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An Extended Reality-based Platform for Digital Twin applications in Urban Air Mobility and Advanced Air Mobility: Framework proposed within MOST Project

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Abstract. Urban Air Mobility (UAM) is currently emerging as innovative mobility solution for urban transport. To ensure its seamless integration into existing systems, advanced simulation frameworks are strongly needed. Extended Reality (XR) technologies offer powerful tools to support such simulations. This paper presents a suite of Extended Reality-based integrated simulation and interaction platforms for multipurpose testing of UAM through Digital Twins of missions and scenarios. The platforms combine various hardware and software infrastructures and components, including the IRIS Cave Automatic Virtual Environment (CAVE), an eVTOL passenger simulator, and an Augmented Reality application for drone-based aircraft maintenance. Developed within the framework of the MOST – Sustainable Mobility Project, these platforms aim to support diverse use cases and contribute to the safe and efficient integration of UAM systems.

Introduction

In the context of rapid technological advancements and increasing digitalization of systems, the airspace domain is moving towards new solutions such as Advanced Air Mobility (AAM) and Urban Air Mobility (UAM). AAM is enabled by electric take-off and landing (eVTOL) aircraft and Unmanned Aerial Systems (UAS) and UAM refers to its implementation in urban scenarios [1]. These innovative aerial operations are expected to enhance the overall efficiency and sustainability of airspace systems. However, their integration into existing environments poses significant challenges related to safety, infrastructure development, and public acceptance. To address these challenges, a collaborative approach among the various stakeholders involved in this emerging transportation ecosystem is essential for achieving full-scale deployment. One key aspect of this process involves sharing information and data within realistic visualization and interactive environments. In this regard, the use of Extended Reality (XR) technologies for visualizing Digital Twins (DT) of aircraft and/or operational scenarios offers a promising path to support stakeholders, providing comprehensive, high-fidelity environments for prediction,

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monitoring, and decision-making [2]. In the aerospace domain, DT applications have already been carried out across different areas such as aircraft design and development, manufacturing, operation and maintenance [3]. Further applications have been proposed in the context of Urban Air Mobility, such as exploring ground infrastructure location and aerial corridors [4] and supporting airspace management [5]. Although there exists no consensus on the formal definition of a DT, most reputable research shares the commonality that a DT is a cyber-physical system consist of at least three components: a physical system, a virtual model and their interactions [2][6][7]. Extended Reality (XR) Technologies, including VR (Virtual Reality), AR (Augmented Reality) and MR (Mixed Reality), enable seamless human–Digital Twin interaction by blending real and digital content, integrating high-fidelity simulation modules, and fostering collaboration among users [9]. Building upon these concepts, this work presents a modular and collaborative XR-based platform for Digital Twin visualization and interaction, developed through close cooperation between academic and industrial partners within the framework of the MOST – Sustainable Mobility Project.

XR-based Simulation Platform for Digital Twin applications in AAM and UAM

In the MOST Project, an XR multisensory simulator supports the need of a convergence place for safe AAM and UAM simulation and interaction and has ultimately two main goals: i. to integrate multi-layered DT capabilities in three-dimensional DT models of UAM and AAM missions; ii. To enable a realistic, collaborative and interactive user experience through simulation platforms designed to the analysis of DTs. The proposed simulation framework has been deployed, in both software and hardware infrastructure, to different facilities of project partners and has the capability to support and simulate multiple use-cases including eVTOL passenger transport, AR drone-enhanced aircraft maintenance and public acceptance. The overall hardware-software architecture of the XR multisensory simulator is depicted in *Figure 1*.

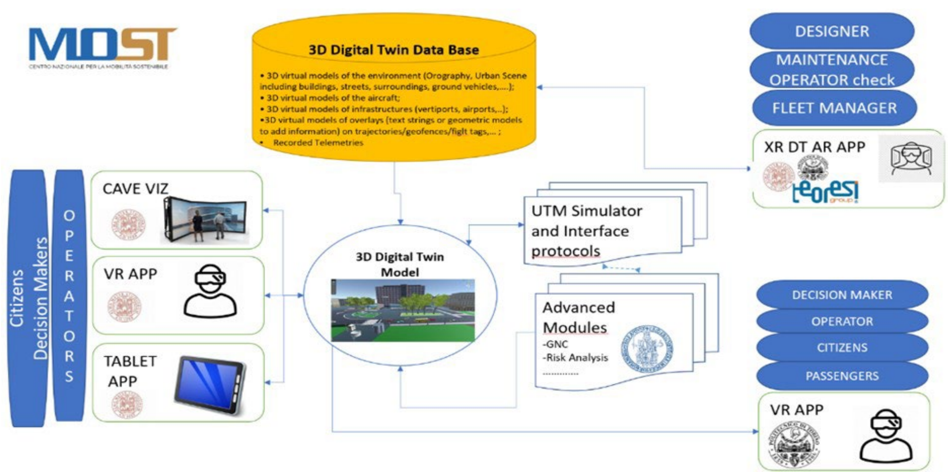

Figure 1 *The overall suite XR-based simulation platforms for Digital Twin visualization and interaction developed in the framework of MOST - Sustainable Mobility Project.*

The architecture of such XR Platform follows a modular design and is built upon the creation of a virtual scene composed of different data layers that can be combined between themselves and deployed according to the desired application. These layers are the Digital Twin Model layer, in which the three-dimensional models of the individual objects for each layer are integrated, including high-fidelity 3D models of eVTOLs and drones, urban environments and its components (e.g. buildings, streets, ground vehicles, terrain data), infrastructure dedicated to UAM (known as *vertiports*), overlays (text strings or geometric models to add information) and the recorded trajectories and paths database; The XR Visualization layer, that provides the XR Human Machine

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Interface through which the application will be experienced and interacted to by the user and the Integration and Simulation Engine layer: responsible for managing layer interaction logics and data communication with external simulators or telemetry sources.

The MOST XR Platform modules

IRIS – Immersive Reconfigurable Innovative System is a unique cutting-edge immersive simulation infrastructure that allows users to experience Virtual Reality applications within an environment projected onto the walls of a room-sized cube (See Figure 2). The facility installed at the University of Bologna site in Forlì, leverages key features such as *immersion*, enabled by multiple projectors displaying high-resolution three-dimensional environments and *interaction*, enabled by input devices (e.g. tracking systems). A simulator aiming at replicating onboard flight experience from the point of view of passengers was developed by the Polytechnic of Turin (See Figure 3). The simulator reproduces an autonomous or piloted UAS mission under different visibility conditions (e.g. clear daylight, clear nighttime, cloudy with rain and foggy scenarios), during which other UAM traffic is visible to the user.

Figure 2 Immersive Reconfigurable Innovative System (IRIS) Cave platform in its open configuration displaying the Digital Twin model of Fuorigrotta, Naples, developed within MOST Project.

Figure 4 Passenger view from the UAV Passenger Simulator.

Aircraft maintenance activities can benefit from Augmented Reality interfaces due to the high level of interaction intrinsic of such procedures [10]. An AR interface to enhance drone-based maintenance and inspection procedures was proposed by Teoresi (See Figure 4*)*. The system primarily focuses on enhancing real-time situation awareness by leveraging Augmented Reality to display telemetry data (e.g. battery status, aircraft position and key metrics) to remote drone operators while executing predefined aircraft inspection activities. As the operator can visualize key information to support efficient and informed decisions. The ultimate goal is to boost precision, responsiveness and overall effectiveness of airport inspection and maintenance tasks through AR-enabled workflows. To demonstrate the capability of supporting the smooth integration of AAM and UAM into the current airspace scenario, the various infrastructures and components of the XR framework were tested through a series of pilot cases integrating advanced simulation modules, such as and the risk analysis framework developed by the University of Naples and the Unmanned Traffic Management simulator provided by TopView through Cascade Funding. A further module is the Simultaneous XR simulator for airport scenarios immersive experience provided by TXT through cascade fundings.

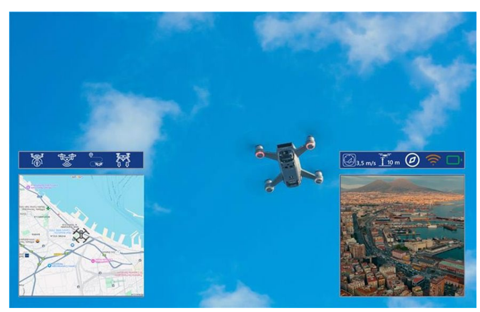

Figure 3 The AR for AR-enhanced aircraft maintenance.

Conclusion

AAM and UAM are promising concepts for the future of aerial transportation; however, further efforts are still required to ensure their effective integration into existing airspace systems. To this end, this paper has presented an XR-based platform designed for Digital Twin (DT) applications in UAM and AAM simulation. Three hardware components have been developed: the IRIS immersive system, the eVTOL passenger simulator, and an AR enhanced, drone-based maintenance application. The proposed simulation framework demonstrates the potential of bridging XR technologies and DTs, not only as tools for visualization and interaction but also as a foundation for informed decision-making among UAM and AAM stakeholders.

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