it, forward or backward.

Figure 36 - AR Mission Replay Video Panel in HoloLens

3.2.3. HUD

This view is a hidden one [37], shown, when activated, in front of all other objects like an overlay. It is activated only through voice inputs and, when shown, looks like a normal airplane HUD, where all subcomponents of this can be enabled or disabled with specific commands. For example, we have five different parameters in the HUD, the pitch ladder, airspeed, altitude, roller, and compass, each of which is enabled or disabled with the following formula -

component name + "Enable" or "Disable". After the command, audio feedback will be given. A HUD is nothing more than a canvas in the screen space with objects representing some drone metrics.

Figure 37 - AR Mission Replay HUD Panel in HoloLens

3.2.4. Graphics with Metadata

Probably during the replay of a mission, a deep analysis of specific data should be made. Therefore, viewing graphs is a good option to see how variables change over time, checking for any anomalies. At the view [38], we can see what data is currently active and what is the represented color in the chart. It has a direct association between the color of the metadata represented by the cube in the “Metadata Selection”. When you go over the graphic with a glance, you can check the value at each moment. Again, this is one of the modules powered by the current state. This view is on the right of the one shown in the “Video & Metadata Streams”.

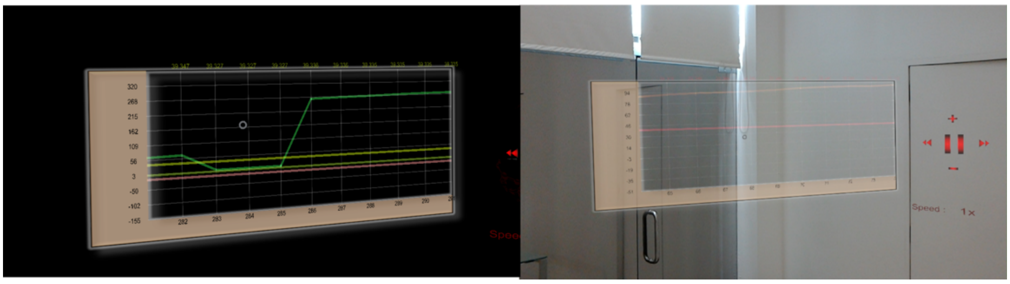


Figure 38 - Graphics Data Variation in HoloLens

3.2.5. Metadata Selection

After a previous table mapping, this view is placed on the top of it [39]. It has the responsibility of mapping all data that has been parsed so far and saved in the current state. The view is currently represented as a list of items. Where each one has a label and a toggle cube that changes the color and rotates, giving feedback to the user of which data is currently active and shown in the graphics view. Can be accessed and controlled via gaze and gestures.

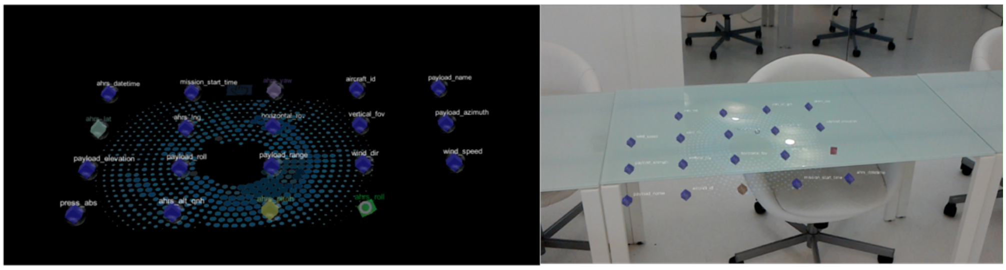


Figure 39 - Metadata Selection View with active fields in HoloLens

3.2.6. Navigation Map

The navigation map [40], placed in the center, is one of the most important modules. Here we have a faithful representation of the area covered [41] in the mission or even the world, depending on the zoom [42]. This is possible by making use of the Bing and SRTM files. Bing blocks are responsible for the actual textures with different zooms and SRTM files for elevations around the world, represented in the prototype on a smaller scale. It is still possible to observe, above the map, a company drone model that, with the help of the current state, has the correct data to show the developers all drone behaviors during the mission. For instance, check if the drone is at the correct altitude or slopes (raw, pitch, yaw) and more.

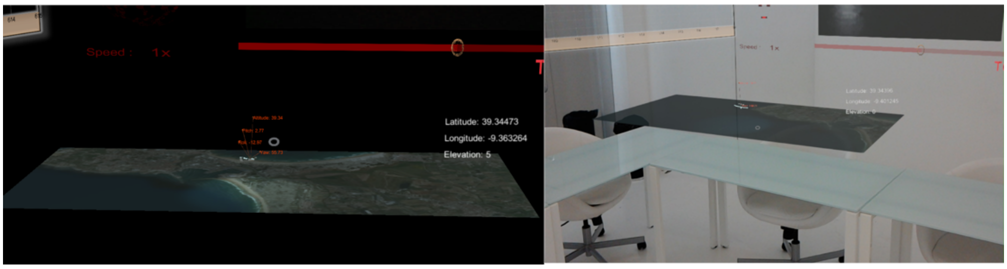


Figure 40 - Data in Navigation Map in HoloLens

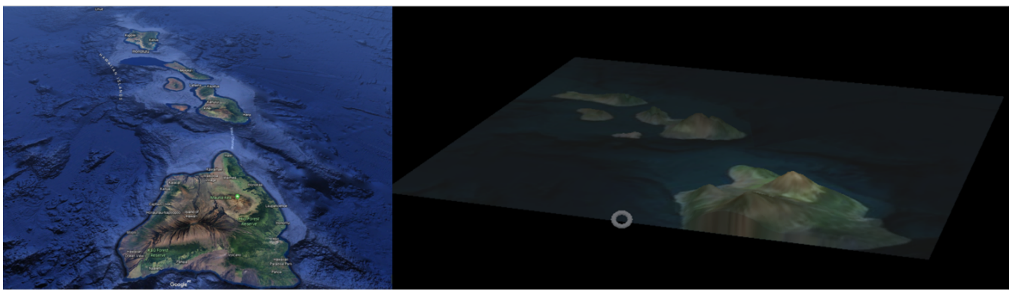


Figure 41 - AR Mission Replay Terrain elevations - Comparative results in Hawaii region

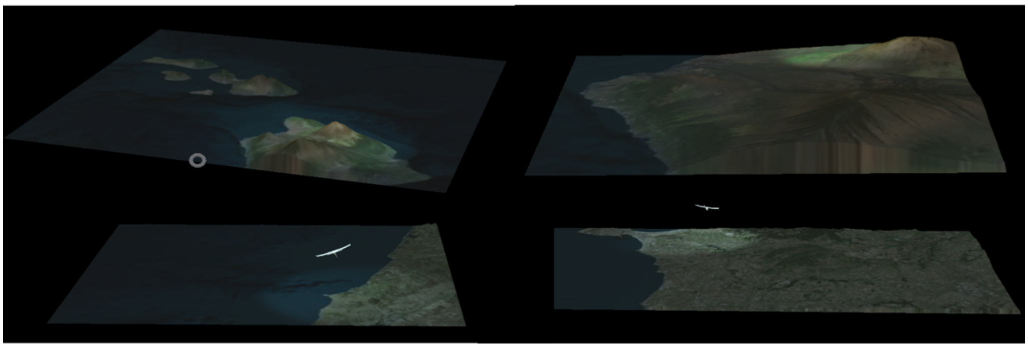


Figure 42 - AR Mission Replay terrain with different zoom levels

3.2.7. Share View

To further promote collaboration among users "Share View" was created [43]. Placed to the right of the video view it has two elements. The first element represents a button that functions as an application wizard. After clicking this button, in the form of a robot, a menu is presented with two different options. One concerns the information sharing button relative to what is being viewed and another responsible for activating the application's voice recognition. The second element of this view, whose model is a wireless connection signal, after being clicked presents an interactive list of the last three users who shared information. Each element in the list, in turn, displays the IP of the user that is sharing and the corresponding time video. After clicking on an option in the list the environment changes and displays the content that the user shared at a given moment.

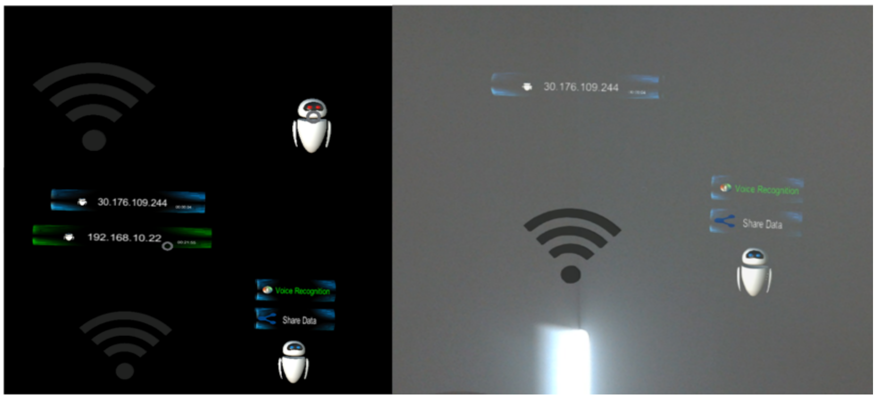


Figure 43 - Closed & Opened Share View in HoloLens

3.3. Discussion

After this brief explanation of the architecture, it is possible to verify that this prototype presents the most different views and modules for good mission analysis, always taking into account the collaborative component between users. In this sense, using all that has been explained previously, it is possible to observe how the whole application works. Firstly, a user is asked to be responsible for mapping the room. Then anchor points are created for all users in the room, namely Video Player and Share View. Once the common points have been created the remaining components are created by the scene controller, which are unique for each user, among them navigation map, graphics with metadata and metadata selection. After all this process it is then time to begin to analyze the mission, being this one customizable according to the preference of each one. Once a failure or something significant is detected, users can share what are seeing with all the staff present at the meeting.

Next, we intend to demonstrate the results of the AR prototype and compare them with what is currently in Mission Replay 2D.

4. Evaluation

For this project, the evaluation consisted of only one final phase of testing.

In this phase, a prototype of the product was already presented with all the implemented requirements. Thus, with the enrolment of 8 users, a conference room and HoloLens goggles, they undertook a review of a mission using AR technology. Data sharing, mission visualization, interaction with the data visualization model, both by gestures and voice, dynamic visualization of the mission through the map presented below the panel and correct synchronization of all data with the different modules were tested. During the tests, the same users who tested in AR performed the same tasks in the mission replay 2D model. After this evaluation, it was time to evaluate the results of the tests performed, and thus, to know in which points it is necessary to improve and where are the gains of this aspect in RA of MR.

4.1. Methodology

The main objective of the evaluation was to see if users were prepared to transition to the AR version in cooperative meetings or individual analyzes. However, the goal was not to make the old version obsolete, as it could continue to be used for single use or even quick queries.

In this way, we achieve a gradual level of adaptation and transition of the users because the majority of the employees is not yet accustomed to wearing HMD glasses, not being the transition success only responsibility of the application.

4.1.1. Environment

The tests took place in a TEKEVER meeting room. It is a room with 40 m^2 and four white walls. However, one of the walls has half the glass and thus captures some natural light. The room also contains chairs and tables.

Figure 44 - Tests Room

The set of equipment and materials used in the tests include: a HoloLens glasses, which ran the augmented reality application, a desktop, which was used by users to respond to the questionnaires and perform tests in the MR 2D application, plus one intervener simulating a collaborative environment, since no more augmented reality glasses are available.

Figure 45 - AR Glasses Experience

4.1.2. Methodology

The users had a set of steps to follow where each one needed to complete tasks individually detailed in the next section. It was asked for them to perform these in sequence, and the Test Coordinator provided an order of execution.

The methodology of conducting the tests assumes the following steps:

1. Distribution of the Testing Guide and its reading by users (Testing guide detailed on Appendix C);
2. Users fill in an Initial Questionnaire to register the user profile and its demographic characteristics (Initial Questionnaire in detail on Appendix A);
3. A brief presentation of the project to users, including their objectives and operation;
4. Demonstration by the Test Coordinator of prototype functionalities, including application startup, room mapping for item placement, a brief introduction of the video player, metadata selection view, graphical view, shared view, hud overlay, a terrain model and airplane.
5. Free trial of the prototype by the user;
6. Execution by the user of the three tasks indicated by the Test Coordinator in AR;
7. Execution by the user of the three tasks indicated by the Test Coordinator in AR by the second time;
8. Execution by the user of the three tasks indicated by the Test Coordinator in the MR 2D application;
9. Completion, by the user, of a Final Questionnaire to record their experience and opinion about the test performed (Final Questionnaire in detail on Appendix E).

4.1.3. Tasks

Next, we describe the three tasks that users had to perform sequentially. It was decided to carry out the tasks in this way and not random so that it was possible to observe the weight of the adaption factor to the glasses. It would be more complicated if you took the random form, as it would be necessary to spend more time and do more tests in order to find out if the difficulty was present in the use of the glasses or the task in question.

The following tasks were presented to the user in a sequential order:

A. Determine the altitude, raw, pitch and yaw value of the airplane as well as the latitude and longitude sometime during the second 50 of the mission.
B. Show how the value varies for 5 seconds from certain data to the user's choice after being activated in the selection menu.
C. Check the speed value through the application HUD during the mission min 1, activate the speed data in the data selection menu and share the view.

4.1.4. Metrics

As the final step, it is important to talk about what measures we tried to achieve. Regarding the objective measures were decided to verify the total time of the tasks A, B and C in both applications, this is, the AR and the 2D and finally the number of errors during the completion of the tasks. As subjective measures numerous parameters were taken into account, such as, global facility, convenience of use, visibility and ease of control of mission video, ease of use the graph, ease of use of the objects responsible for activating metadata, ease of use of the central navigation map with the terrain model and the airplane, ease of use of HUD, ease of use of Shared View, capability of the transition between the augmented reality environment and MR 2D environment and last if it allows collaboration. Note that the evaluation of these parameters will be obtained through the final questionnaires.

4.2. Results Analysis

In order to test the performance of the application, eight users were asked to respond to a set of questionnaires and perform predefined tasks, explained at the testing guide.

The tasks were performed in a predefined order, being that initially an initial questionnaire was carried out, going through the execution of the tasks and finally a final questionnaire in which each one of the users gives his opinion on the experience.

4.2.1. User Profile

In relation to the first questionnaire, it was possible to obtain several data about our sample of users (see Appendix B for all the results of the initial questionnaire).

The vast majority of users who participated in the study were males, representing 85% of test users, being the level of school divided between Bachelor and Master.

Age was also considered an interest factor to analyze since the level of adoption of new technologies is often influenced by this.

It should be noted that the overwhelming majority of testers are divided by the intervals between 20 and 40 years of age, with the remaining 25% occurring over 40 years.

Testing people from this last age group can be a big challenge if they are not people related to this type of technology. This is because it is a recent technological launch and the level of adaptation of older people tends to be more limited due to the fact that they have not been in contact with technologies during their lives, given the more widespread use of computers since the 1990s. In contrast, we have young people under the age of 40, with early access to technology and thus better adapted to respond quickly and intuitively to new technological stimuli.

When asked about the most attractive meeting methodology, the option "without devices" was never chosen. There is always an additional interest for meetings using technology, regardless of gender, age or academic degree.

One of the points we wanted to validate was the level of additional motivation that could bring the use of this new technology to meetings. In order to test the availability and willingness of users to convert to this new model of analysis, 87.5% of users were particularly motivated by this stimulus.

The vast majority of users despite being very motivated by new technologies have not all had the opportunity to try augmented reality glasses, I believe possibly because it is still a very restricted technology. However, according to the data, we can see the interest it arouses.

Then, to understand the involvement of test users with augmented reality and to perceive their level of experience, two questions were asked throughout the questionnaire that allowed us to meet these answers, in a sustained manner.

We seek not only to understand the level of experience with augmented reality applications in general but also the level of experience in using AR glasses.

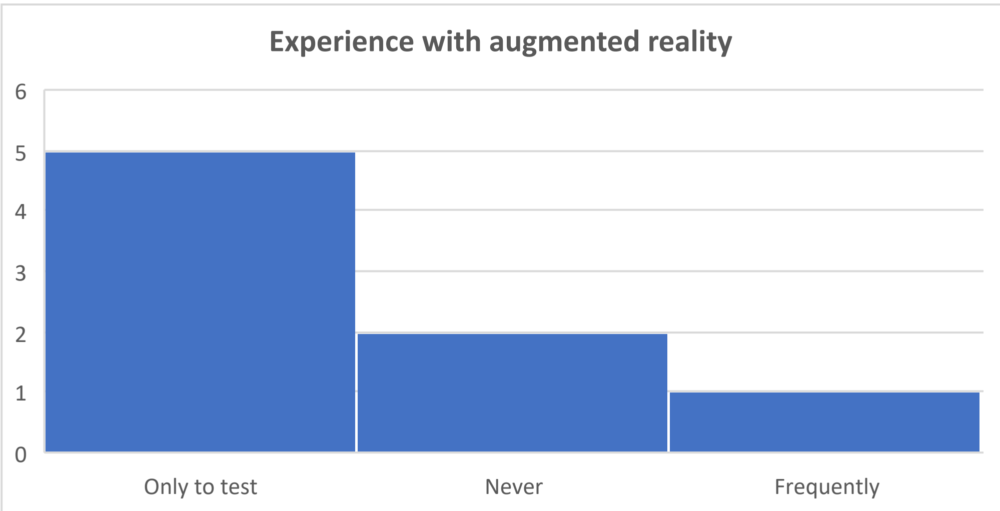


Figure 46 - Augmented Reality experience sample

The vast majority of users have reported having contact with augmented reality technology for testing purposes only. Regarding the level of experience with AR glasses, the high peak of users was considered level 1 (37.5%). Also, note that 1/4 of users say they have a considerable level of experience - level 4 and 5.

It is important to note that the minimum experience level is one, and the maximum is 5. This is a very subjective issue, but to make it more objective users have been told that experience level 5 is someone who wears glasses frequently and on the contrary level 1 is someone who never uses. In the average rating, the number 3 is someone who sometimes uses, for example for testing purposes. One more topic that was discussed with users was about the experience they had with AR applications in general since most stated that they only had contact in tests however they forget that they have had contact with very famous games, like Pokemon Go.

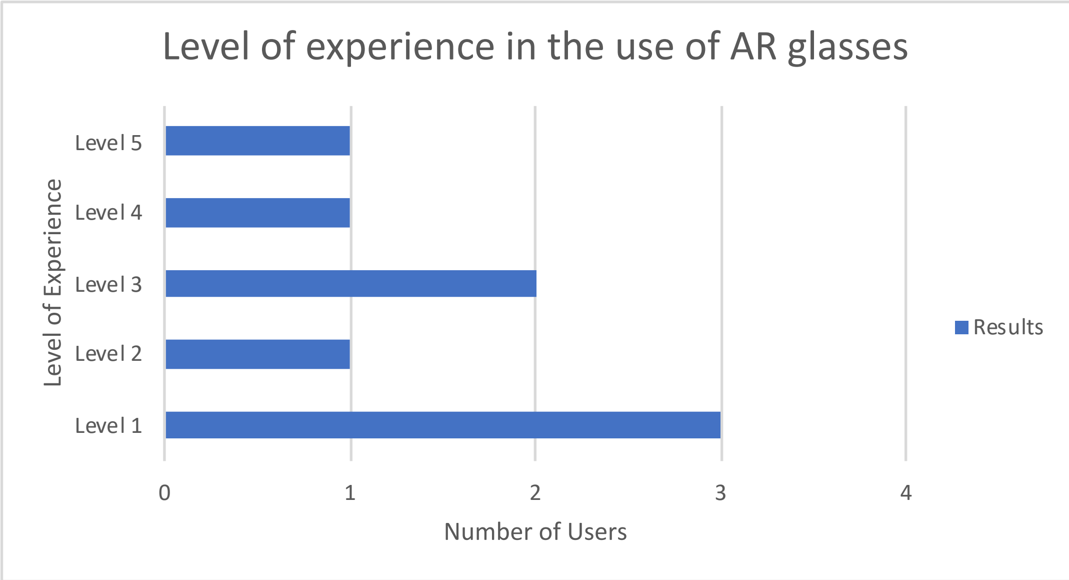


Figure 47 - AR Glasses level of experience sample

These data are very important to take into account when analyzing test results because if the vast majority of people had not had contact and experience with this technology, it is expected that the adoption will be slower than in people who have already experienced and used this technology in other formats and applications.

In order to understand the level of involvement that users may have with the application, another of the focused issues was on the experience they had for the purpose of this application, mission analysis. 37.5% of the interviewees were experienced with this type of task. Of the 37.5% performing mission analysis, 66.7% preferred to do collectively rather than individually. The latter being one of the main points of improvement proposed by the new development. It is interesting to note that collective analysis, although preferred, is not a unanimous choice. Perhaps these responses are also affected by how the collective analysis is done in normal 2D missions. What is proposed with this project is a cooperative collective analysis, which can influence this 33.3% who currently prefers individual analysis to make collective analysis preferential.

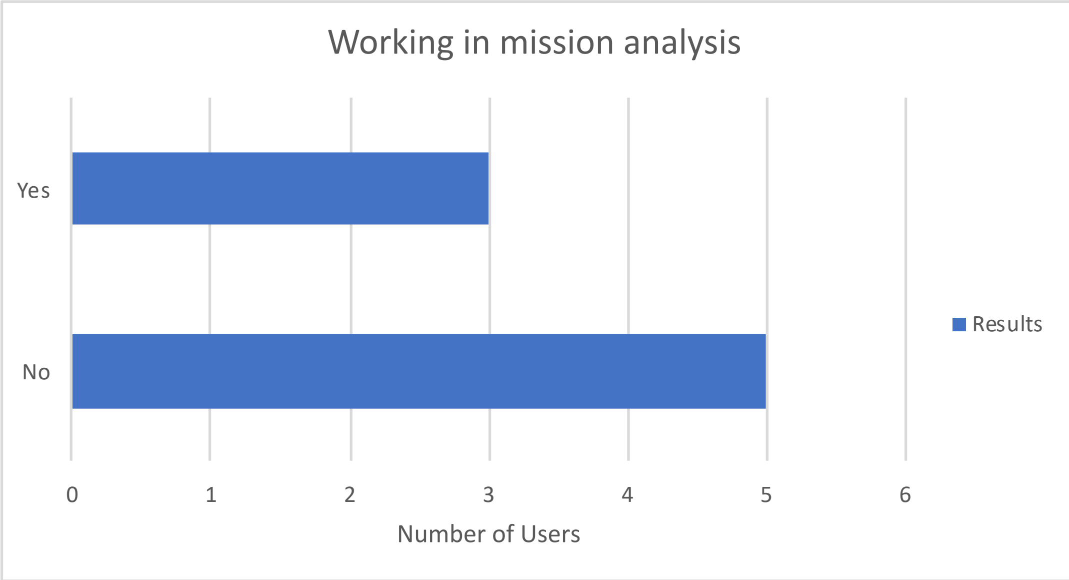


Figure 48 - Working in mission analysis sample

Another fundamental improvement we suggest is the more immediate availability of the analysis. Inquiring the participants 100% prefer the combined between analyzing at the time and after. This combined analysis brings more advantageous because it can bring the best of both worlds, not only an analysis more corrective but also a more careful one. In terms of local analysis, it helps in the execution of sequential missions, allowing the user to identify faults in the mission and correct them. This analysis monetizes the movement of analysts to the mission site because as soon as they detect the mission error, they can correct and re-simulate at the moment. The subsequent analysis, for example in an office, is also important because it is usually a more careful analysis where it should be possible to take more attention to detail, due to the type of meeting, in an office environment.

After the results of the initial questionnaires, it was possible, together with all the information, to have a sample of the respondents. These were the same for the tests and the final questionnaire.

We organize the data of the respondents in the form of a table, represented in table 5, in order to be able to correlate them more clearly (see Initial Questionnaire on Appendix B).

Of note that, within the people who have experience in analysis, only one of them prefers to do it individually. Thus, from the user test group, user 4 was the main conversion challenge for the AR application, as one of the key points of this new development, as already mentioned, is its cooperative potential. The fact that User considered that his level of motivation for new technologies is 5, helped him to feel particularly motivated for this application, and thus end up joining more easily to cooperative and collaborative analysis. This new model covers what are the limitations of regular collective analysis since the user can analyze their own data, along with other users, and share their points of view in a dynamic way.

4.2.2. Quantitative Analysis

Following the testing guide, which is described on Appendix C, the users performed a set of tasks, described below, sequentially.

A. Determine the altitude, raw, pitch and yaw value of the airplane as well as the latitude and longitude sometime during the second 50 of the mission.
B. Show how the value varies for 5 seconds from certain data to the user's choice after being activated in the selection menu.
C. Check the speed value through the application HUD during the mission min 1, activate the speed data in the data selection menu and share the view.

The execution of this set of tasks had the objective of measuring the execution times, in order to perceive the usability of the tool.

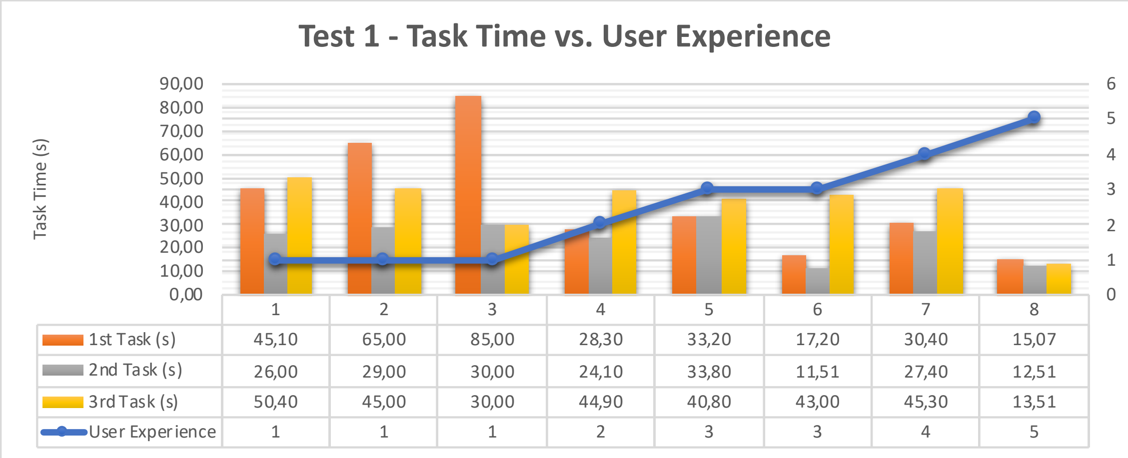
We chose to do the tests in an orderly way since our goal was not to compare times between tasks but to compare users according to their level of experience and adaptive capacity. Thus, we set the order so that we can reduce the number of tests required to perform, assessing the adaptability to the technology and the difficulty of executing tasks simultaneously. If the task was taking too long, up to a maximum of two minutes, it would be considered a failure and should move to the second task. The tests were explained in a test guide as well as orally by the coordinate during the experiment.

a) Test 1 in table 6 (see Results of the Tasks Tests on Appendix D)

The user with experience of type 5, as he is more experienced, in the results of the first test presents right away better times in general, in any one of the tasks to execute, comparatively with the others.

Users with level 1 experience in the first task they performed, showed times greater than 1 minute, with a gap of 60-70 seconds versus the more experienced users. It is possible to see a clear improvement for the 2nd task they perform, with the gap versus the more experienced users reducing to only about 18s.

In the last task, one of the users level 1 surpasses even an intermediate user, in the execution of tasks, proving thus there is an easy adaptation to the application.



	1	2	3	4	5	6	7	8
1st Task (s)	45,10	65,00	85,00	28,30	33,20	17,20	30,40	15,07
2nd Task (s)	26,00	29,00	30,00	24,10	33,80	11,51	27,40	12,51
3rd Task (s)	50,40	45,00	30,00	44,90	40,80	43,00	45,30	13,51
User Experience	1	1	1	2	3	3	4	5

Figure 49 – Test 1, Relation between user-level experience and time spent on the task

The average time for the tasks allows us to draw conclusions about the complexity of the tasks even though this is not our test focus. In order to substantiate these lessons in a sustained way, it would be necessary to increase the number of tests to be performed.

	1st Task (s)	2nd Task (s)	3rd Task (s)
Average	**39,91**	**24,29**	**39,11**
Standard Deviation	**22,62**	**7,58**	**11,13**

Table 2 – Average and Standard Deviation task execution time - Test 1

b) Test 2 in Table 7 (see Tasks Tests on Appendix D)

The main purpose of having a second test is to be able to assess the margin of improvement that we achieve with exposure to a longer use.

At this point, each User had already performed at least three distinct tasks, which made him more agile in the use of the application.

	1st Task (s)	2nd Task (s)	3rd Task (s)
Average	**21,48**	**18,75**	**27,97**
Standard Deviation	**5,02**	**6,86**	**8,37**

Table 3 – Average and Standard Deviation task execution time - Test 2

It is interesting to note that in general, all tasks had a clear better performance in test 2. Having a variation of -18.43 s in task 1, -5.54s in task 2 and -11.14 in task 3.

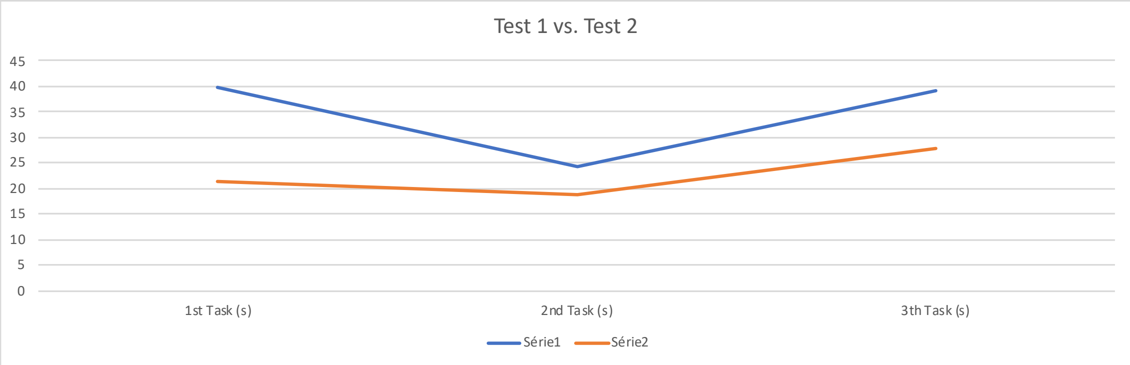
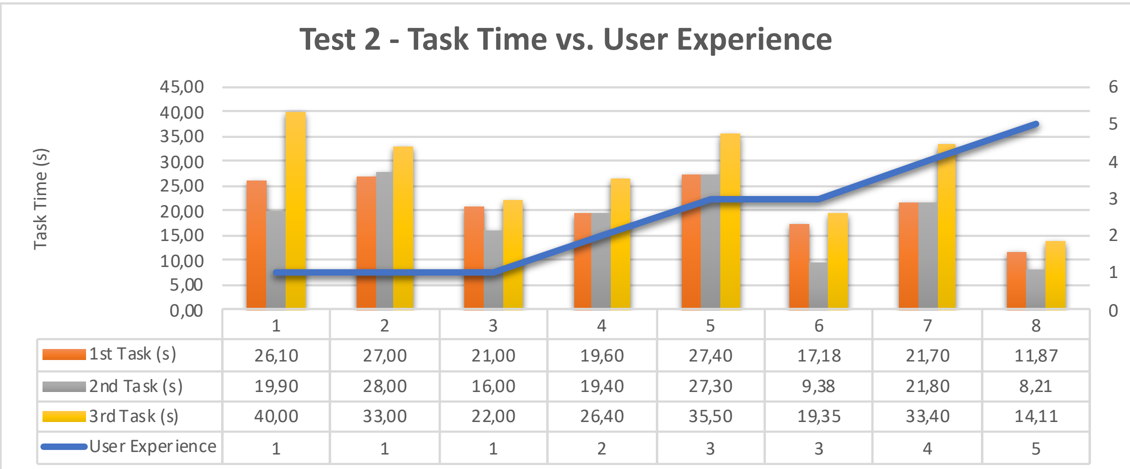


Figure 50 - Variation of average task execution time – Test 1vs.Test 2

The task where there was the longest time variation from one test to the next was task 1, which is normal because this was the task that all users performed first. It was thus a task influenced by the adaptation factor in a more accentuated way, versus the others.

We can now also draw more conclusive conclusions on the complexity of the proposed tasks, although this is not the purpose of the tests. There is an added complexity in the last task. Also note that 2nd task was the fastest, for both tests performed.



	1	2	3	4	5	6	7	8
1st Task (s)	26,10	27,00	21,00	19,60	27,40	17,18	21,70	11,87
2nd Task (s)	19,90	28,00	16,00	19,40	27,30	9,38	21,80	8,21
3rd Task (s)	40,00	33,00	22,00	26,40	35,50	19,35	33,40	14,11
User Experience	1	1	1	2	3	3	4	5

Figure 51 – Test 2, Relation between user-level experience and time spent on the task

It is possible to verify in table 8 (see results of the Tasks Tests on Appendix D) that the most significant improvements were as we saw in task 1, but particularly by users who classified their level of experience in this technology as level 1 (1 being the lowest level and 5 the most advanced level). Experienced users showed less room for improvement because they did not have to struggle with the adaptation factor.

Only 1 in 24 samples showed worse results in the second test versus the first, with a difference that we consider contemptible for not reaching 1s.

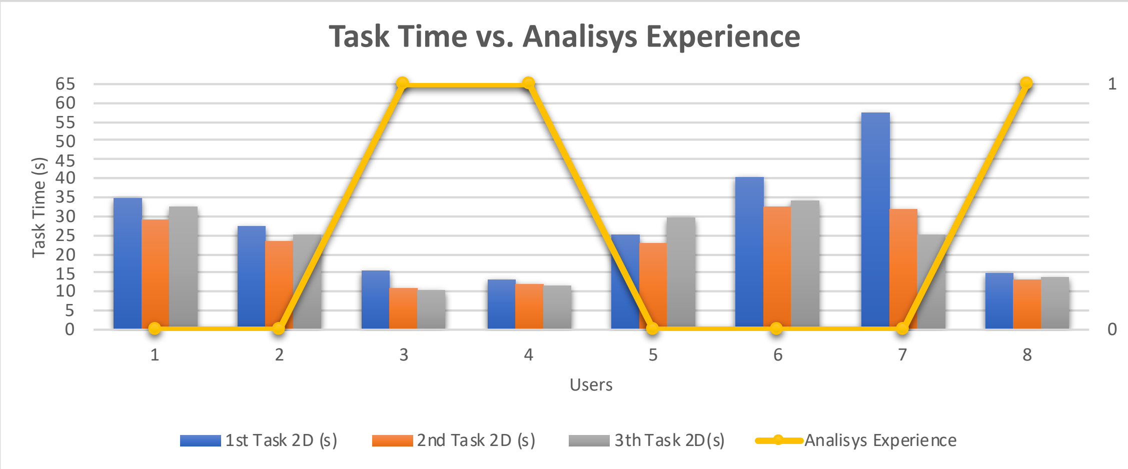


Figure 52 - Test 2, Relation between user-level experience and time spent on the task

When analyzing the data collected during the tasks executed in the 2D application, we found that only three people really had experience in mission analysis. By relating the level of experience to the times performed, it is clear that those who have had contact with the application practice times faster than the others. However, the difference in values is not very high and the gap presented in tasks one, two and three are respectively 44.59s, 21.50s, and 23.60s.

	1st Task 2D (s)	2nd Task 2D (s)	3rd Task 2D(s)
Average	**28,59**	**21,50**	**23,60**
Standard Deviation	**14,27**	**8,32**	**8,97**

Table 4 – Average and Standard Deviation task execution time - Test 1 2D

4.2.3. Qualitative Analysis

After the execution of the testing guide, each participant was asked to respond to a questionnaire in order to get the most realistic opinions possible about how the augmented reality experience was. It is possible to see in more detail the results of the final questionnaire and additional statistical information about all box plots in Appendix F.

4.2.3.1 Prototype

Regarding Prototype, was subject of the questionnaire the interface, the input response, the layout, the comfort associated with the use of glasses, and whether or not it is an intuitive product.

Many of these responses are influenced not only by development but also by the hardware used. Hololens glasses, where the tests were carried out, are still in the development and improvement phase, both in terms of operation and ergonomics. This conditions some of the test target points, such as stimulus-response and whether or not it is comfortable to use.

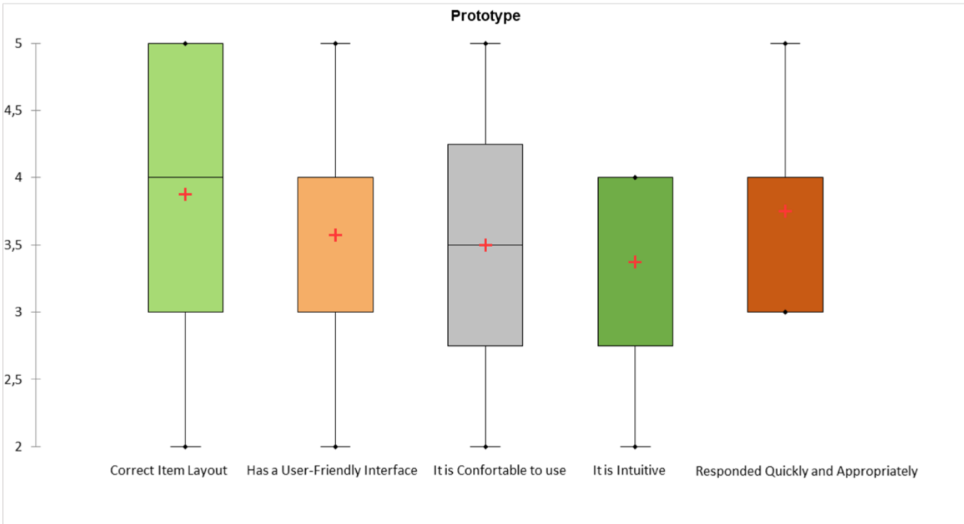


Figure 53 – Users Feedback on Prototype

As for how the Prototype responds quickly and appropriately to the various stimuli, all users agreed with the statement. The variation at this point is thus not very marked.

The remaining answers given vary widely, and four different levels were practically always used to classify the prototype in its different points.

We can take as relevant data that 37% of the respondents rated the application as level 4 and 13% assigned the level 5, from a User-Friendly Interface point of view. As for the intuitive character of the prototype, a point that is usually directly associated with whether or not it is User-Friendly, the above percentage has increased to 63%. This indicates that 13% of the people, who rated the interface below 4 with respect to being User-Friendly, rated it above with regard to whether or not it is intuitive.

Also, note that two of the users that tested disagreed with being an application both user-friendly and intuitive.

These disparate responses may be possibly justified by the disparity in the level of experience regarding RA technologies.

Experienced users who have previously experimented with similar technologies and/or tools tend to be more receptive in one approach versus the other, where the adaptation factor will weigh in the way they view the application because they will be conditioned by how they interact limited.

4.2.3.2 Test Tasks

Another of the target issues had to do with the complexity of the tasks. It is evident from the data the increased difficulty of task C versus the remaining two.

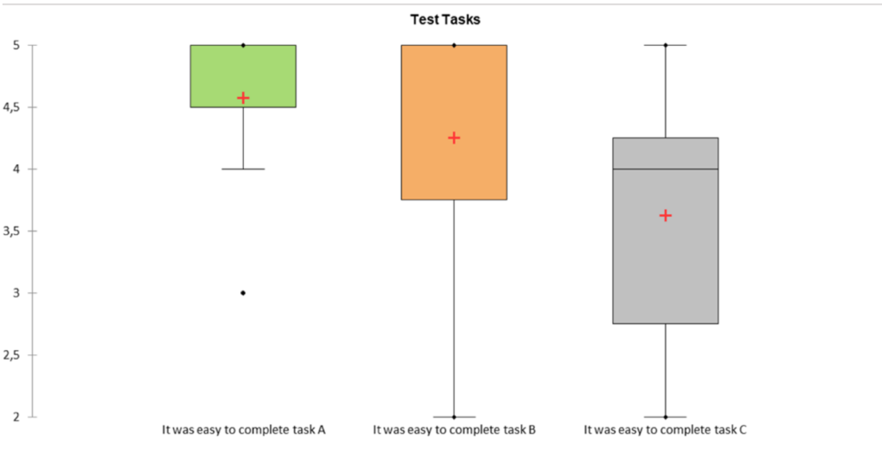


Figure 54 - Users Feedback on Test Tasks

These data support the time taken during the execution of the tasks, and the lessons learned through them, in the testing guide phase.

Task A and Task B were both easy to complete according to the majority of the users. About 63% of users in both have fully agreed that it is an affordable task. It should also be noted that one user considered tasks A and B difficult, disagreeing with the statement "It was easy to complete".

4.2.3.3 Video Player

Regarding the functionality of the Video Player, it was asked about the ease of use, size, operation of the buttons and design (colors and icons).

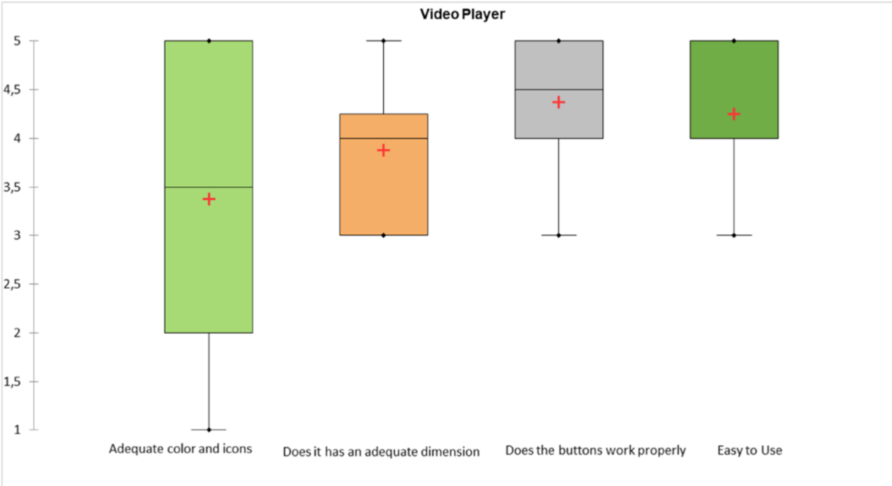


Figure 55 - Users Feedback on Video Player

At all points related to functionality, users generally agree that the application works properly for this menu.

The point of contention, which generates a range of results from 1 to 5, concerns colours and icons. As this is a question related to design is a difficult point to please/satisfy all users. However, it is important to consider that the majority presents a positive or neutral opinion regarding the theme (63% of Users).

4.2.3.4 UAV And Terrain

Regarding the UAV and the terrain, a menu where it is possible to see the positioning of the airplane on the world map, considering elevation and inclination, was inquired about ease of use, alignment/positioning in space, dimension and whether or not to show the correct date.

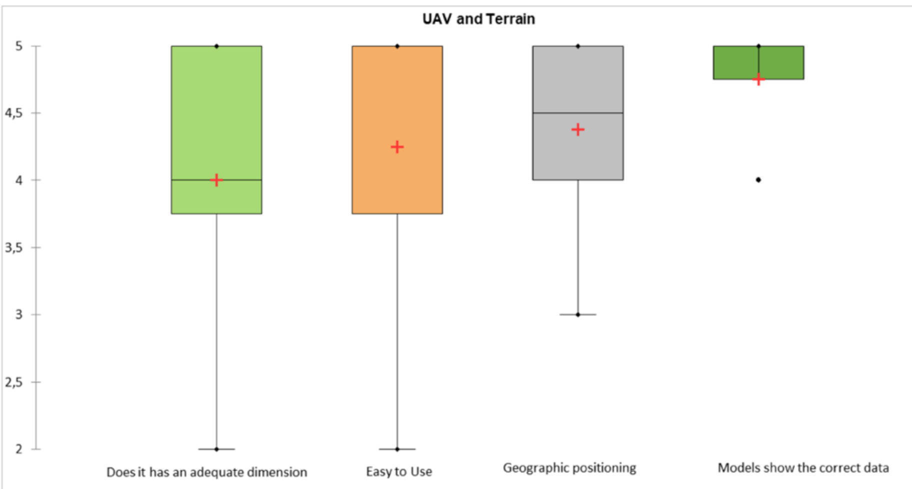


Figure 56 - Users Feedback on UAV and Terrain view

Most issues related to UAV and terrain had the answer "Totally agree" as the most selected.

It should be noted that the statement "Models show the correct date" presented a total agreement with 75% of users assigning five on the concordance scale and the remaining 25% assigned four.

Regarding the geographic positioning of the menu, the answers are all between the neutral and positive spectrum.

Regarding the ease of use, although it also has a significant percentage of "Totally agree", corresponding to 62.5%, there is a greater dispersion of responses. As for the issue related to the adequate dimension, there is also no consensus and linearity in the responses, although they are mostly positive and distributed between option 4 and 5.

4.2.3.5 Metadata Selection

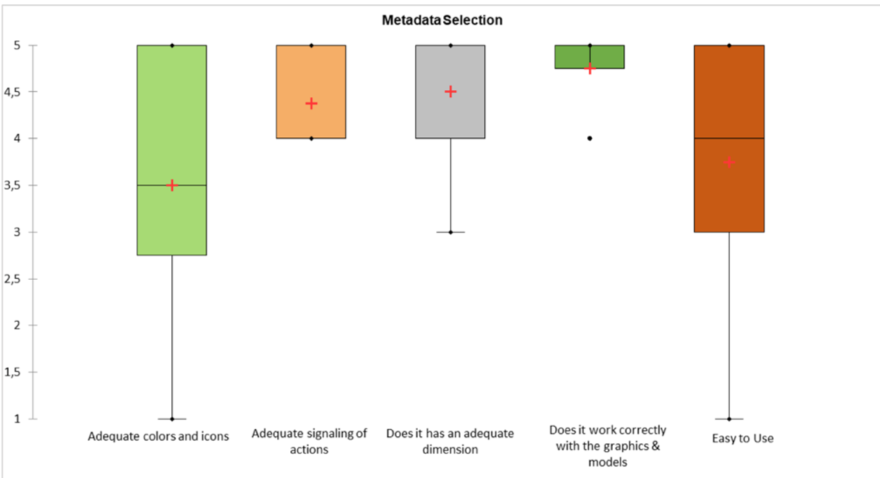


Figure 57 - Users Feedback on Metadata Selection

Regarding the selection of metadata, with regard to the signaling of actions and the correct functioning with the other models, the opinion is unanimous that the prototype is functional, with results above four on the scale of 1 to 5 available.

Dispersion at the level of responses is most evident in situations related to ease of use, dimension, colors, and icons. With regard to statements related to these parameters opinions differ.

Ease of use is one of the main points of dispersion of the survey results. This ease of use may be directly correlated with the level of user habituation to HoloLens sunglasses technology.

Data selection is a thorough task, requiring some accuracy, which may be more difficult in the first instance for users who are not accustomed to wearing the glasses. This technology works based on clicks and the movement of the cursor that is done according to the look, gaze, as already explained. In this way, users are required to have adequate hand positioning when selecting data. This implies a greater learning curve if the user is not used to this type of interactions and technologies.

As far as design is concerned, there is the same problem that has already been mentioned in previous points. The opinion is very mixed because it depends a lot on the personal taste of each user.

4.2.3.6 Graphic Window

The graph is the view where the user can see the data information previously activated in the Metadata menu. It was important to realize if this menu was easy to understand by itself and if it was once again just like the other menus, in the correct positioning and with the appropriate colors and icons.

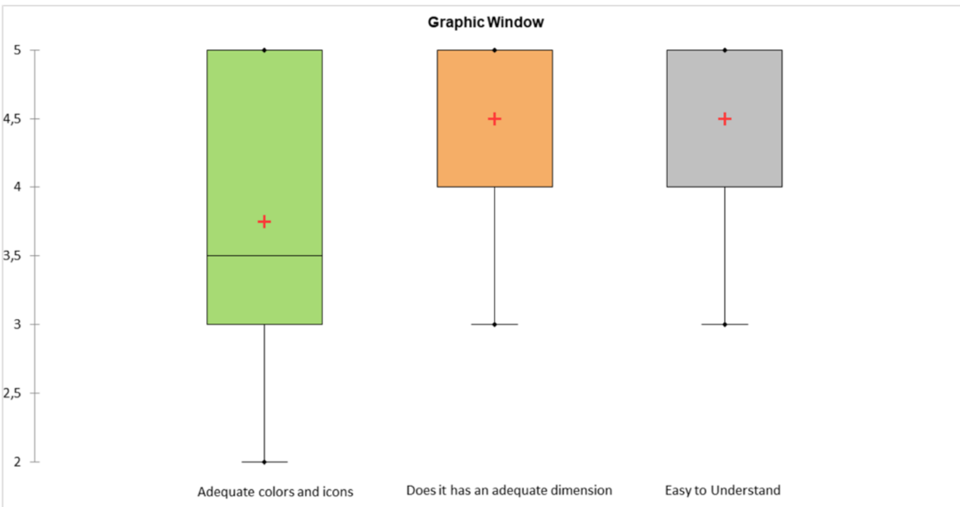


Figure 58 - Users Feedback on Graphic Window

In general, the opinion about this module was good, and most respondents presented a positive or neutral position regarding the statements "Easy to understand" and "Does it have an adequate dimension".

When we return to question about the colors and icons we have once again a dispersion of answers by the different options.

4.2.3.7 Collaboration View

The Collaboration Menu is an entirely dedicated field to the sharing of views among users, to make mission analysis more cooperative.

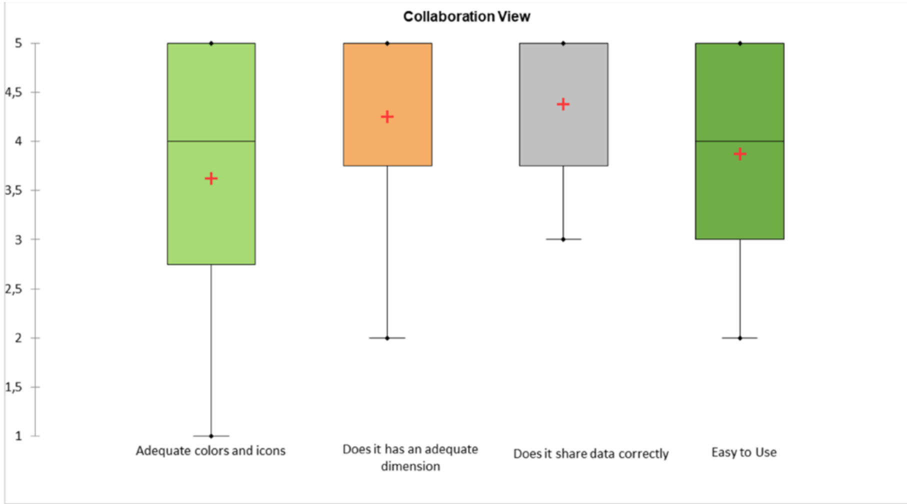


Figure 59 - Users Feedback on Collaboration View

This menu brings a breakthrough versus 2D technology. It is through this menu that we can increase the value of the application in a real environment. It was not possible to test this feature fully because Tekever only has a pair of glasses. Either way, Users were asked to test the ability to share.

Regarding the reliability of the data, the general opinion was that the data were correctly shared.

As far as ease of interaction is concerned, only 1 User disagreed with being an easy-to-use menu. Possibly the fact that this functionality is included in the longer task that was asked to execute impacted the user's perception regarding the ease of this menu. The remaining users tested agreed with the statement "Easy to use".

Regarding the dimensions, 62.5% is completely in agreement with the appropriate dimensioning, 12.5% assigned level 4 and 12.5% level 3. In this menu, we again have 1 User that disagrees with the fact that the dimensions are adequate. According to the ratio and taking into account that it is a matter of personal taste, we have decided to keep as it is currently, in order to try to please the majority of users.

4.2.3.8 HUD View

This was possibly the menu that gained greater consensus on responses from users. Hud met user preferences at all test points.

Totally agree was the most chosen option by the Users towards all the statements related to this menu.

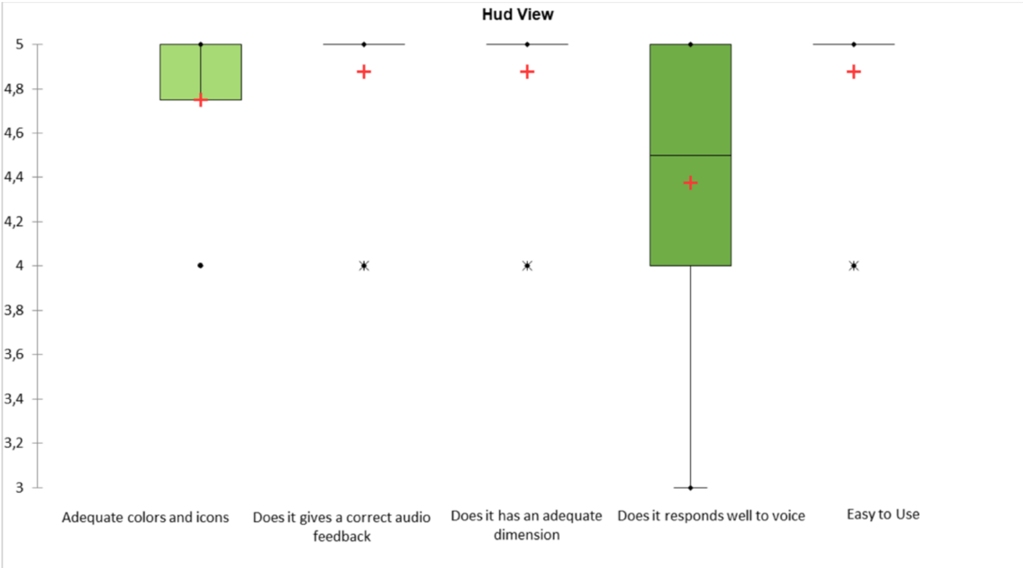


Figure 60 - Users Feedback on HUD

4.3. Discussion

After the formal completion of the tests, it was possible to obtain feedback from several users, who in general were all very pleased with the experience provided. In this way and after an analysis of the results, I believe I can say that the tests were carried out successfully.

Next, the results obtained in the previous section will be analyzed. Starting from the relationship of the user's experience with the tasks times obtained in the first test it was found that all those who already showed experience in the use of augmented reality with glasses, had immediately more satisfactory results than those users who were starting in this technology. Here there are some indications that adapting users to the way of interaction with glasses is a very important factor. Now making the bridge for the second test, and after the users have two adaptation phases, one during the first contact with the application and other in the first test, a substantial reduction of the tasks times was observed by almost all. The exception belongs to those who already have high levels of experience. This shows that it is a fast-paced application and the results of the mission analysis will soon appear.

In order to obtain some comparison times between mission replay applications, the same users were asked to try to perform the same tasks proposed in AR, now in an already well-integrated application for mission analysis, the 2D Mission Replay.

To be fair in a first approach, we will make a comparison to the first tests performed in both applications, regardless of whether some users have a high degree of expertise in the existing application. In the following graphs, it is observed that times are very similar in each of the three tasks. However, MR 2D generally shows some gains compared to GoAR.

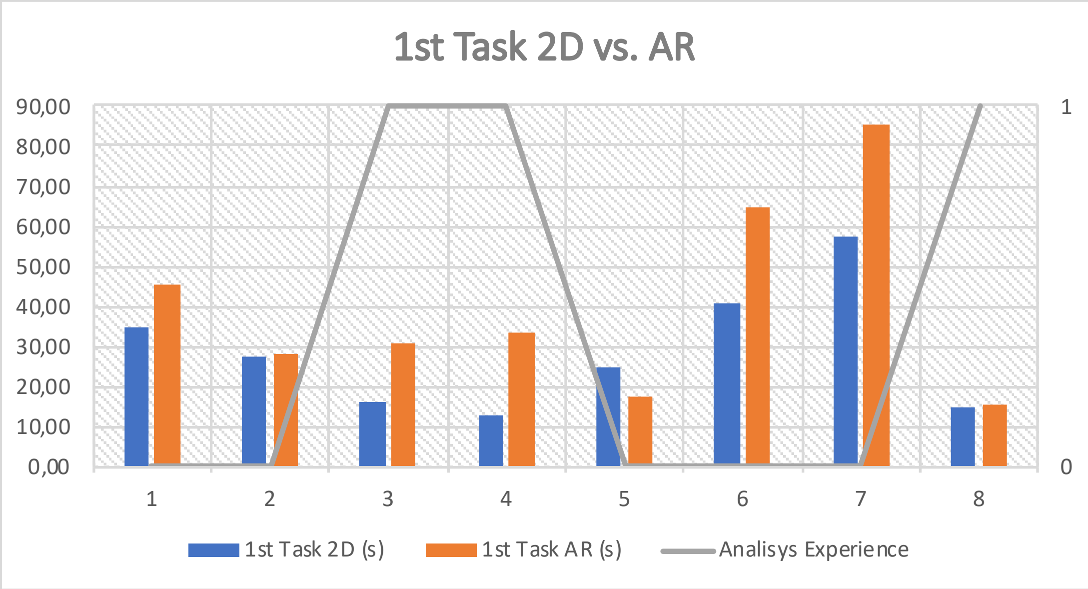


Figure 61 - First Task 2D vs First Task of the First AR Test

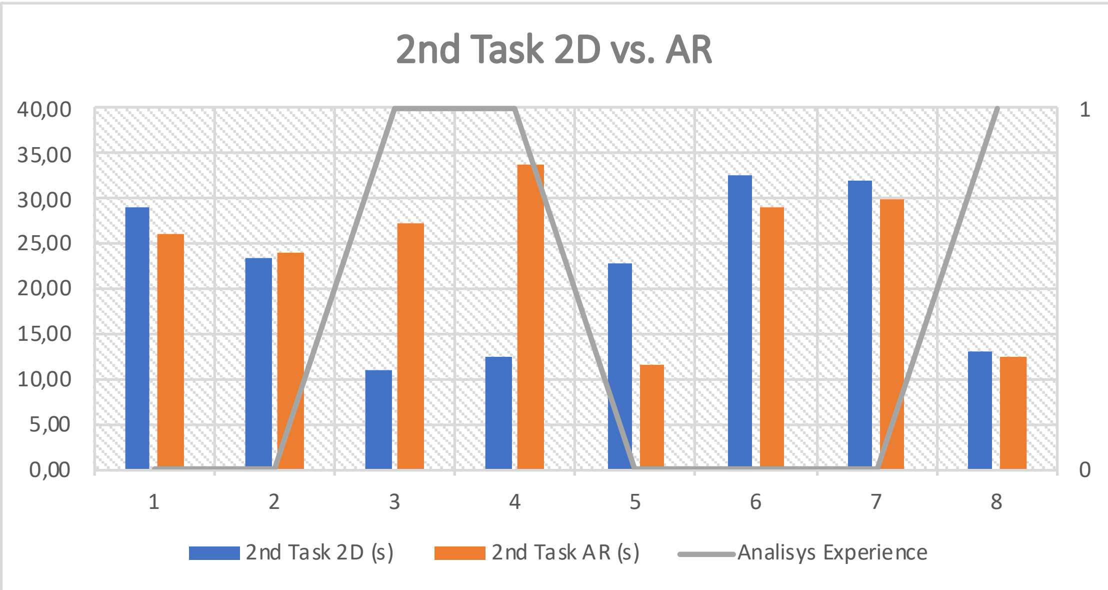


Figure 62 - Second Task 2D vs Second Task of the First AR Test

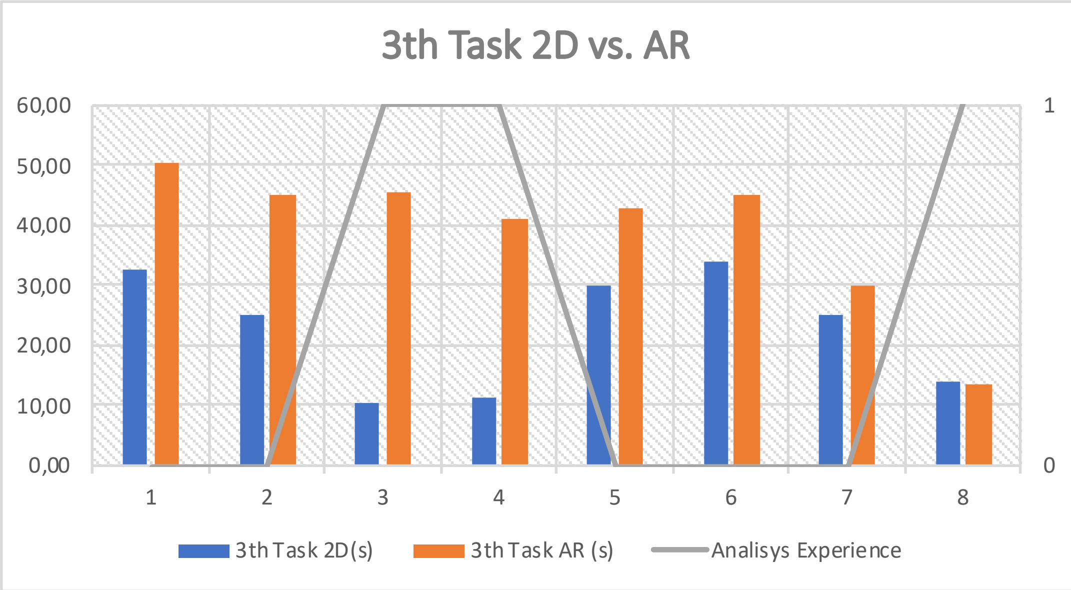


Figure 63 - Third Task 2D vs Third Task of the First AR Test

It is noteworthy that during the execution of the tasks in the 2D MR application, the users found plenty of difficulties in completing the tasks. This happens because this application does not have some features that the AR application presents. As an example, in task 2 the observation of a parameter for 5 seconds, and in task 3 the data sharing. In the second task, in both applications, it is possible to check how the data varies over time. However, if we want to look with detail to the values that were obtained in the past 5 seconds, this is only possible in the AR application. In this sense, the test in the 2D application was performed faster, since there were fewer actions to be performed. The same occurred in task 3, from the moment the user would have to share data with another participant. Only half the task could be done in MR 2D. Comparing now the values of 2D tasks with those of AR, but belonging to the second group of tests, we found that there is a huge improvement in AR times, and many of them obtained even better results than the concurrent application.

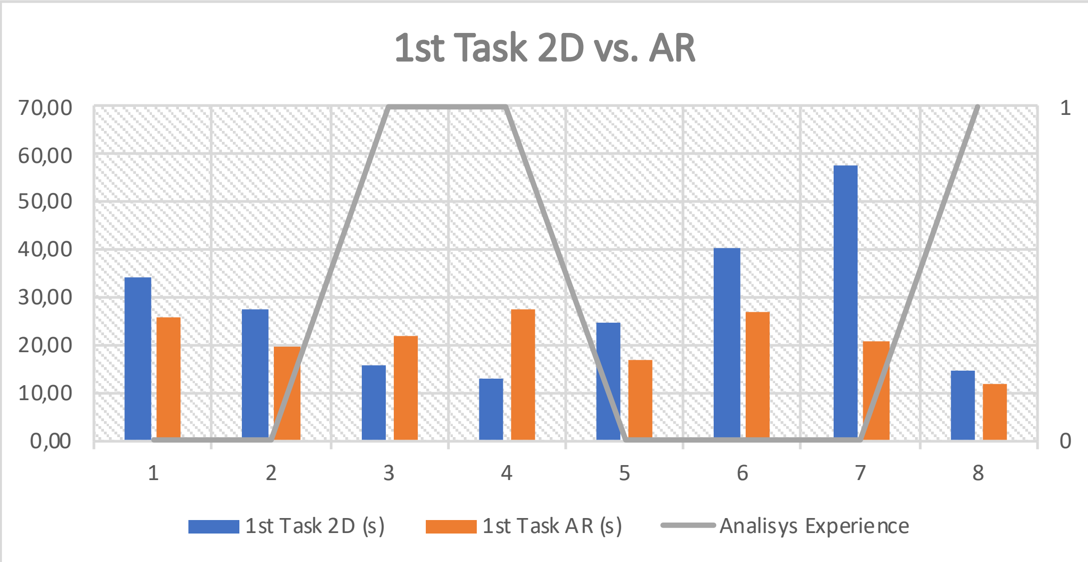


Figure 64 - First Task 2D vs First Task of the Second AR Test

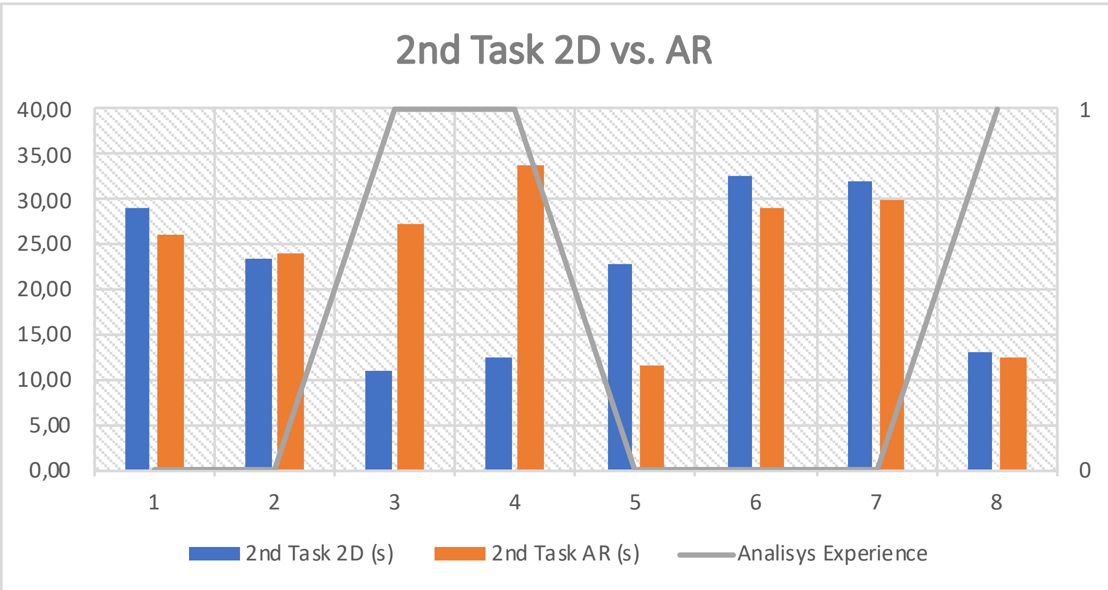


Figure 65 - Second Task 2D vs Second Task of the Second AR Test

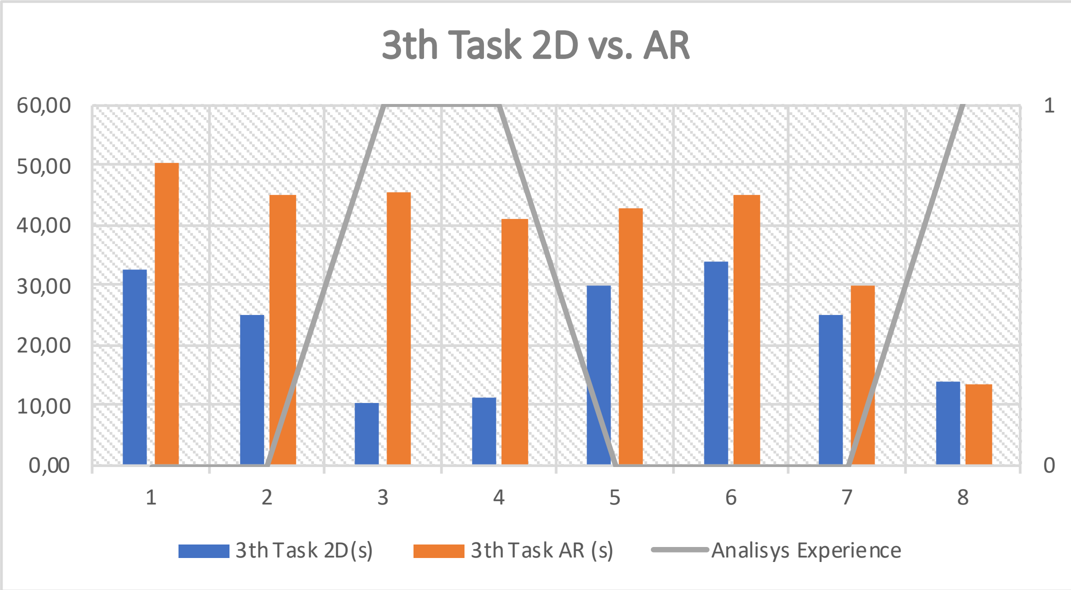


Figure 66 - Third Task 2D vs Third Task of the Second AR Test

Continuing both quantitative and qualitative analysis of the collected data, we noticed that the greater discrepancy of results appears when the design is involved. In this respect, responses were the most distinct, in which almost all values were selected, from the lowest to the highest. This being a very subjective point, it was decided to try to please the greater percentage of users. A common point to all users was the almost unanimity in answers, regarding the proper functioning of the application in all views presented by the AR application. It is important to highlight the response speed to the inputs and the correct display of the data selected and analyzed.

Being that the main focus of Mission Replay in AR was the collaboration was very interesting to verify that all the users agreed that this is a good tool to promote the analysis of missions in collaboration. Besides the augmented reality experience already being quite immersive with the other users in the room, it still presents the right components for correct data sharing with the other collaborators. Note that 100% of users agree that this application allows collaboration.

5. Conclusion

The development of the present study allowed an analysis of how the creation of software using augmented reality technologies can increase improvements in the quality of aeronautical mission analysis. This involved a literature search that could substantiate this claim either through written documentation about applications related to drone control and visualization of missions or from AR applications. In general, after the analysis of the selected articles, it was verified that through the separation and automation of concepts, it is possible to reduce the operator's work, as well as to improve the planning of missions reducing the place to failures.

It was decided to present chronologically subsequent articles within the subtopics, in order to analyze the evolution of augmented reality technology and how it contributed in each time period to the most different areas, with special attention to the area of focus of the project, aeronautics.

The goal of this work was to bring the best of augmented reality, and apply it to *Mission Replay*, based on a broader visualization format with resources to various forms of interaction and arrangement of simultaneous images, giving freedom of choice to the operator, and following a model that aims at a greater abstraction of the visualizations. With all of this combine it was possible to bring to life a prototype for mission review with a view to better future planning.

As a future work there is still much work to be done. Not only in terms of UI but also features. Currently, in terms of UI, telemetry and other data are mapped to a table, accessible with a gaze and gestures, but in the near future, the table will be provided with some sensors, allowing users to click on the table just like any other 2D interface we are accustomed. This will be an improvement, as it will allow users to rest their upper limbs, used in most other interactions. One more upgrade to the interface will be in the navigation map where we'll be able to check the mission waypoints as well as the view from the different cameras inside the airplane.

With these upgrades and some more in terms of software to control the airplane in a near future maybe we'll be able not only to replay mission but also watch in real time and even control the drone.

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Appendix A

GoAR Initial Questionnaire

This questionnaire lasts approximately 3 minutes and aims to know your profile.
All information given will be treated confidentially and will only be used for academic purposes.
Thank you for your time and availability.

Gender? *

- ○ Male
- ○ Female
- ○ Prefer not to say

Age? *

- ○ < 20
- ○ 20 to 30
- ○ 30 to 40
- ○ > 40

Education? *

- ○ High School
- ○ Bachelor Degrees
- ○ Master Degrees
- ○ PHD
- ○ Outro: ____________________

What kind of meetings do you prefer? *

- ◯ Without devices
- ◯ With the aid of some presentation tool
- ◯ Some specific design tool
- ◯ Outro: ____________

How many objects do you bring with you to a meeting? *

- ◯ 0 to 1
- ◯ 2 - 3
- ◯ > 3

Do you feel more motivated when meetings involve recent technology? *

0	1	2	3	4	5
◯	◯	◯	◯	◯	◯

Do you have some experience with augmented reality? *

- ◯ Never
- ◯ Only to test
- ◯ Frequently

How would you rate your level of experience in the use of AR glasses? *

0	1	2	3	4	5
◯	◯	◯	◯	◯	◯

Have you some experience in mission analysis? *

- ◯ Yes
- ◯ No

Answer to the following question only if you answered yes in the previous question

How do you prefer your analysis?

- ◯ Individual
- ◯ Collectively

Where would you prefer to analyze a mission?

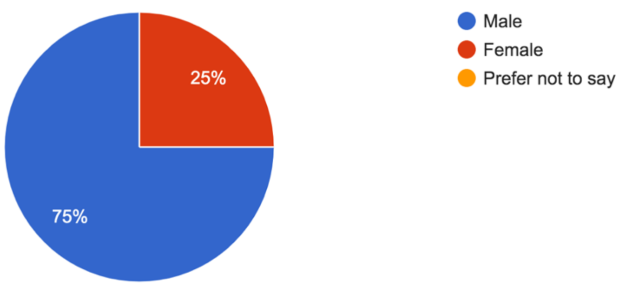
- ◯ Immediately after the mission, on site
- ◯ Later in the office
- ◯ Both previous
- ◯ Outro: ____________________

Appendix B

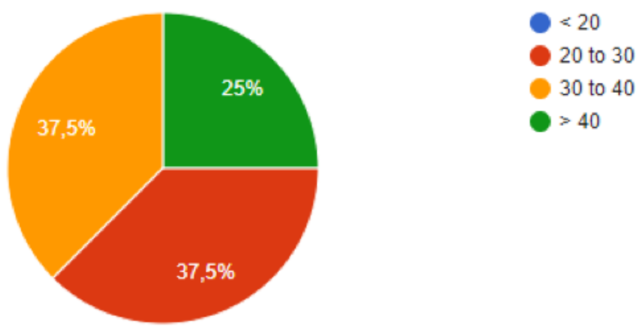
Initial Questionnaire Results

The following tests were answered by eight users, right at the beginning of the experience in order to obtain their user profile.

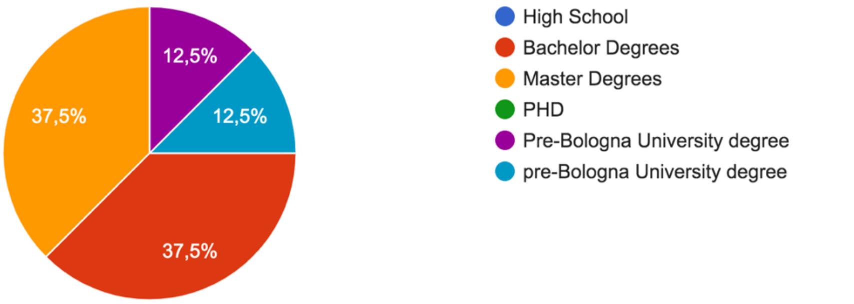
Gender?



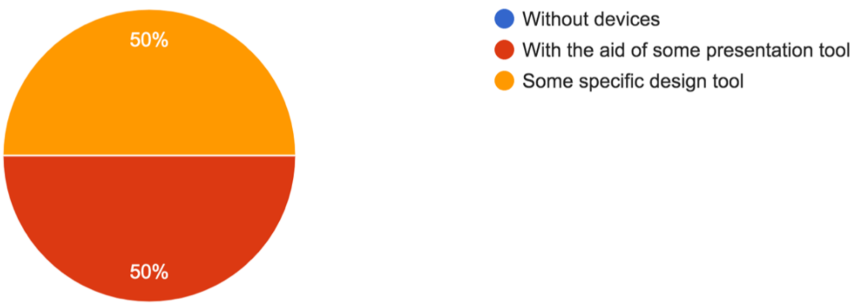
Age?



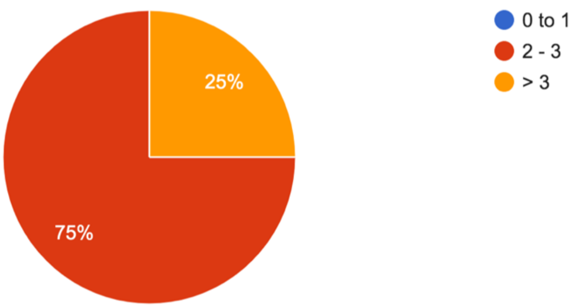
Education?



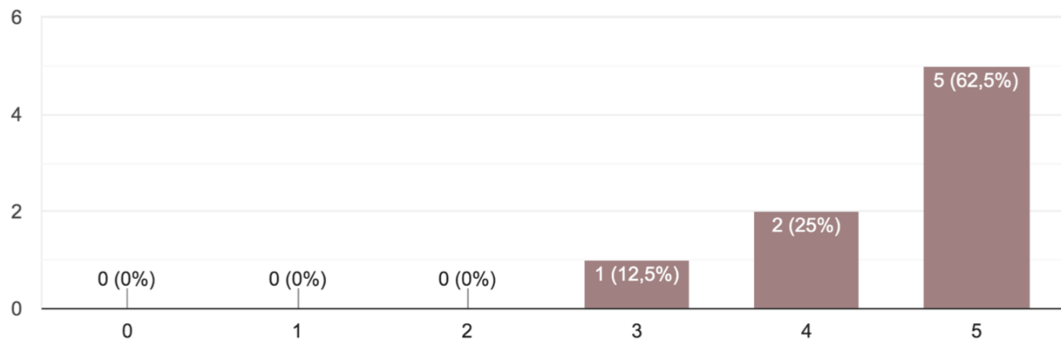
What kind of meetings do you prefer?



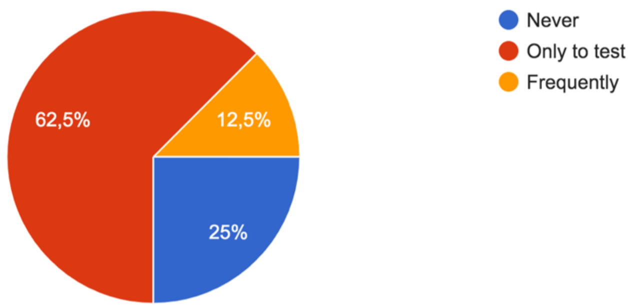
How many objects do you bring with you to a meeting?



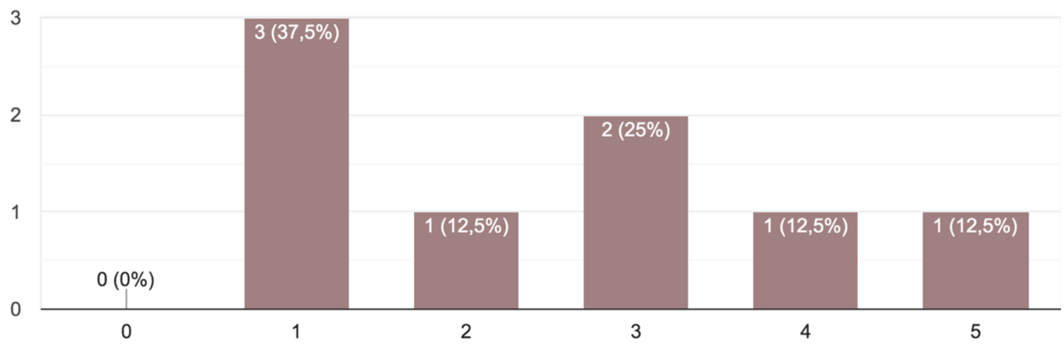
Do you feel more motivated when meetings involve recent technology?



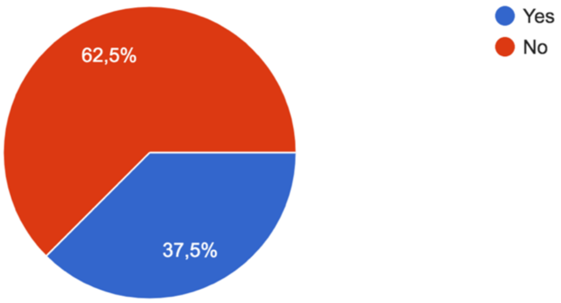
Do you have some experience with augmented reality?



How would you rate your level of experience in the use of AR glasses?

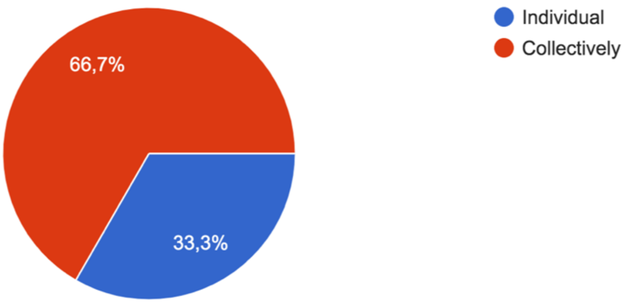


Have you some experience in mission analysis?

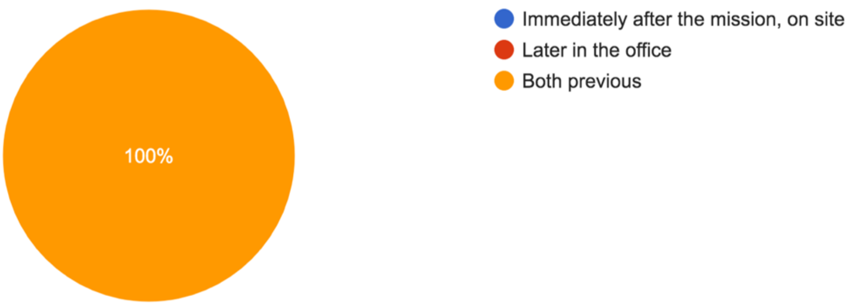


The next two questions were answered if only the previous question was answered affirmative.

How do you prefer your analysis?



Where would you prefer to analyze a mission?



User ID	Gender	Age	Education	Kind of meetings	Motivated when meetings involve recent technology	Experience with augmented reality	Level of experience in the use of AR glasses	Experience in mission analysis	Analysis	Analysis - Where
1	Male	30-40	Master Degree	With the aid of some presentation tool	3	Only to test	1	No		
2	Male	20-30	Bachelor Degree	With the aid of some presentation tool	4	Only to test	2	No		
3	Male	30-40	Master Degree	Some specific design tool	5	Only to test	4	Yes	Collectively	Both Previous
4	Male	30-40	Master Degree	Some specific design tool	5	Only to test	3	Yes	Individual	Both Previous
5	Female	20-30	Bachelor Degree	Some specific design tool	5	Only to test	3	No		
6	Male	> 40	Pre-Bologna University Degree	With the aid of some presentation tool	4	Never	1	No		
7	Female	> 40	Pre-Bologna University Degree	With the aid of some presentation tool	5	Never	1	No		
8	Male	20-30	Bachelor Degree	Some specific design tool	5	Frequently	5	Yes	Collectively	Both Previous

Table 5 - Initial Questionnaire Resume

Appendix C

GoAR Testing Guide

What will be evaluated:

The main objective of the tests is to evaluate the usability of a user interface in an augmented reality environment. It is intended to test the ability of the application for the analysis of missions, validating the possibility of conversion of the users of the 2D mission replay application to this new model, based on the ease of obtaining information and data.

System to evaluate:

The system to be evaluated consists of an augmented reality application prototype for the HoloLens glasses [1].

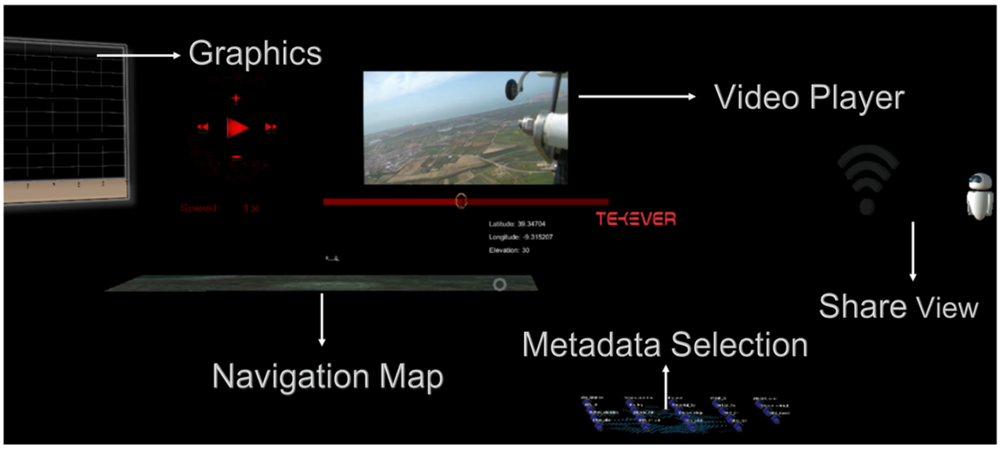


Figure 1 - Detailed AR Mission Replay Prototype

An AR application for UAVs mission analysis was built in a collaborative environment that aims to bridge the limitations of the 2D application of the current mission replay system as well as add value that only 3D technology can provide.

The augmented reality interface allows the user to view, from an already executed mission, a Video Player placed on a wall that has been previously mapped. This view has several buttons to control the flow of the mission. Among them, the play/pause button, the forward and backward buttons, which allows the user to walk only 3 seconds forward or back respectively, the time control buttons and a timeline, for more control over the time of the mission.

After this primary functionality, we highlight how to obtain information to evaluate the success or failure of a mission. As the mission is viewed on the video player, it is possible for the user in the central zone to observe and retrieve terrain and airplane data [2].

Terrain and airplane were built in 3D so that this view is as realistic as possible to observe the most varied behavior of the aircraft and the elevations of the terrain.

Figure 2 - Data in Terrain & Airplane

Still, in this order of ideas, we present the graph, which allows the user to visualize the variations over time of the different parameters.

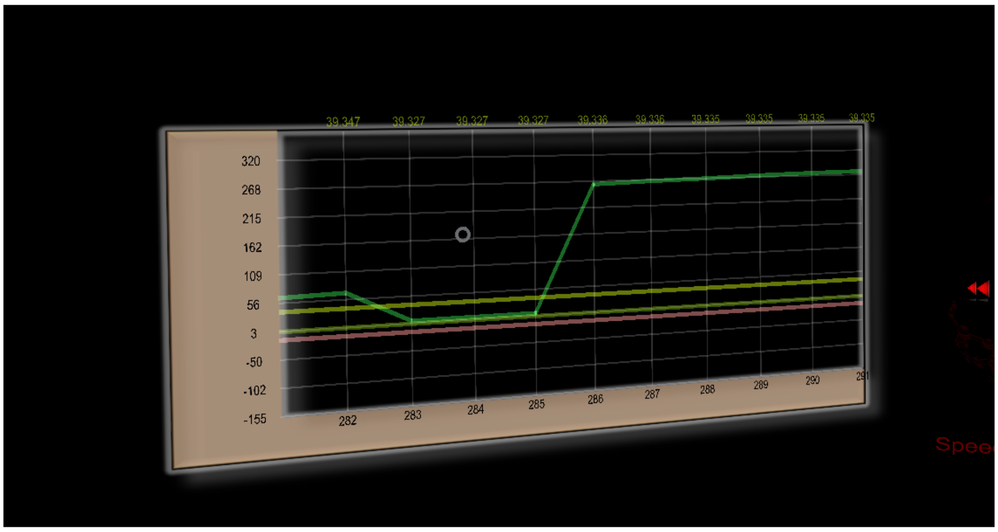


Figure 3 - Variation of data over time

As a junction, we have a view that was created and placed on a table after the mapping of the room. This view contains all the possible data to analyze and that, when activated, with the use of the look and gestures generate additional information both on the chart and in the plane view on the ground. For example, whenever the user focuses on the airplane, the active data set is represented in the 3D model to make it easier to obtain information for analysis.

In addition to the data obtained in the other views, we still have one that is activated only by voice command, the HUD. This HUD is a universal view that allows the user to observe a set of previously defined data without having to activate them.

Figure 4 - HUD view

In the last analysis, the collaboration part is a focal point because the 2D application does not allow this freedom to users to share and investigate the data they want since they are limited to what the group wants to analyze. In this view, each one from the same video can draw the most diverse conclusions depending on what is active or not. These conclusions can be shared at any time for each user's analysis.

Environment:

The tests will take place in a TEKEVER meeting room. It is a room with 40 m^2 and four white walls. However, one of the walls has half the glass and thus captures some natural light. The room also contains chairs and tables.

Figure 5 - Tests Room

The set of equipment and materials to be used in the tests include: a HoloLens glasses, which will run the augmented reality application, a desktop, which will be used by users to respond to the questionnaires and perform tests in the MR 2D application, plus one intervener simulating a collaborative environment, since no more augmented reality glasses are available.

Figure 6 - AR Glasses Experience

Methodology:

The tests will include individual completion by users of each of the tasks detailed in the next section. You will be prompted to perform these in sequence, and the Test Coordinator will provide you with a random, order of execution.

The methodology of conducting the tests assumes the following steps:

1. Distribution of the Testing Guide and its reading by users;
2. Users fill in an Initial Questionnaire to register the user profile and its demographic characteristics;
3. A brief presentation of the project to users, including their objectives and operation;
4. Demonstration by the Test Coordinator of prototype functionalities, including application startup, room mapping for item placement, a brief introduction of the video player, metadata selection view, graphical view, shared view, hud overlay, a terrain model and airplane.
5. Free trial of the prototype by the user;
6. Execution by the user of the three tasks indicated by the Test Coordinator in AR;
7. Execution by the user of the three tasks indicated by the Test Coordinator in AR by the second time;

8. Execution by the user of the three tasks indicated by the Test Coordinator in the MR 2D application;
9. Completion, by the user, of a Final Questionnaire to record their experience and opinion about the test performed.

Tasks:

The following tasks will be presented to the user in a sequential order:

1. Determine the altitude, raw, pitch and yaw value of the airplane as well as the latitude and longitude sometime during the second 50 of the mission.
2. Show how the value varies for 5 seconds from certain data to the user's choice after being activated in the selection menu.
3. Check the speed value through the application hud during the mission min 1, activate the speed data in the data selection menu and share the view.

Metrics:

Objective measures:

- Total time for tasks 1, 2 and 3 (seconds) in the AR application;
- Total time of tasks 1, 2 and 3 (seconds) in the MR 2D application;
- Number of wrong operations on each task.

Subjective measures (Attached Final Questionnaire):

- Global facility;
- Convenience of use;
- Visibility and ease of control of mission video;
- Easy to use graph;
- Ease of use of the objects responsible for activating metadata;
- Ease of use of the central navigation map with terrain model and airplane;
- Ease of use of HUD;
- Ease of use of Shared View;
- Adequacy of the transition between the augmented reality environment and MR 2D environment;
- Allow Collaboration;

Appendix D

Results of the Tasks Tests

User Experience	1st Task (s)	2nd Task (s)	3rd Task (s)
1	45,10	26,00	50,40
2	28,30	24,10	44,90
4	30,40	27,40	45,30
3	33,20	33,80	40,80
3	17,20	11,51	43,00
1	65,00	29,00	45,00
1	85,00	30,00	30,00
5	15,07	12,51	13,51

Table 6 - Tasks execution time for Test 1

User Experience	1st Task (s)	2nd Task (s)	3rd Task (s)
1	26,10	19,90	40,00
2	19,60	19,40	26,40
4	21,70	21,80	33,40
3	27,40	27,30	35,50
3	17,18	9,38	19,35
1	27,00	28,00	33,00
1	21,00	16,00	22,00
5	11,87	8,21	14,11

Table 7 - Tasks execution time for Test 2

User Experience	1st Task (s)	2nd Task (s)	3rd Task (s)
1	-19,00	-6,10	-10,40
2	-8,70	-4,70	-18,50
4	-8,70	-5,60	-11,90
3	-5,80	-6,50	-5,30
3	-0,02	-2,13	-23,65
1	-38,00	-1,00	-12,00
1	-64,00	-14,00	-8,00
5	-3,20	-4,30	0,60

Table 8 - Variation of task execution time by User – Test 1vs.Test 2

Appendix E

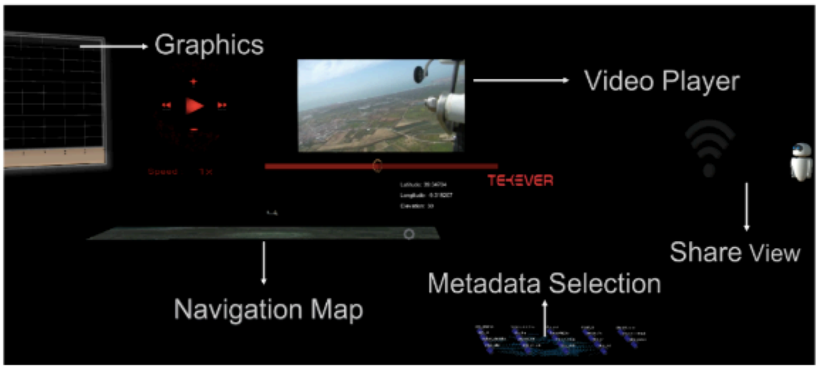
GoAR Final Questionnaire

This questionnaire lasts approximately 5 minutes and aims to record your opinion about the test.

All information given will be treated confidentially and will be used solely for academic purposes.

Thank you for your time and availability.

Prototype



Prototype *

	1 - Totally disagree	2	3	4	5 - Totally agree
Has a user-friendly interface	○	○	○	○	○
Responded quickly and appropriately	○	○	○	○	○
Correct item layout	○	○	○	○	○
It's comfortable to use	○	○	○	○	○
It is intuitive	○	○	○	○	○

Regarding test tasks *

	1 - Totally disagree	2	3	4	5 - Totally agree
It was easy to complete task A	○	○	○	○	○
It was easy to complete task B	○	○	○	○	○
It was easy to complete task C	○	○	○	○	○

Video Player - Control the flow of the application

Video Player - Control the flow of the application *

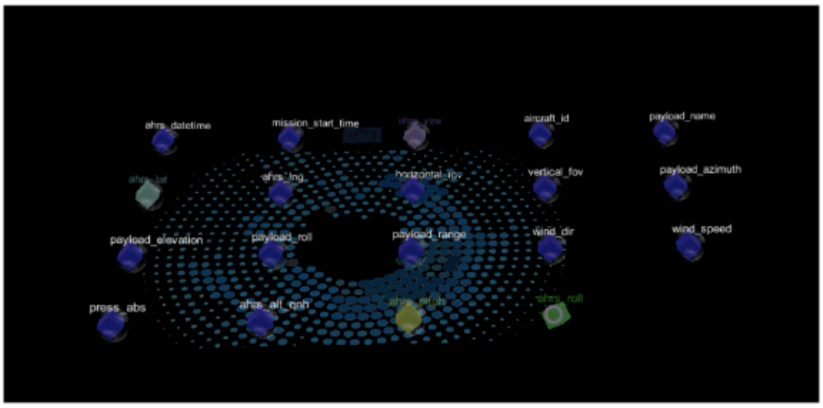
	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to use	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Does the buttons work properly	○	○	○	○	○
Adequate colors and icons	○	○	○	○	○

UAV and Terrain

UAV and Terrain *

	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to use	○	○	○	○	○
Geographic positioning aligned with other views	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Models show the correct data	○	○	○	○	○

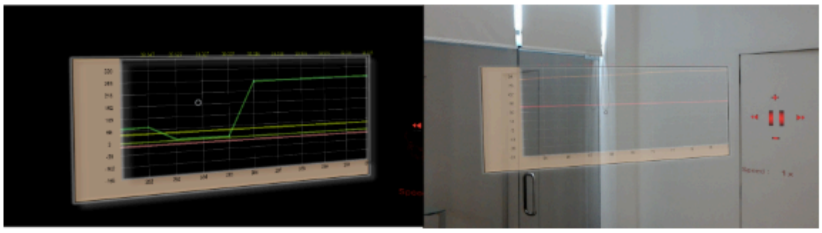
Metadata Selection - Menu with all the available data



Metadata Selection - Menu with all the available data *

	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to use	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Does it work correctly with the graphics & models	○	○	○	○	○
Adequate signaling of actions	○	○	○	○	○
Adequate colors and icons	○	○	○	○	○

Graphic Window - Show the metadata variation over time



Graphic Window - Show the metadata variation over time *

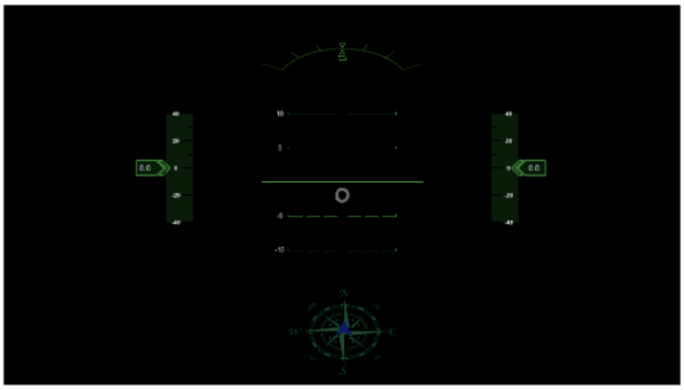
	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to understand	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Adequate colors and icons	○	○	○	○	○

Collaboration View

Collaboration View *

	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to use	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Does it share data correctly	○	○	○	○	○
Adequate colors and icons	○	○	○	○	○

Hud View



Hud View *

	1 - Totally disagree	2	3	4	5 - Totally agree
Easy to use	○	○	○	○	○
Does it has an adequate dimension	○	○	○	○	○
Does it responds well to voice	○	○	○	○	○
Does it gives a correct audio feedback	○	○	○	○	○
Adequate colors and icons	○	○	○	○	○

Allow collaboration *

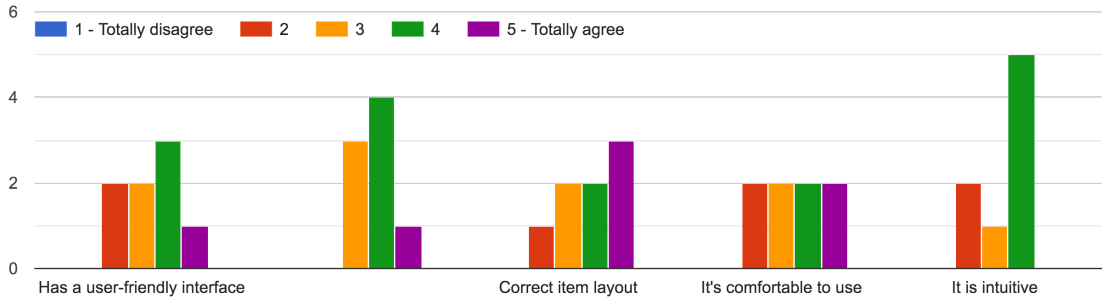
- ○ Yes
- ○ No

Appendix F

Final Questionnaire Results

The following tests were answered by eight users, right after the execution of the experience in order to obtain their feedback about the GoAR prototype.

Prototype

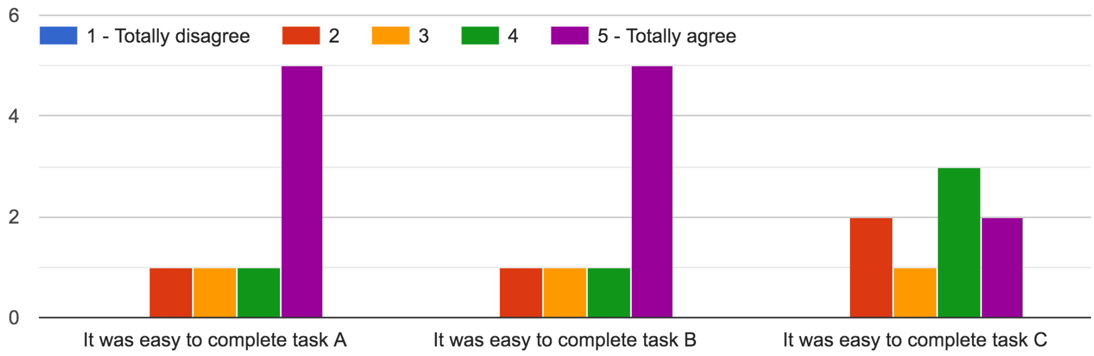


Descriptive statistics (Quantitative data):

Statistic	Correct Item Layout	Has a User-Friendly Interface	It is Confortable to use	It is Intuitive	Responded Quickly and Appropriately
Nbr. of observations	8	7	8	8	8
Minimum	2,000	2,000	2,000	2,000	3,000
Maximum	5,000	5,000	5,000	4,000	5,000
1st Quartile	3,000	3,000	2,750	2,750	3,000
Median	4,000	4,000	3,500	4,000	4,000
3rd Quartile	5,000	4,000	4,250	4,000	4,000
Mean	3,875	3,571	3,500	3,375	3,750
Variance (n-1)	1,268	0,952	1,429	0,839	0,500
Standard deviation (n-1)	1,126	0,976	1,195	0,916	0,707

Table 9 - Box Plot Prototype Descriptive statistics

Regarding test tasks

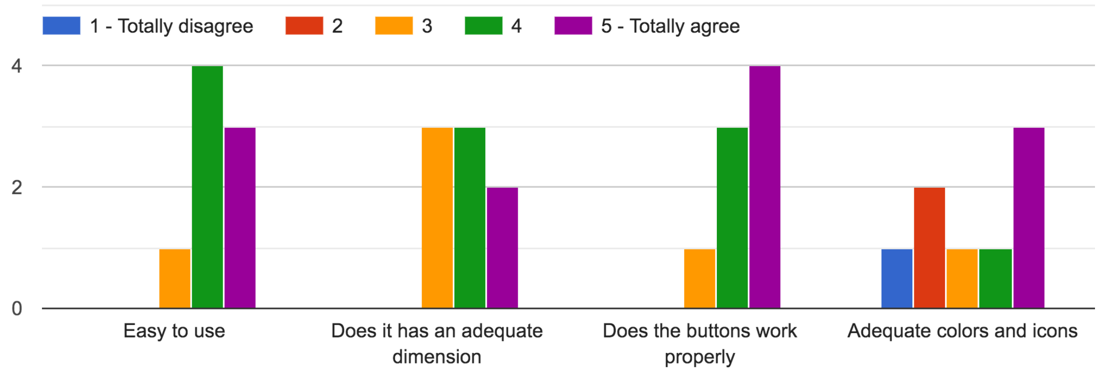


Descriptive statistics (Quantitative data):

Statistic	It was easy to complete task A	It was easy to complete task B	It was easy to complete task C
Nbr. of observations	7	8	8
Minimum	3,000	2,000	2,000
Maximum	5,000	5,000	5,000
1st Quartile	4,500	3,750	2,750
Median	5,000	5,000	4,000
3rd Quartile	5,000	5,000	4,250
Mean	4,571	4,250	3,625
Variance (n-1)	0,619	1,357	1,411
Standard deviation (n-1)	0,787	1,165	1,188

Table 10 - Box Plot Test Tasks Descriptive statistics

Video Player - Control the flow of the application

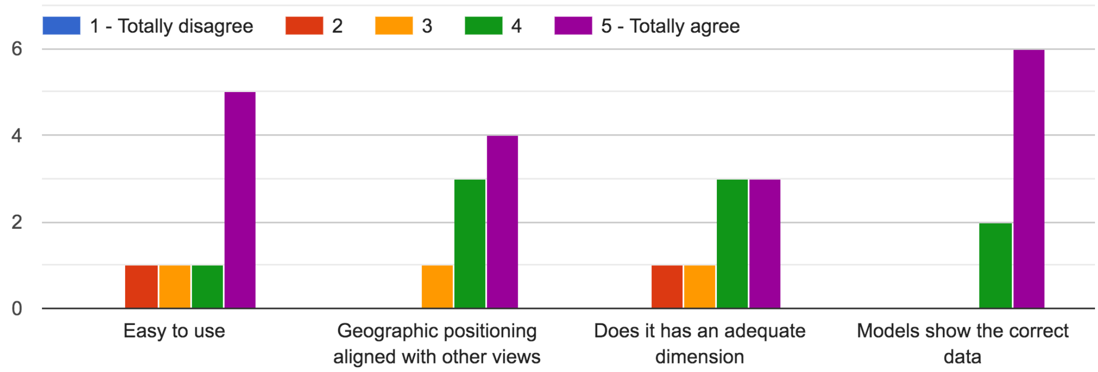


Descriptive statistics (Quantitative data):

Statistic	Adequate color and icons	Does it has an adequate dimension	Does the buttons work properly	Easy to Use
Nbr. of observations	8	8	8	8
Minimum	1,000	3,000	3,000	3,000
Maximum	5,000	5,000	5,000	5,000
1st Quartile	2,000	3,000	4,000	4,000
Median	3,500	4,000	4,500	4,000
3rd Quartile	5,000	4,250	5,000	5,000
Mean	3,375	3,875	4,375	4,250
Variance (n-1)	2,554	0,696	0,554	0,500
Standard deviation (n-1)	1,598	0,835	0,744	0,707

Table 11 - Box Plot Video Player Descriptive statistics

UAV and Terrain

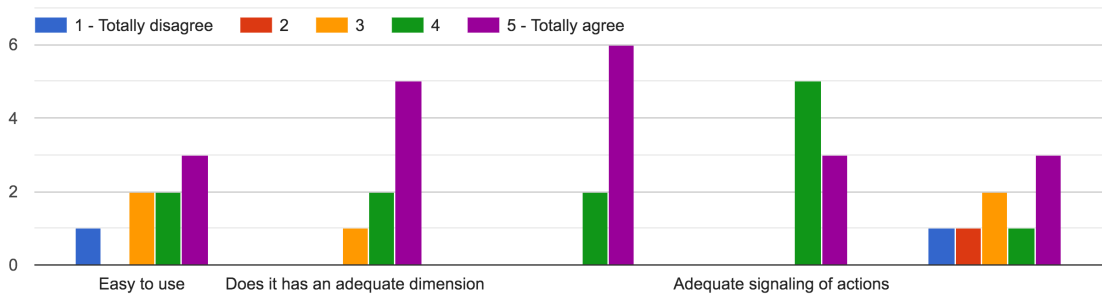


Descriptive statistics (Quantitative data):

Statistic	Does it has an adequate dimension	Easy to Use	Geographic positioning	Models show the correct data
Nbr. of observations	8	8	8	8
Minimum	2,000	2,000	3,000	4,000
Maximum	5,000	5,000	5,000	5,000
1st Quartile	3,750	3,750	4,000	4,750
Median	4,000	5,000	4,500	5,000
3rd Quartile	5,000	5,000	5,000	5,000
Mean	4,000	4,250	4,375	4,750
Variance (n-1)	1,143	1,357	0,554	0,214
Standard deviation (n-1)	1,069	1,165	0,744	0,463

Table 12 - Box Plot UAV and Terrain Descriptive statistics

Metadata Selection - Menu with all the available data

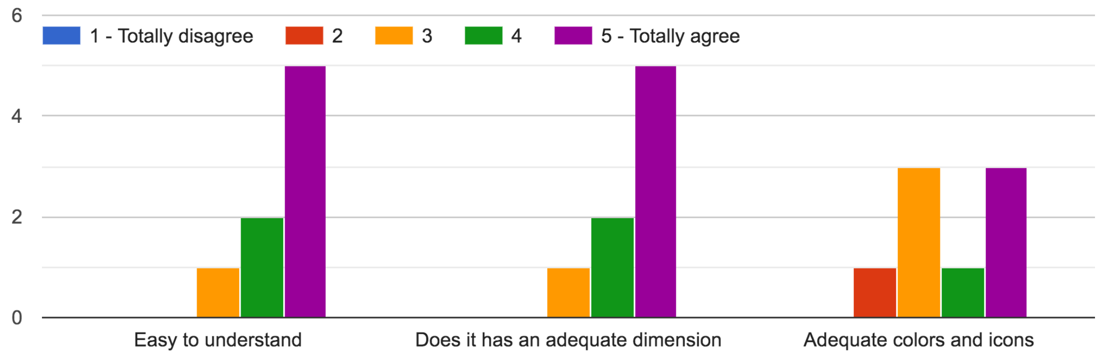


Descriptive statistics (Quantitative data):

Statistic	Adequate colors and icons	Adequate signaling of actions	Does it has an adequate dimension	Does it work correctly with the graphics & models	Easy to Use
Nbr. of observations	8	8	8	8	8
Minimum	1,000	4,000	3,000	4,000	1,000
Maximum	5,000	5,000	5,000	5,000	5,000
1st Quartile	2,750	4,000	4,000	4,750	3,000
Median	3,500	4,000	5,000	5,000	4,000
3rd Quartile	5,000	5,000	5,000	5,000	5,000
Mean	3,500	4,375	4,500	4,750	3,750
Variance (n-1)	2,286	0,268	0,571	0,214	1,929
Standard deviation (n-1)	1,512	0,518	0,756	0,463	1,389

Table 13 - Box Plot Metadata Selection Descriptive statistics

Graphic Window - Show the metadata variation over time

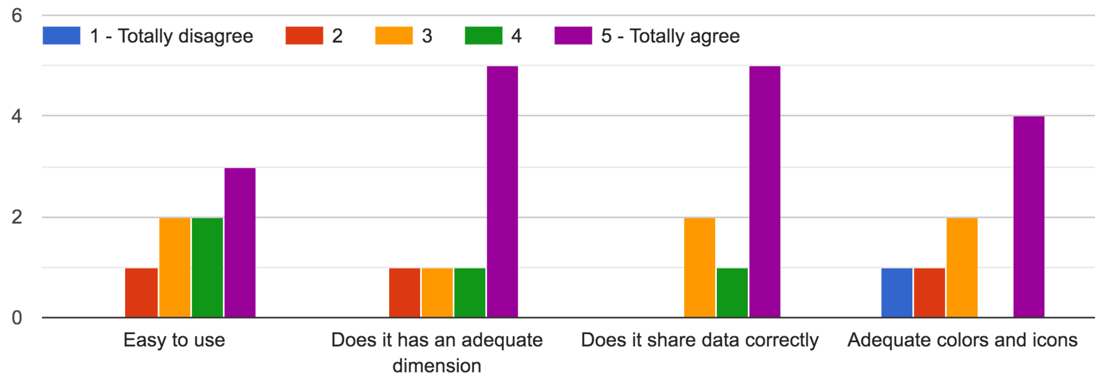


Descriptive statistics (Quantitative data):

Statistic	Adequate colors and icons	Does it has an adequate dimension	Easy to Understand
Nbr. of observations	8	8	8
Minimum	2,000	3,000	3,000
Maximum	5,000	5,000	5,000
1st Quartile	3,000	4,000	4,000
Median	3,500	5,000	5,000
3rd Quartile	5,000	5,000	5,000
Mean	3,750	4,500	4,500
Variance (n-1)	1,357	0,571	0,571
Standard deviation (n-1)	1,165	0,756	0,756

Table 14 - Box Plot Graphic Window Descriptive statistics

Collaboration View

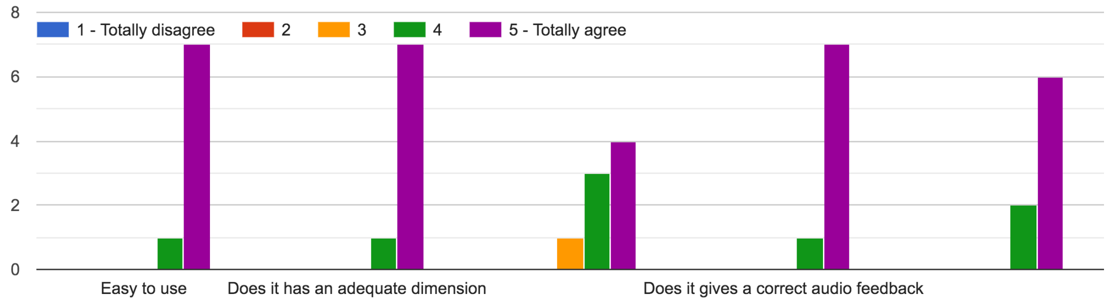


Descriptive statistics (Quantitative data):

Statistic	Adequate colors and icons	Does it has an adequate dimension	Does it share data correctly	Easy to Use
Nbr. of observations	8	8	8	8
Minimum	1,000	2,000	3,000	2,000
Maximum	5,000	5,000	5,000	5,000
1st Quartile	2,750	3,750	3,750	3,000
Median	4,000	5,000	5,000	4,000
3rd Quartile	5,000	5,000	5,000	5,000
Mean	3,625	4,250	4,375	3,875
Variance (n-1)	2,554	1,357	0,839	1,268
Standard deviation (n-1)	1,598	1,165	0,916	1,126

Table 15 - Box Plot Collaboration View Descriptive statistics

Hud View



Descriptive statistics (Quantitative data):

Statistic	Adequate colors and icons	Does it gives a correct audio feedback	Does it has an adequate dimension	Does it responds well to voice	Easy to Use
Nbr. of observations	8	8	8	8	8
Minimum	4,000	4,000	4,000	3,000	4,000
Maximum	5,000	5,000	5,000	5,000	5,000
1st Quartile	4,750	5,000	5,000	4,000	5,000
Median	5,000	5,000	5,000	4,500	5,000
3rd Quartile	5,000	5,000	5,000	5,000	5,000
Mean	4,750	4,875	4,875	4,375	4,875
Variance (n-1)	0,214	0,125	0,125	0,554	0,125
Standard deviation (n-1)	0,463	0,354	0,354	0,744	0,354

Table 16 - Box Plot HUD View Descriptive statistics

A Final question about collaboration was asked, “if it allow collaboration?”, where 100% of the users responded Yes.