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Extended reality-based human machine interface for drone monitoring in airport control tower environment

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Abstract. This study aims to exploit digital technologies to develop and validate an innovative *Extended Reality Human Machine Interface for drone monitoring in Airport Control Towers.* The model for the interface prototype exploits multimodal interaction features and implements technologies and functions such as Extended Reality, drone identification and tracking labels, and safety net visualisation.

Introduction

As unmanned aerial systems (UASs) continue undertaking a growing array of activities, the risk of encountering these vehicles is also rising. This poses potential threats to operational safety, including the possibility of collisions with other aircraft or structures and unauthorised entry into restricted areas like airports. Furthermore, the expanding scope of UAS operations necessitates increased investment and research into monitoring and managing drone activity technologies, including future “air taxis” [1].

A key challenge lies in identifying potential hazards posed by nearby drones. This study focuses on the concern of drones intruding into restricted airport zones, requiring airport safety and security units and control tower operators to monitor and manage such airspace intrusions. Various studies have explored methods for detecting unauthorised UAS activity and assessing the potential benefits of cooperative drone operations in the airport environment [2]. Recognising the need to monitor and regulate UAS traffic, Europe has developed the concept of *U-Space* under its Air Traffic Management research program *SESAR*. U-Space constitutes dedicated airspace for integrating UAS traffic with conventional aircraft, providing essential services for safe operations, and facilitating the identification and tracking of all involved actors.

Recent research has led to the publication of the fourth edition of the *U-Space Concept of Operations (ConOps)*, aligning with European regulations [3]. This document outlines requirements for safe drone operations, including identification, tracking, monitoring, geofencing, and segregation.

When dealing with Air Traffic Control (ATC) operations, monitoring UAS traffic near airports is expected to add additional workload to the controllers. As a matter of fact, supplementary dedicated interfaces intended for UAS traffic information shall be included in airport control towers. To improve ATC operations, while reducing controllers workload, several studies suggest to exploit digital technologies, such as eXtended Reality (XR), to provide users with innovative Human-Machine Interfaces (HMI) presenting surveillance information in a head-up display aligned with the controllers' direct view [4-5].

Leveraging insights from civil aviation traffic management, this work proposes extending XR visualisation techniques to Advanced Air Mobility (AAM) scenarios, drawing upon previous SESAR projects, such as *RETINA - Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision* and *DTT – Digital technologies for tower*. This study aims to

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develop a novel XR-based interface that can be seamlessly integrated into control towers and to present unmanned traffic information in the airport vicinity for surveillance tasks.

XR-based HMI for drone monitoring in Airport Control Tower

Drawing from advancements in technologies such as those developed in projects like *RETINA* and *DTT*, this study endeavours to harness digital innovations to create and validate an XR-based Human Machine Interface tailored for Air Traffic Controllers (ATCOs) tasked with monitoring UAS traffic near airports. This interface aims to facilitate a more intuitive and efficient interaction within the control tower, enhancing both performance and situational awareness for ATCOs who must navigate the integration of autonomous drones.

Guidance from the U-Space concept of operations offers valuable insights into anticipated services, future information availability, and potential surveillance capabilities.

The interface design also draws inspiration from previous research on airport control towers, incorporating established concepts such as tracking labels, air gestures interaction [6], visual and aural cues for external elements, and safety net-based alert systems [7]. These inputs inform the development of a comprehensive interface tailored to the unique demands of monitoring UAS traffic in complex airspace environments.

In particular, the presented concept proposes including an on-demand semi-transparent augmented interface that live-streams the area surrounding the UAS ground infrastructure (vertiport) in the aerodrome area. To avoid the constant presence of an additional interface in the control tower, the ATCOs equipped with a see-through head-mounted display (ST-HMD) can visualise the HMI only when needed, exploiting the air gestures to activate and deactivate the interface (Figure 1).

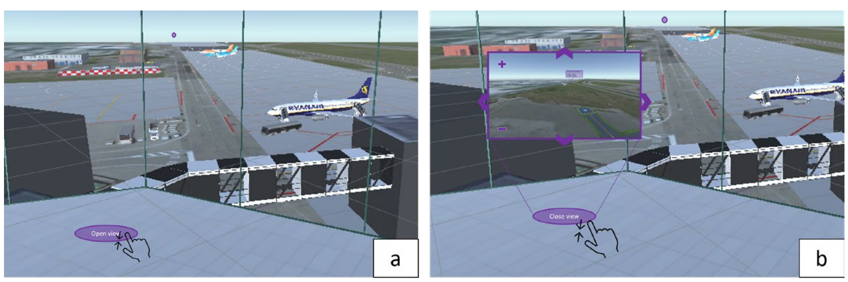

Figure 1 Proposed concept design for the XR-based HMI for drone monitoring in airport control towers.

After reviewing various sources, a suggested layout for visualised information emerges. This layout encompasses essential data points for the drones, such as identification details, velocity vector, battery status, ongoing activity, potential conflicts, and proximity to vertiport or airport boundaries. Several critical components are necessary for an effective surveillance interface, building upon interface designs crafted for airport control towers. These include a distinct marker to denote detected drone position, a corresponding label including the necessary surveillance data, and visual or auditory indicators to emphasise potential risks.

Assessment of the preliminary interface design

A human-in-the-loop validation activity is planned to be performed in a virtual environment to assess the goodness of the proposed concept and design. The user, provided with an HMD device, is immersed in a virtual representation of the Bologna Airport (LIPE) control tower. The simulation proposes to the user a futuristic AAM scenario where a UAS ground infrastructure is placed in an area of the aerodrome neighbouring the taxiway but outside the field of view of the ATCOs. The simulation foresees UAS traffic (air taxis) departing and landing from and to the vertiport.

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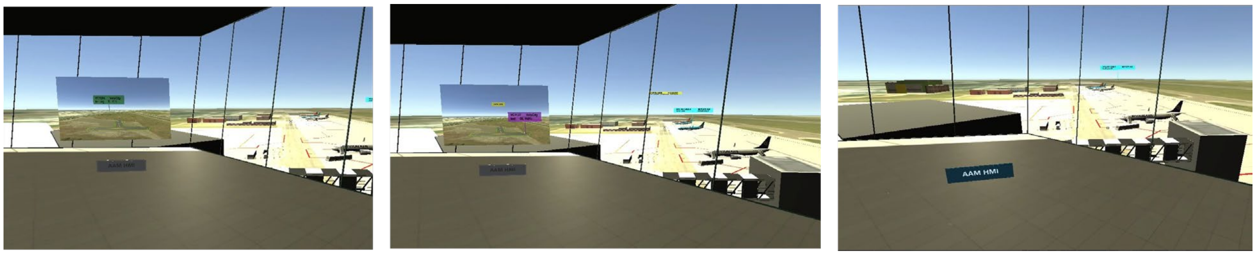

Figure 2 XR-based HMI for drone monitoring proposed concept in a virtual environment representing an airport control tower.

Figure 2 shows a preliminary proposal for the interface design in a completely virtual environment. The three images show the active HMI displaying the vertiport close to the runway with a landing (green label), a departing air taxi drone (purple label), and the inactive interface. Figure 3 shows the representation of a safety net activated by a drone trespassing into a restricted airport zone. If a hazardous situation happens while the interface is closed, it automatically opens and signals the alarm through visual and auditory cues to guide the controller's attention. Moreover, the label of the involved drone turns red until the situation is solved.

Figure 3 Safety net visualisation: a landing drone trespassing into a restricted area.

During the validation campaign, objective quantitative and subjective qualitative measurements from the ATCOs will be collected to refine the design and accommodate the user's needs before implementing the final interface to be assessed and validated in a real control tower. Figure 4 shows the proof of concept of the proposed HMI in a real airport control tower integrated with a real-time Augmented Reality (AR) interface for tracking airport traffic to support ATC operations,

Figure 4 XR-based HMI for drone monitoring (virtual) integrated with a real-time AR interface for tracking airport traffic in Bologna airport control tower as visualized by a user wearing a Microsoft HoloLens2 devices.

which is currently under development [8]. The interface streams a virtual scenario of a vertiport close to the runway and the related traffic and is provided to users wearing ST-HMD devices. In this real environment, the user can use the gesture interaction to display and deactivate the interface and move and scale it in the desired position.

Conclusions

The increasing prevalence of unmanned aerial systems in airspace operations necessitates effective strategies for monitoring and managing their traffic, particularly near airports where safety is paramount. This study explores the development of an XR-based Human Machine Interface tailored for Air Traffic Controllers to enhance situational awareness and operational efficiency. Drawing on insights from the U-Space ConOps and previous research on airport control towers, the proposed interface integrates essential features such as geoawareness, traffic information, and UAS identification. By leveraging XR technologies and incorporating elements like tracking labels and safety nets, the interface aims to provide ATCOs with intuitive tools for monitoring UAS activity. The interface design offers flexibility and adaptability to different operational contexts and allows for seamless interaction and visualisation of UAS traffic data. Moreover, features like on-demand interfaces and gesture-based interaction enhance usability and minimise cognitive load for ATCOs. The interface enhances safety and operational efficiency in managing UAS traffic near airports by providing timely alerts and visual cues for potential hazards.

It is possible to conclude that the development and validation of this XR-based interface can contribute to taking a step forward in addressing the challenges posed by integrating unmanned aerial systems into complex airspace environments. Through continued refinement and implementation, such technologies hold the potential to revolutionise ATC operations and ensure safe and efficient airspace management in the era of autonomous drones.

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