ADVANCED HUMAN MACHINE INTERFACES FOR DRONE MONITORING: ASSESSMENT OF THE TECHNOLOGICAL FRAMEWORK FOR THE DESIGN OF AN AUGMENTED REALITY INTERFACE

Sara Bagassi[1], Tommaso Fadda[1] & Marzia Corsi[1]

[1]Department of Industrial Engineering, Università di Bologna – Campus di Forlì, Forlì, Italy

Abstract

The growing deployment of unmanned aerial systems (UASs) and electrical Vertical Take-Off and Landing vehicles (eVTOLs) necessitates advanced solutions for collision avoidance and unauthorized area management. This paper investigates the application of augmented reality (AR) for enhanced monitoring and control of UAS traffic, especially in non-collaborative or hazardous scenarios. By leveraging concepts from SESAR projects, including RETINA and DTT, the study introduces a novel AR interface designed for real-time visualization of drone telemetry and georeferenced data. This interface, tailored for airport tower control and remote piloting, aims to streamline situational awareness by integrating critical surveillance information into a head-up display. Preliminary tests with simulated drone incursions promise substantial improvements in operator efficiency and situational awareness. This study provides a framework for the safe and efficient integration of UASs into controlled airspace, highlighting the potential of AR interfaces to meet evolving air traffic management needs.

Keywords: Extended reality, ATM, advanced interface design, U-Space, UAS

1. Introduction

As the number and type of activities performed by unmanned aerial systems (UASs) have been constantly increasing over the years, the risk of encounters with these vehicles is growing as well, potentially resulting in a threat to the safety of operations, with a high risk of collisions with other air vehicles or with buildings, as well as the risk of overrun restricted areas such as airports. In addition, UAS activities have seen a general increase in performances, intended tasks, number of operators and differences in skill levels. Consequently, more and more investments and research have been recently directed toward monitoring and deconflicting technologies for drone operations and, more broadly, for electrical Vertical Take-Off and Landing vehicles (eVTOLs), thus comprising future air taxis [1].

A primal problem is the identification of potential hazards resulting from nearby drones. For this paper, two scenarios are identified as particularly relevant. The first one mainly regards identifying and tracking nearby drones by other UAS operators for collision avoidance. A second case refers to the possible trespassing of drones into restricted areas, specifically airports, where safety and security units and control tower operators need to be aware of this type of traffic, whether it would be collaborative or not. For airports, in particular, different studies have already addressed the detection of undesired UASs [2] while also evaluating how collaborative drones could enhance airport operations. Due to the general need for monitoring and regulating UAS traffic, which results in opportunities and threats, Europe has developed the concept of "U-Space" through its ATM research programme SESAR. This new type of airspace is dedicated to integrating eVTOL traffic within conventional aircraft traffic, hence including all the services needed for safe operations, regulating the use of the airspace and the identification and tracking capabilities required for safe operations of all the involved actors.

Research on the definition of U-Space structure and services has recently resulted in the publication of the fourth edition of the "U-Space Concept of Operations (ConOps)" [3], which complies with the European regulatory framework on U-Space. As a result of the research, some indications arise that help define the requirements for the safe operations of drones, specifically considering identification, geo-awareness, tracking, monitoring, geo-fencing and segregation. It is worth noticing that some of the services related to these tasks are already being implemented in some countries, such as Italy, where the air navigation service provider has funded a dedicated company for U-Space services.

Whether considering piloting rather than air traffic control operations, eVTOLs' traffic monitoring adds up to already complex tasks, leading to an increase in the operator's workload (both pilot and tower controller), with the need for a dedicated interface reporting eVTOLs traffic information and potential hazards. While the complexity of airport operations monitoring is well known, UAS remote pilots are undergoing a similar condition, especially for utility applications. This is mainly due to the continuous increase in task complexity (e.g. plant monitoring, inspection, surveillance, agricultural activities), drone performances and control options, and drone sensor's number and variety [4]. Reacting to this trend, researchers attempted to improve drone interfaces and simplify piloting operations, developing innovative control interfaces.

In a similar complex and high-risk scenario, piloting/traffic controlling tasks can account for big improvements with the novel use of advanced human-machine interfaces, i.e. augmented/mixed reality (A/MR) and virtual reality (VR) - defined together as extended reality (XR) -, as suggested by studies from Yeo [5] and Bräker et al. [6]. As for airport control towers, these techniques have been tested respectively in conventional towers within SESAR-founded projects RETINA [8] and DTT [9, 10], as well as in remote towers already operational across Europe. The outcomes of these solutions were improved performances and reduced controllers' workload, obtained by moving surveillance information from multiple interfaces in the operator workstation to a head-up position collinear with controllers' out-of-the-window direct or video-based view (for conventional and remote towers, respectively).

Regarding drone piloting, video-based virtual/augmented reality goggles are becoming increasingly common in professional piloting tasks, making the user vision correspond to that of a drone's frontal camera. Recently, see-through augmented reality has also been tested [11] employing a Microsoft HoloLens 2 device, considering the possibility of looking at the drone directly, with an exocentric additional video stream, or through a first-person view (FPV).

Exploiting the results matured for civil aviation traffic in A/MR, it thus appears possible to extend these visualization techniques to drones. This paper proposes to benefit from a set of technologies, concepts and techniques previously developed within RETINA, DTT and other SESAR projects to extend the developed tracking and monitoring capabilities in extended reality from civil aircraft to drones. The aim is to propose a novel A/MR interface concept capable of showing information coming from UASs and applying it to both surveillance and piloting tasks, providing users with a proper set of visual information in the head-up position without requirements for an additional user interface. The expected outcomes will be, in particular, increased situational awareness in the context of collision avoidance and traffic management.

The present work will focus on the development of a general framework for the real-time visualization and monitoring of drones in A/MR for different tasks. It will rely on enabling concepts derived from previous research, as well as on the proper design of the visualization interface, which exploits tracking labels and alerts/cues for potentially hazardous events.

Rather than on the multiple available detection techniques for UASs, the research will first look at the required steps to properly register and visualize this information in different A/MR environments, evaluating the maturity of various techniques ranging from see-through head-mounted displays (HMDs) to real-time "augmented" video streams, in both the cases of indoor (e.g. airport control tower) and outdoor (e.g. remote piloting activities) environments. The research aims to confirm the required maturity for all the steps involved in the visualization process, evaluating a working framework for future developments.

As a second step, the research will focus on the surveillance interface design and content definition, considering different inputs from the state-of-the-art augmenting technologies for conventional and remote towers and the requirements identified for the European U-Space concept of operations.

The organization of the paper is as follows. Section 2. will present past related work providing a state-of-the-art and the foundation basis for the proposed implementation framework. Section 3. will explain the methodology behind the research, highlighting the requirement issued from literature analysis and the authors' past experience in the field of augmented reality for airport control towers. Section 4. will then verify the satisfiability of all requirements presented in Section 3. and will propose some concept designs for the A/MR interface, also providing a preliminary implementation of the interface for testing its integration in airport control towers. Section 5. will then discuss possible future advances in the research and provide some conclusions to the work presented.

2. Related work

This section will introduce multiple aspects of previous research on AAM infrastructure, drone monitoring, and XR applications for air mobility.

2.1 Advanced Air Mobility infrastructure and U-Space

In response to the drone's industry growth, countries are trying to regulate the use of eVTOLs, defining novel concepts for the system infrastructure through the development of a new air mobility concept referred to as Advanced Air Mobility (AAM). In the European Union, the integration of eVTOLS and UAS (since eVTOLs are expected to be mainly unmanned in the future, the term UAS will be used often in the paper referring to all aircraft flying in the very low airspace) into the airspace has been ruled by two EU regulations, the EU Implementing Regulation 219/947 [12] and the EU Implementing Regulation 2021/664 [13], which defined the requirements for eVTOLS airworthiness and of the airspace infrastructure, introducing the concept of U-Space among others. In order to find the best solutions to bring into practice the regulations, the European Single European Sky ATM Research Joint Undertaking (SESAR JU) funded the CORUS project, a cluster of multiple working packages whose more recent results have been published in [3], as guidelines for future implementation of the AAM. Following this Concept of Operations (ConOps), the U-space should be initially segregated from the traditional airspace, reducing conflicts between traditional and AAM traffic.

Interestingly, the guidelines provide a summary of the requirements of the surveillance and monitoring infrastructure for drones in Europe, defining the services that will be provided and, consequently, which kind of surveillance information will be available to the operators. These services will include network identification (tracking and surveillance data exchange), traffic information, tactical conflict prediction and resolution, emergency management and conformance monitoring. All these services require a continuous connection between pilots, drone operators, U-Space Service Providers (USSPs) and ATC for shared or contiguous airspace. These services are partially similar to conventional ATC, and eVTOLs will still be required to compile flight plans and have clearances, especially near risky areas such as airports.

For the surveillance and compliance with flight plans, the ConOps reckon on a series of data that should always be available to operators and USSPs, with the eVTOL continuously communicating with the AAM infrastructure through the network identification service. This information is expected to be shared in real-time, being available for other pilots and traffic control operators (ATCOs) whenever a cooperative UAS is flown. This information includes the operator registration number, the drone ID, the drone activity category (such as imagery, agricultural, inspection, et cetera), the drone geographical position (with high accuracy), the drone tracking (velocity vector and expected trajectory), compliance with filed flight plan (including geo-awareness of the drone's position with respect to the authorized airspace volume reserved for the mission), emergency status, and position of remote pilot and/or home position. The information will be considered available for cooperative drones in the following sections of the paper. In addition, a traffic information service is foreseen for sharing information about other traffic (UAS and traditional) with the stakeholders needing it. Finally, a conflict resolution service should be available in the future for automatic deconfliction or provision of suggested actions.

In risky environments, where very-low-altitude AAM traffic is more likely to conflict with conventional traffic, constant monitoring is required, and the introduction of a common procedural interface with ATC is planned, giving access to all the available information about near traffic to both pilots and air traffic controllers.

2.2 Drone monitoring and conflict resolution

Drone monitoring has become a major issue, especially near crowded or critical areas such as airports [14], where careless and malicious drones have caused major accidents in recent years. Whether for collaborative UASs, the surveillance information requested by the ConOps is sufficient for the tracking of aircraft exceeding authorised boundaries (GNSS position and velocity vector directly sent to U-Space by the drone), malicious drones should be passively detected through various systems, such as high-resolution RADARs, LIDARs, or AI based computer vision as proposed in [1, 2, 15, 16]. In both cases, researchers have investigated the possibility of predicting drone intentions from their flight history [17]. An important aspect of monitoring tasks is geofencing and deconfliction, which, in the future, is expected to become an automatic feature, with drones receiving instructions directly from the USSP system without needing remote pilot intervention.

In parallel, an important issue is the mitigation of disruption provoked by the intrusion of a UAS in a segregated and unauthorized portion of airspace. Pascarella et al. [18] defined a framework for resilient airport operations in case of a UAS intrusion in the aerodrome traffic zone (ATZ). Thanks to advanced surveillance systems, the drone can be localized within the airport, and the risk for aircraft operations can be assessed, limiting the disruption with the closure of single airport areas/sectors and giving detailed information about the intrusion to all the interested operators through a shared management system. This way, the closure of the entire airport is considered the last possibility. The system described by the authors can detect and track unauthorized drones, recognize drone features, alert about intrusion and support threat assessment, estimate the level of risk and provide "support to counter-drone actions", limiting the controller's workload and improving their situational awareness.

2.3 UAS piloting and interface design

Adding traffic monitoring tasks over piloting can be detrimental for drone operators, as they are already involved in mentally demanding tasks. Kim-Phuong et al. [19] evaluated the workload of such tasks on the operator, trying to define human-factor-based requirements for the design of detect-and-avoid interfaces which facilitate the work of remote pilots. These have to control drone trajectory and mission advancement while monitoring important parameters such as UAS altitude, ground speed, heading, battery voltage (or battery charge), distance from home and GNSS accuracy. They usually do this relying on a head-down interface, which can also contain video streams or other information on the drone payload, an artificial horizon, and other mission information, for instance, the current status of flight plan authorization/completion. A typical control interface is shown in Figure 1.

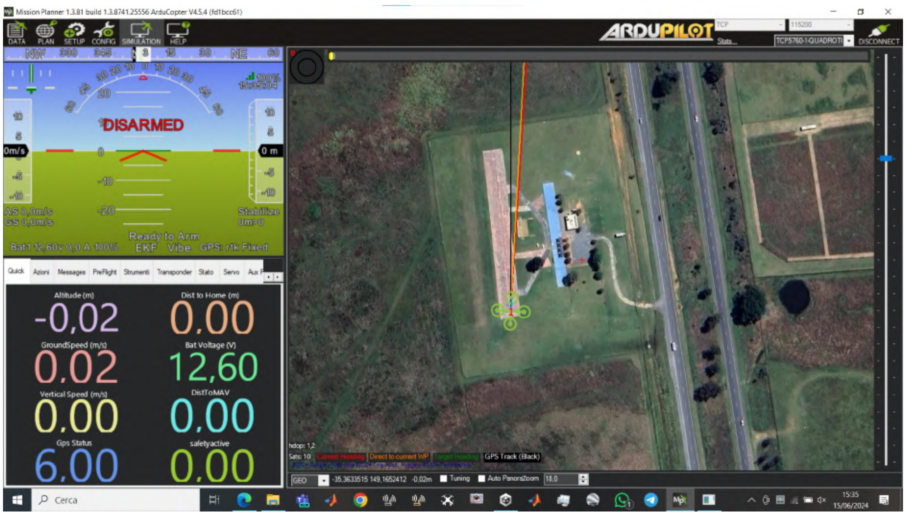


Figure 1 – A conventional head-down interface for drone piloting built on the ArduPilot Mission Planner open-source software.

Trying to reduce the operator's workload, research focused on the development of novel control concepts, studying the effect of the control interface design on the workload and situational awareness

[20] using human-centred design and ecological interface design criteria. Improvements have commonly consisted of substituting conventional remote controllers with graphic interfaces [21, 22] and intuitive gestural/vocal controls [23] while addressing known issues such as the inconsistency between operator and drone orientation during piloting [22] in exocentric view, trying to overcome the field of view limitations of egocentric (first person view) piloting techniques, as shown by Okan et al. [24]. The authors also evaluated how modern digital technologies, i.e. Extended Reality, can bring improvements, especially in the exocentric control mode, hence increasing the operator's situational awareness. The next Subsections will evaluate the role of extended reality technologies in improving operators' performance in the domain of air traffic control, with a focus on the role of augmented reality in monitoring traffic in crowded and high-risk scenarios such as airports.

2.4 Extended reality technologies

Extended Reality (XR) is an umbrella term for technologies ranging from Augmented Reality (AR) to Virtual Reality (VR). All these technologies are characterized by the superimposition of a visual layer of computer-generated digital elements over the user's view of the real world. While these technologies were considered distinct in the beginning, they are nowadays considered as part of a single continuum of different techniques, which differ in the predominance of either the real world or the virtual world, following a concept first proposed by Milgram and Kishino 1994 [25].
AR and VR differ in that the first aims at blending the digital elements coherently with the user's view of the real world, "augmenting" its perceptive capabilities and extending its sensing. Virtual reality, on the other hand, results in the user being completely immersed in the virtual environment, perceiving her/himself as "present" in the digital scenario, with the involvement of additional sensory cues, such as aural and haptic ones. Following the idea of a continuum among these techniques, it appears possible to adapt the digital content to external conditions, varying the quality and quantity of the information visualised from a barely augmented view to a substantially synthetic experience, passing through some intermediate techniques that come under the generic name of Mixed Reality (MR), while being sometimes addressed as a type of AR.
For this research, Augmented/Mixed Reality (A/MR) seems to be a promising technology, as it allows the collimation of a digital infographic layer, such as a human-machine interface, together with the user's view of the real world, increasing the users' situational awareness. A crucial aspect of A/MR is the registration process, which involves digital projections' continuous and real-time alignment with the user's real-world view.

2.5 A/MR for surveillance tasks in control towers

In the past years, A/MR has found useful applications in traffic surveillance scenarios such as maritime and aviation ones. In the context of air traffic control towers, A/MR as the potential to reduce operator workload and enhance situational awareness by enabling direct visual access to essential information without diverting gaze from aircraft. This improvement is expected to enhance both safety and traffic fluidity.
Initial explorations into AR applications for control towers were conducted by Reisman in 2006 [7], who identified significant technological challenges but recognized A/MR's potential for providing surveillance information. In the following years, other research emphasized the need for user-centric design due to the specificity of traffic scenarios and highlighted A/MR's potential to enhance situational awareness but also noted ergonomic and data visualization challenges in HMDs, demonstrating increased task performance but also overconfidence among tower controllers in a virtual traffic scenario.
Our previous work [8] focused on the development of the RETINA concept under the SESAR framework, proposing A/MR applications for control towers through different display techniques, including see-through head-mounted displays (HMDs) and spatial conformal displays. Between 2019 and 2020, the researchers validated the RETINA project's operational concept, demonstrating improved task performance and situational awareness while reducing workload. The findings suggested that see-through HMDs were the most effective technology, whereas spatial displays lacked the maturity to handle multiple controllers efficiently. At a further stage of the research, the DTT project [10] evolved this concept through real-time virtual simulations of various airport scenarios. All proposed

solutions featured tracking labels for aircraft positions, presenting critical surveillance information to controllers. These solutions were validated using human-in-the-loop methodologies involving tower controllers in simulated scenarios, confirming reduced workload and enhanced situational awareness. Objective metrics such as increased head-up time and improved task efficiency supported these findings.

Recent work from Fadda et al. [26, 27] tested a system for the visualization of real aircraft along with relevant surveillance information in A/MR in the operative control tower of the Bologna's Guglielmo Marconi Airport, with a proper registration process for a live feed of aircraft positions based on GNSS (Global Navigation Satellite System) technology. The application was capable of correctly tracking moving traffic on the ground and in the air while integrating surveillance information such as weather, flight plans and flight phase status.

While these solutions were developed for head-mounted displays, some research also addressed video-based A/MR, assessing augmentation of data in virtual/remote airport control towers [28, 29], evaluating which overlays can be directly projected on the tower's video monitor to help track aircraft and surveil the overall operations.

Thus, aircraft tracking has already been tested indoors and outdoors for see-through and video-based A/MR displays. The subsequent step needed for this research would be the extension of these technologies to drone applications.

Moving toward this concept, Corsi [30] began integrating a simulated drone scenario in the same interface used by Fadda, mimicking some U-Space traffic invading the airport scenario, and exploring how an interface could be designed in A/MR, helping the controllers in managing contingent and conflicting situations avoiding an unnecessary increase in workload. Figure 2 shows the simulated AAM scenario together with real aircraft tracked from Bologna Guglielmo Marconi airport control tower.

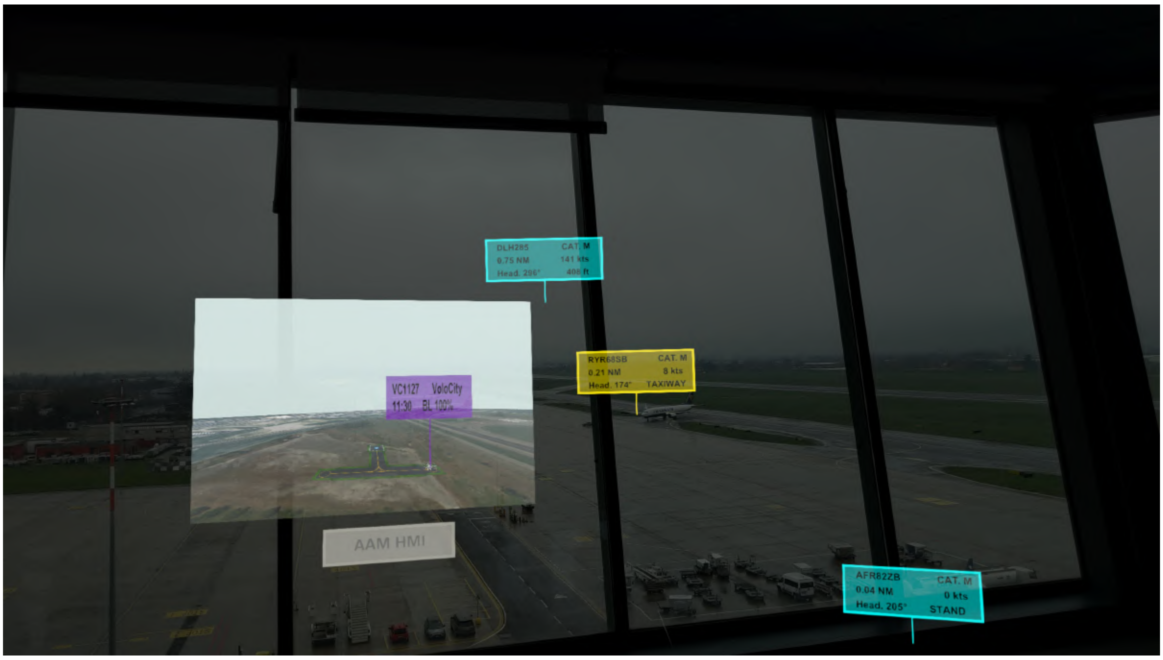


Figure 2 – Testing of a simulated interface for AAM traffic monitoring in the Bologna airport control tower.

2.6 Drone Monitoring and Control in A/MR

While previous work has been established on a solution for drone incursion monitoring by A/MR in airport control towers, an assessment of the maturity of the technological framework for foreign drone surveillance is missing. In addition, work from Corsi [30] focused on the interface triggering more than on the interface content needed for the proper management of a UAS incursion contingency.

Some work exists instead on A/MR interfaces for drone piloting, as previously mentioned. Konstantoudakis et al. [11] developed an application for the visualization and control of a drone through A/MR, addressing many important questions as the best telemetry source for position estimation (data from the drone's aggregate IMU readings) and the calibration of an A/MR device in the outdoor. The researchers dealt with the transmission of live telemetry data from the drone to an A/MR see-through head-mounted display (HMD), providing the user with an exocentric view of the drone, whose position in the user's view was highlighted via a digital twin of the drone itself. Meanwhile, an exocentric video stream of the drone's frontal camera could be visualized in the A/MR interface, providing the user with an egocentric control option. This solution comes as a foundation for evaluating the feasibility of an A/MR application for monitoring foreign drone incursion during a piloting task, as discussed below.

3. Methods

Aiming to address the attainability of an interface for the future monitoring of foreign drones in A/MR. Considering the shared interest in avoiding incursions and incidents in reserved airspace, this section will highlight the requirements of applications for drone monitoring in the cases of a remote UAS pilot and an airport traffic controller.
The steps needed for the tracking of foreign UAS, including data flow and network infrastructure, are identified as follows:

- A source for the UAS system's position must be available in real-time.
- The UAS position must be accurate enough for direct-view surveillance.
- The UAS kinematic vector must be available in real-time.
- The UAS kinematic vector must be accurate enough for trajectory tracking and prediction.
- Other relevant surveillance information, such as ID and pilot's position, must be available.
- A real-time connection between U-Space infrastructure and ATC/drone pilot is needed.

The needed tracking capabilities of the A/MR device (both indoor and outdoor) for a proper registration process are:

- Acquisition of the UAS position with high accuracy.
- Acquisition of the UAS position in real-time (minimizing positioning information reception latency).
- Tracking of the aircraft position accurately in the A/MR environment.
- Acquisition and tracking of information for multiple UASs at the same time.
- Tracking of the UAS position in real-time.
- Matching of the A/MR environment with the real world for accurate UAS position identification.
- Rendering of the UAS tracking holograms.
- Evaluation of possible error sources and implementation of counteractions.
- Security of precision and reliability of tracking and positioning system.
- Development of an appropriate labelling system for UAS tracking.
- Visualisation of ATC and U-Space information usually available on traditional interfaces.
- Visualisation of helping tools for low-visibility conditions.

Table 1 – Guidelines for content of A/MR interface for airport intrusion management

Display of aircraft traffic scenario and surveillance information
Display of intruded drones with tracking of past and expected trajectory
Assessment of risk level for drone intrusion
Information on level and area of disruption
Assessment of drone's intentions
Focus on overall traffic scenario

Table 2 – Guidelines for content of A/MR interface for remote piloting

Display drone control information (battery level, position, distance from home, etc.
Tracking of piloted drone in A/MR
Proper organization of invasive elements as an egocentric video stream from drone's camera
Visualization of other nearby drones
Assessment of conflict/collision risk
Awareness of airspace reserved for mission task
Display of cues for intruding drones in a non-invasive scheme
Keep the pilot's focus on the piloted drone

Finally, Tables 1 and 2 focus on specific design requirements of airport monitoring piloting and interfaces, respectively. Such requirements will be guidelines for the design of an interface prototype, highlighting which and how content should be visualised in the interface time by time.
The next section will analyse these requirements, evaluate the maturity of the technology needed for the concept of A/MR drone traffic monitoring, and present a rendering of two concept interface designs for the cases of aerodrome traffic control and remote piloting.

4. Results

4.1 UAS tracking and visualization system concept

This section analyses the elements needed for the intended A/MR visualization platform, i.e. techniques for "registering" the digital layer with the user view of the physical world, starting from a real-time stream of georeferenced data positions (from radar or GNSS units).
To support the feasibility of a similar interface, it is worth emphasizing that nowadays, most UASs provide exhaustive tracking telemetries with high transmission rates, which appear sufficient for GNSS-based tracking of far objects. In Europe, under-development technologies such as EGNOS (European Geostationary Navigation Overlay Service) and ARAIM (Advanced Receiver Autonomous Integrity Monitoring) have been investigated for the future provision of improved geopositioning data. In addition, ConOps foresee the compulsoriness of transmitting of this telemetry to the U-Space infrastructure in real-time for broadcasting to infrastructure operators. It is thus reasonable to consider current solutions for controlled drones to be extendable to foreign drones in the near future. In the case of non-cooperative drones, especially nearby airports, passive detection methods, for instance, those presented in Section 2. seem feasible solutions. It is worth noticing that drone visualisation in A/MR has also exploited Inertial Measurement Unit (IMU) readings from the drone telemetry to reconstruct its kinematics and, hence, the evolution of its position. While this method can generate higher precisions than GNSS systems, which is useful when tracking a piloted drone whose dimension is too small with respect to the precision of common GNSS units, it is unfeasible that IMU readings will be available to the USSPs. In addition, GNSS precision appears satisfactory for deconfliction issues, as even an error of a few meters in the non-cooperative drone position will not affect the intended purposes.
In addition to position information, other telemetry elements are likely to be available to the U-Space and ATC operators in the near future, including velocity and trajectory information, expected intentions, identification and remote pilot/take-off position. Drones such as the DJI Mavic 2 Enterprise transmit this information, which is hence considered available for the purpose of this work.

A second important aspect is the possibility of exploiting the received surveillance data for visualization in an A/MR interface, for instance, a Microsoft HoloLens 2 HMD. Since drone surveillance information is similar to aircraft surveillance information, with similar data rates and content, it is reasonable to assume that the technologies for aircraft tracking tested in an operative control tower with actual air traffic are easily adaptable to drone visualisation in A/MR. In particular, Fadda et al. [26] managed the registration of multiple aircraft in real-time through GNSS technology, exploiting the broader studies conducted through the SESAR DTT project for the design of the interface content (tracking labels, visual cues and attention guidance). All these techniques are, hence, readily available for drone tracking applications.
Devices such as HoloLens 2 use the SLAM (Simultaneous Localization and Mapping) techniques for registration of the digital layer indoors, mapping the environment and the user's position and gaze inside it in real-time. The use of SLAM techniques for indoor A/MR applications has been largely tested, for instance, in airport control towers, but the performance of see-through displays in outdoor environments is more uncertain. However, Konstantoudakis et al. [11] successfully tracked a drone using A/MR outdoor, exploiting the IMU system of a HoloLens 2 device rather than its camera tracking to ensure the stability and constant registration of the digital overlay with the real world. Yet, SLAM techniques gave positive results in outdoor barely-anthropized environments for aircraft tracking (i.e., in the proximity of buildings or smaller infrastructures such as fences, see Figure 3).

a) Aircraft tracking indoor. b) Aircraft tracking outdoor.

Figure 3 – HoloLens aircraft tracking indoor and outdoor.

In the case of environments without practical references, such as plain fields, markers could be used to give the A/MR device some reference, considering remote pilots usually move in a rather small area. A second problem with outdoor applications is the sunlight, which can make holograms projected on a see-through display not visible to the user due to their low luminosity with respect to the environment. Some handcrafted solutions have been explored by applying photochromatic films on the A/MR device lenses.
Following the previous discussion, the proposed A/MR interface framework for drone monitoring looks realisable, given the possibility of tracking drones indoors and outdoors in A/MR based on GNSS information, along with solutions for surveillance information management.

4.2 Interface design

This section addresses the design of the visual interface for the A/MR application. The development of this interface will be guided by the previously identified requirements, particularly those related to de-confliction and collision avoidance.
Insights from the U-Space concept of operations have been significant in elucidating the services likely to be provided, the types of information expected to be available in the future, and the possible modes of surveillance. Currently, the identified services essential for proper operations include:

- geo-awareness;
- traffic information;

- flight authorization;
- geo-fencing;
- identification;

The second set of inputs for interface design emerges from existing research on airport control towers, encompassing established concepts such as tracking labels, visual and aural cues for out-of-the-window elements, and safety net-based alerts.
Preliminary cross-checking of these sources has led to a proposal for visualizing information, which includes parameters such as distance from the operator, the airport boundaries or the piloted drone, identification codes, velocity vectors, types of current activities, expected trajectories, and potential conflicts.
Drawing on interfaces developed for airport control towers, several critical components have been identified for inclusion in a surveillance interface. These components comprise a marker (e.g., a circle or rectangle) to identify the detected drone, a label associated with the marker that contains relevant surveillance data, and visual cues designed to highlight potential hazards that are not within the user's immediate view.
Ultimately, the designed interface will serve as a standardized framework for multiple tasks, enabling specific adaptations with minimal alterations.
To achieve this, a user-oriented approach was employed in the selection of pertinent information and the definition of cues and alerts. Given that the design is task-driven (encompassing tracking, monitoring, de-confliction, and collision avoidance), a human-centred design approach is deemed appropriate, as it addresses the needs of the end user in a mentally demanding task. The interface content and organization incorporate concepts from the DTT project and research on remote towers, comparing various label designs and cue options and integrating these with advanced solutions from drone interfaces, such as those from [11].

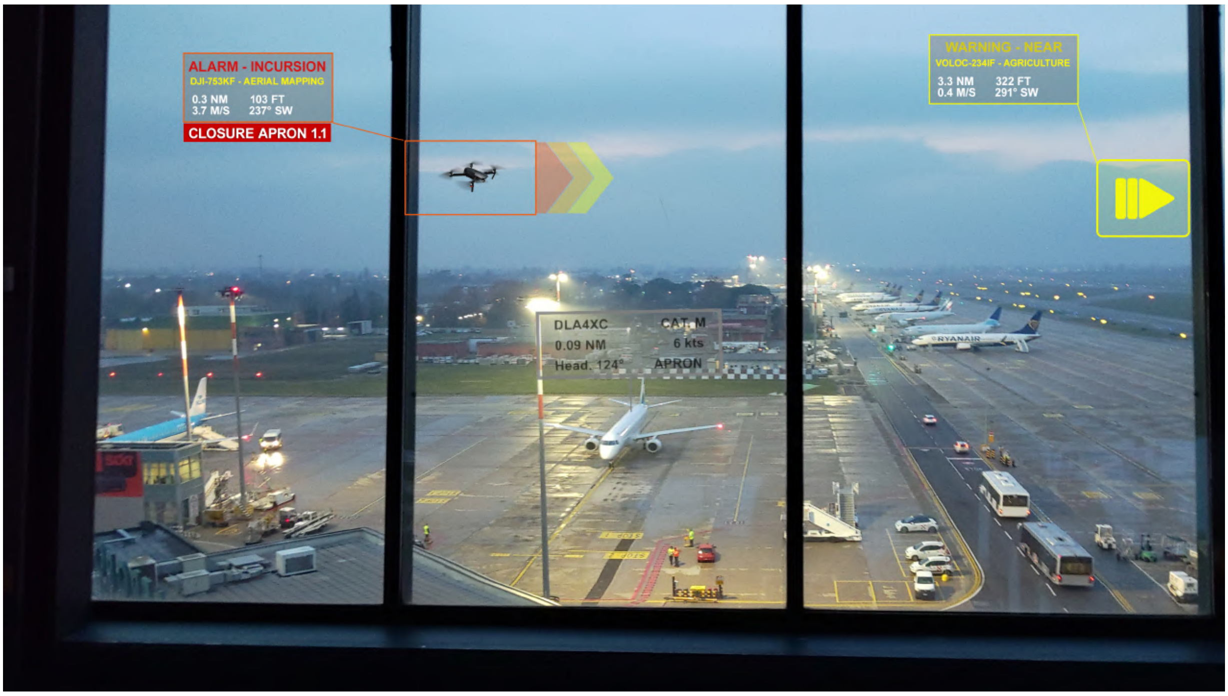


Figure 4 – Proposed design for the drone interface in an airport traffic control scenario.

Figure 4 shows a preliminary proposal for the interface design in the case of an airport scenario. The interface reproduces a user view at an airport facility, integrating a real picture of an augmented reality application for the tracking of airport traffic taken from an airport control tower. Regarding the in-the-view UAS, the interface contains verbal and graphical elements highlighting the risk level for the detected drone, using specific terms for the type of hazard (e.g. incursion in a restricted area,

collision risk...) and progressive colour coding. Graphical elements provide the operator with intuitive and responsive indicators of the risk level. A series of arrows - two-dimensional in the picture, three-dimensional in the designed application - depicted using colour coding and progressive dimension and salience relative to risk level highlight the drone's aiming direction. The label also contains an identification code and the expected use activity. Distance from the operator/relevant point and targeting direction are also provided. A second graphical element, on the right, identifies an out-of-the-view drone presenting similar surveillance information with a visual cue - a two-dimensional arrow - suggesting the drone's direction relative to the user's view.
The second case, presented in Figure 5, differs from the tower interfaces as the pilot is primarily focused on the control of the drone rather than on monitoring a spatially extended traffic scenario. The interface presents some key elements for drone control, such as speed, Euler angles, battery level, altitude, vertical rate and distance from home. The piloted drone is highlighted through a purple hologram, which tracks its current position. In the upper area of the interface, two boxes visualise the drone's position and mission status on a 2D map and the egocentric video stream of the drone's frontal camera. The interface organisation is inspired by VR goggles used for professional drone piloting. Since pilots cannot lose focus on the drone, the cues for conflicting UAS traffic, eluding the reserved airspace volume, should be presented in a non-invasive manner, highlighting the incursion direction and the level of danger without occluding the user's view of the piloted drone. In this case, a box highlighting the intruding drone's position is considered unnecessary as it will not increase the pilot's situational awareness. Still, it will result in an increase in interface cluttering. Instead, an additional cue is presented in the 2D map of the terrain to help identify the direction from which the threat is expected to approach.

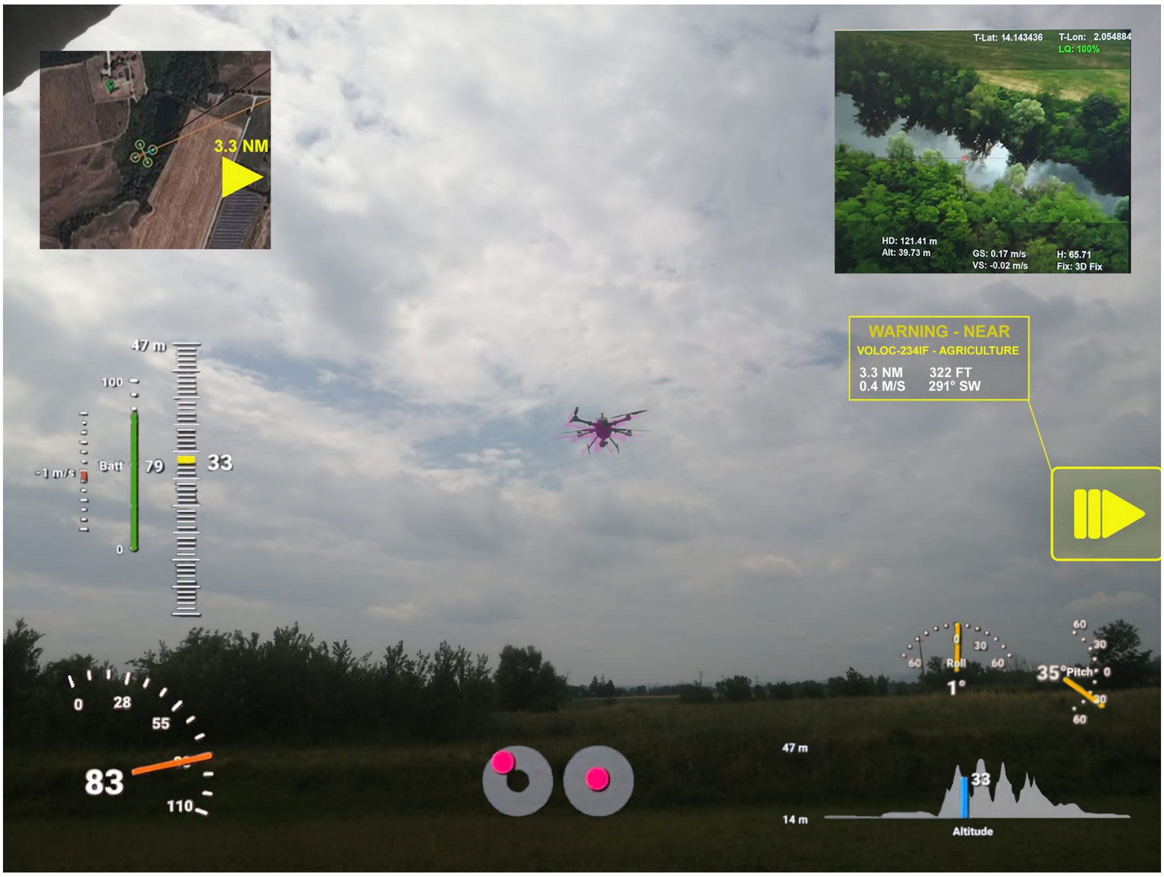
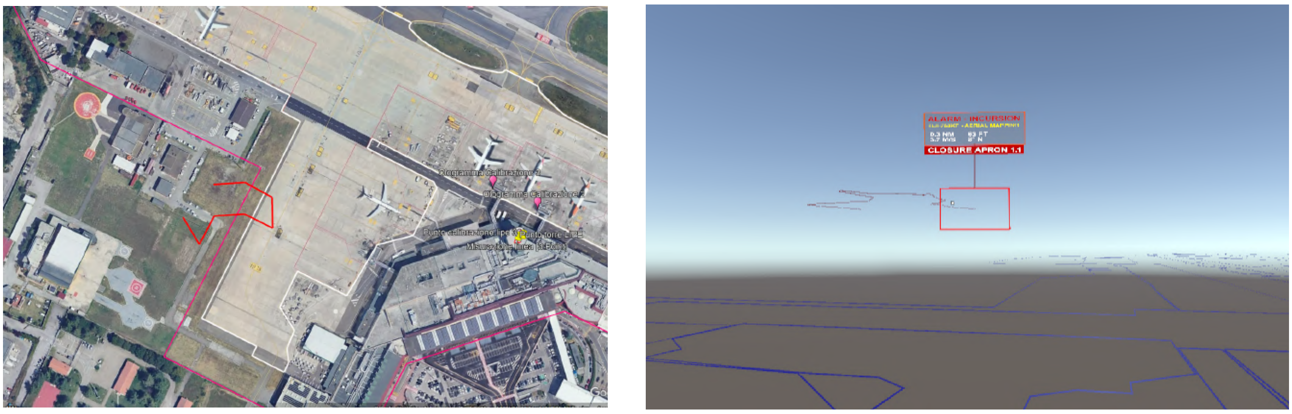


Figure 5 – Proposed design for the drone interface in a piloting scenario.

4.3 Proposed case study

As a final task of this research, a case study is defined to evaluate the effectiveness of the chosen design, trying to evaluate the integration of the proposed surveillance concept for malicious drones

together with the demanding operations of airport traffic management.
As for the interface design, this should be tested to evaluate the usefulness of the visualized information while performing other tasks, at least for control tower operators. In this paper, a concept implementation for the HoloLens is presented using a set of real telemetry data from a DJI drone.
At this stage, the application has only been implemented in Unity without testing in the real world. However, the design and the logic have been tested in the Unity development environment with the original log of drone data (taken from the telemetry of a real mission) and aircraft ADS-B telemetry (previously collected at the Bologna airport), evaluating the recognition of the drone's intrusion in different airport sectors and of the risk level due to the extension of the trespassing and heading of the drone.
The use of real telemetry helps assess the feasibility of the data rate for monitoring purposes, additionally facilitating the development of realistic simulated scenarios for extensive design evaluation. Moreover, the application uses authentic georeferenced information about the Bologna airport, thus ensuring that the logic layer of the application will work properly in the real world. Figure 6 shows the planned drone incursion's trajectory in the airport restricted area from a Google Earth view, and the subsequent simulation of the incursion in the Unity scenario. The drone is entering the airport area in proximity of Apron 1, similarly with the scenario presented in Figure 4.



a) Drone incursion's trajectory visualised on Google Earth software (in red). Airport borders are depicted in pink.

b) Visualisation in the simulation environment of the interface appearance during a drone intrusion inside the airport restricted area.

Figure 6 – Aerial and simulation environment's view of the scenario defined for the case study.

In the near future, the application will be tested with real-time traffic.

5. Conclusions

This paper aims to assess the improvements offered by augmented reality for monitoring unmanned systems vehicles, especially in non-collaborative or hazardous scenarios. To this purpose, a first evaluation is made, starting from previous research, to assess and verify the maturity of the concepts required for tracking drones in augmented reality, such as the real-time visualization of georeferenced data coming from drone telemetry. As a second step, a possible interface design is proposed based on a task analysis of requirements for safe drone operations and concepts for surveillance and control in Augmented Reality developed for civil aviation within the SESAR research framework. The proposed interface is implemented inside an A/MR application for airport tower traffic control, which has already been tested for aircraft surveillance in shadow mode inside an operative control tower. The novel interface for drone monitoring will thus tested in the near future, exploiting a simulated drone incursion by means of real telemetry logs of a previously flown drone. The results of this research could be used in the future for integrating complex applications, e.g. including drone surveillance integrated within airport traffic control interfaces or using the developed interface for the monitoring of swarms of collaborative drones. Furthermore, additional surveillance overlays could be easily integrated, including aids for low-visibility/night conditions and obstacle/aiming point identification.

6. Contact Author

Tommaso Fadda
Department of Industrial Engineering, Università di Bologna – Campus di Forlì
Via Fontanelle 40, 47121, Forlì (FC), Italy
+39 331 140 0297
tommaso.fadda2@unibo.it

7. Copyright Statement

References

[1] Taha B and Shoufan A. Machine learning-based drone detection and classification: state-of-the-art in research. *IEEE Access*, Vol. 7, pp. 138669-138682, 2019. doi:10.1109/ACCESS.2019.2942944

[2] Heidger R, Lambercy V and Lambers D. Tracking analysis of drone detection systems at airports: methodology and results. *2021 21st International Radar Symposium (IRS)*, Berlin, Germany, pp. 1-17, 2021. doi:10.23919/IRS51887.2021.9466192

[3] U-Space ConOps and architecture (Edition 4). *Deliverable 4.2* of SESAR 3 JU's Corus-Xuam project, 2023.

[4] Tezza D and Andujar M. The state-of-the-art of human–drone interaction: a survey. *IEEE Access*, Vol. 7, pp. 167438-167454, 2019. doi:10.1109/ACCESS.2019.2953900

[5] Yeo, J. The theory of process augmentability". *ICIS 2017 Proceedings*, 2017. https://aisel.aisnet.org/icis2017/TransformingSociety/Presentations/11

[6] Bräker J, Osterbrink A, Semmann M et al. User-centered requirements for augmented reality as a cognitive assistant for safety-critical services. *Business & Information Systems Engineering 65.2*, pp. 161–178, 2023. doi:10.1007/s12599-022-00779-3

[7] Reisman R and Brown D. Design of Augmented Reality Tools for Air Traffic Control Towers. *6th AIAA Aviation Technology, Integration and Operations Conference – ATIO*, p. 7713, 2006. doi:10.2514/6.2006-7713

[8] Bagassi S, De Crescenzio F, Piastra S, Persiani C A, Ellejmi M, Groskreutz A R and Higuera J. Human-in-the-loop evaluation of an augmented reality based interface for the airport control tower. *Computers in Industry*, Vol. 123, 2020. doi:10.1016/j.compind.2020.103291

[9] Santarelli R, Bagassi S, Corsi M, Teutsch J, Lasheras R, Carmona M and Groskreutz A. Towards a digital control tower: the use of augmented reality tools to innovate interaction modes. *SESAR innovation days 2022*, Budapest, 2022.

[10] Bagassi S, Corsi M, De Crescenzio F, Santarelli R, Simonetti A, Moens L and Terenzi M. Virtual/augmented reality-based human–machine interface and interaction modes in airport control towers. *Scientific Reports*, Vol. 14(1), pp. 1-18, 2024. doi:10.1038/s41598-024-63731-3

[11] Konstantoudakis K, Christaki K, Tsiakmakis D, Sainidis D, Albanis G, Dimou A and Daras P. Drone Control in AR: An intuitive system for single-handed gesture control, drone tracking, and contextualized camera feed visualization in augmented reality. *Drones*, Vol. 6(2):43, 2022. doi:10.3390/drones6020043

[12] Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft. OJ L 152, 11.6.2019, pp. 45–71. http://data.europa.eu/eli/reg_impl/2019/947/2022-04-04

[13] Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space. OJ L 139, 23.4.2021, p. 161–183. http://data.europa.eu/eli/reg_impl/2024/1110/oj

[14] Lykou G, Moustakas D and Gritzalis D. Defending Airports from UAS: A Survey on Cyber-Attacks and Counter-Drone Sensing Technologies. *Sensors*, 20(12):3537, 2020. doi:10.3390/s20123537

[15] Slimeni F, Delleji T and Chtourou Z. RF-Based Mini-Drone Detection, Identification & Jamming in No Fly Zones Using Software Defined Radio. *International Conference on Computational Collective Intelligence*. Cham: Springer International Publishing, pp. 791-798, 2022. doi:10.1007/978-3-031-16014-1_62

[16] Samadzadegan F, Farzaneh DJ, Farnaz AM, Gholamshahi M. Detection and recognition of drones based on a deep convolutional neural network using visible imagery. *Aerospace*, 9(1):31, 2022. doi:10.3390/aerospace9010031

[17] Liang J, Ahmad B I, Jahangir M and Godsill S. Detection of Malicious Intent in Non-cooperative Drone Surveillance, *2021 Sensor Signal Processing for Defence Conference (SSPD)*, Edinburgh, United Kingdom, pp. 1-5, 2021. doi:10.1109/SSPD51364.2021.9541485

[18] Pascarella D et al. Drone intrusion management systems in airports: assessment of ASPRID solution. *Journal of Physics: Conference Series*. Vol. 2716. No. 1. IOP Publishing, 2024. doi:10.1088/1742-6596/2716/1/012070

[19] Vu K P L, Rorie R C, Fern L and Shively R J. Human Factors Contributions to the Development of Standards for Displays of Unmanned Aircraft Systems in Support of Detect-and-Avoid. *Human Factors*, 62(4), 505-515, 2022. doi:10.1177/0018720820916326

[20] Wenjuan Z, Yunmei L and David B K. Effect of interface design on cognitive workload in unmanned aerial vehicle control. *International Journal of Human-Computer Studies*, Vol. 189, 2024, 103287, ISSN 1071-5819. doi:10.1016/j.ijhcs.2024.103287

[21] Zul Azfar A and Hazry D. Simple GUI design for monitoring of a remotely operated quadrotor unmanned aerial vehicle (UAV). *2011 IEEE 7th International Colloquium on Signal Processing and its Applications*, pp. 23-27, Penang, Malaysia, 2011. doi:10.1109/CSPA.2011.5759836

[22] Cho K, Cho M and Jeon J. Fly a drone safely: evaluation of an embodied egocentric drone controller interface. *Interacting with Computers*, Vol. 29, no. 3, pp. 345-354, May 2017. doi:10.1093/iwc/iww027

[23] Suárez Fernández R A, Sanchez-Lopez J L, Sampedro C, Bavle H, Molina M and Campoy P. Natural user interfaces for human-drone multi-modal interaction. *International Conference on Unmanned Aircraft Systems (ICUAS)*, pp 1013-1022, Arlington, VA, USA, 2016. doi:10.1109/ICUAS.2016.7502665

[24] Erat O, Isop W A, Kalkofen D and Schmalstieg D. Drone-Augmented Human Vision: Exocentric Control for Drones Exploring Hidden Areas, *IEEE Transactions on Visualization and Computer Graphics*. Vol. 24, no. 4, pp. 1437-1446, April 2018. doi:10.1109/TVCG.2018.2794058

[25] Milgram P and Kishino F. Taxonomy of mixed reality visual displays, *IEICE Transactions on Information and Systems*, E77-D (12), pp. 1321 - 1329, 1994.

[26] Fadda T, Bagassi S and Corsi M. ADS-B driven implementation of an augmented reality airport control tower platform. *Materials Research Proceedings*, Vol. 37, pp. 767-770, 2023. doi:10.21741/9781644902813-164

[27] Fadda T. A roadmap for the implementation of augmented reality solutions for airport control towers in an operative environment. *Materials Research Proceedings*, Vol. 42, pp. 173-177, 2024. doi:10.21741/9781644903193-38

[28] Schmidt M, Rudolph M, Papenfuss A, Friedrich M, Möhlenbrink C, Kaltenhäuser S and Fürstenau N. Remote airport traffic control center with augmented vision video panorama. *2009 IEEE/AIAA 28th Digital Avionics Systems Conference*, Orlando, FL, USA, pp. 4.E.2-1-4.E.2-15, 2009. doi:10.1109/DASC.2009.5347479

[29] van Schaik F J, Roessingh J J M, Bengtsson J, Lindqvist G and Fält K. Advanced remote tower project validation results. *IFAC Proceedings Volumes*, Vol. 43, Is. 13, pp. 135-140, 2010. doi:10.3182/20100831-4-FR-2021.00025

[30] Corsi M. Extended reality-based human machine interface for drone monitoring in airport control tower environment. *Materials Research Proceedings*, Vol. 42, pp. 193-196, 2024. doi:10.21741/9781644903193-42