Integrating Extended Reality in Air Traffic Control: Innovative Interfaces for Drone Monitoring at Airports

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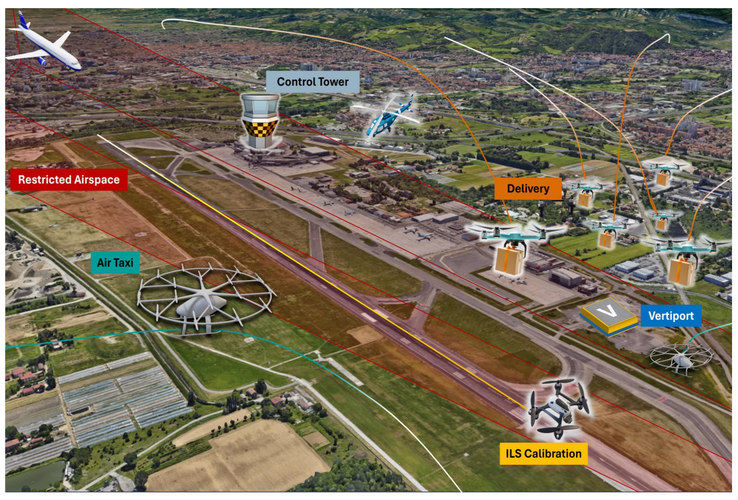


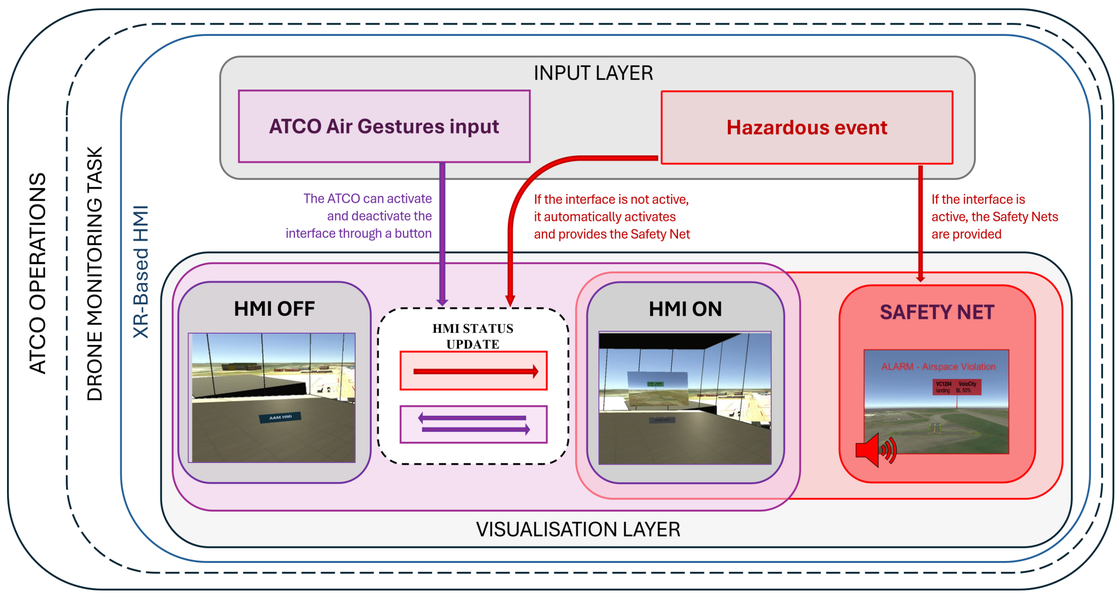
IAM operations near airports require close coordination between ATS units and IAM actors. Vertiports should be within tower ATCOs' visual range to enable direct oversight. Integrating manned and unmanned traffic in shared low-level airspace demands real-time coordination, increasing ATCO workload. To support this, **a novel XR-based HMI** is proposed to seamlessly integrate **into control towers** and provide intuitive **visualization of IAM traffic around airports.**

OBJECTIVES

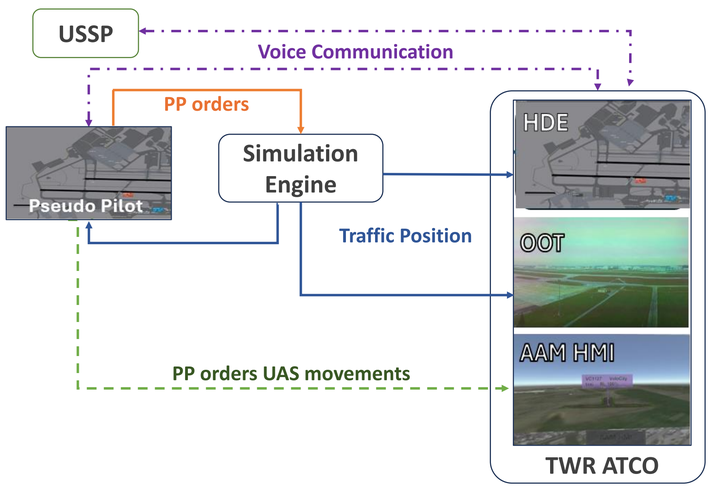
1. **Design** & **implement** XR-based HMI providing RT data overlays for consistent head-up view.
2. Explore the potential of XR for managing the **integration of UAS into controlled airspace.**
3. Conduct a **user evaluation** of the HMI focusing on usability, comfort, and performance.
4. Develop **recommendations** for the **deployment** of XR in real-world ATC environments.

Concept & Apparatus Design

On-demand, semi-transparent XR interface live-streaming the vertiport area located within the aerodrome, and incorporating dynamic overlays that present relevant UAS traffic and operational information.



METHODOLOGY



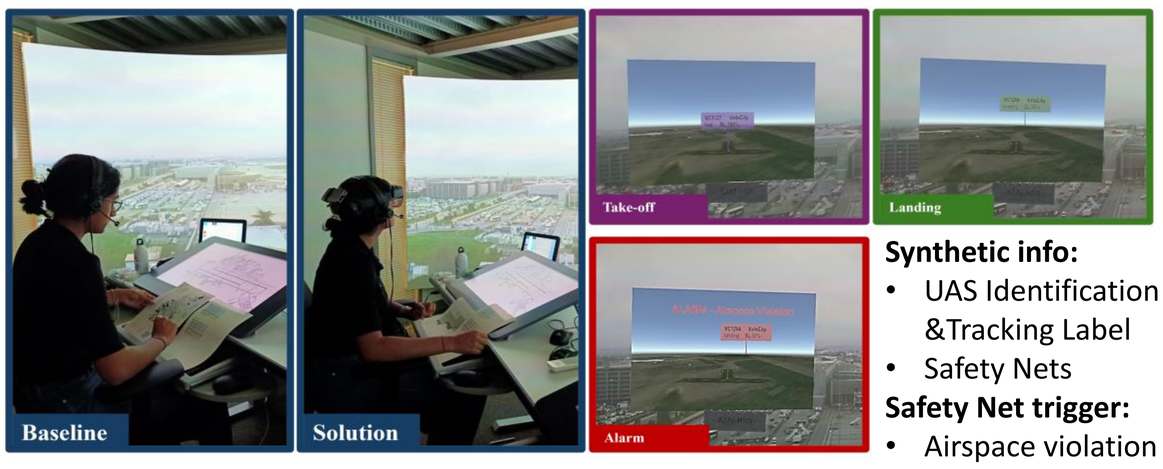
Validation technique:
Real-time HITL

Scenario:
LFBO Airport + Vertiport

Traffic:
Conventional + IAM

Device:
ST-HMD – HoloLens2

Users:
6 ATCOs & 5 ENAC Students



Synthetic info:
- UAS Identification &Tracking Label
- Safety Nets

Safety Net trigger:
- Airspace violation

Validation Results

Objective measurements

- *Physiological Measurements - Heart Rate Variability*
- *Reaction Time*

Trend with decreasing workload	Index	Baseline Mean	Baseline Standard Deviation	Solution Mean	Solution Standard Deviation	t-test	p
Decrease	**SI**	10.19	4.67	9.59	4.65	0.537	0.593
Increase	**SDNN**	53.99	21.77	59.79	28.43	-0.972	0.334
Increase	**HRV_{ti}**	12.2	3.92	12.88	4.28	-0.706	0.482
Increase	**LF**	1647.1	1010.3	1960.6	1210.1	-1.193	0.237
Increase	**HF**	868.66	1143.2	1308.1	2057.6	-1.12	0.266
Increase	**TOT_{pow}**	2698.6	1996.7	3440.5	2794.3	-1.296	0.199
Increase	**SD2**	94.85	31.71	98.37	38.64	-0.421	0.674
Decrease	**Shannon Entropy**	3.19	0.31	3.05	0.29	2.007	**0.049***

Safety Net: drone incursion

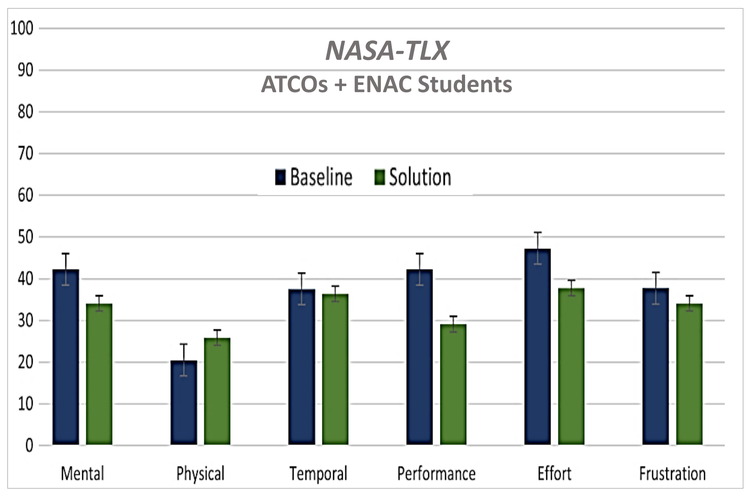
Index	Exe	F	p	Partial η_2
SI	*B*	0.776	0.397	0.066
	S	5.853	**0.034***	0.347
SDNN	*B*	0.147	0.708	0.013
	S	0.026	0.874	0.002
HRV_{ti}	*B*	1.299	0.279	0.106
	S	5.235	**0.043***	0.322
LF	*B*	0.060	0.811	0.005
	S	0.815	0.386	0.069
HF	*B*	0.318	0.584	0.028
	S	0.734	0.410	0.063
TOT_{pow}	*B*	0.104	0.753	0.009
	S	0.222	0.647	0.020
SD2	*B*	2.752	0.125	0.200
	S	1.513	0.244	0.121
Shannon Entropy	*B*	11.100	**0.007***	0.502
	S	20.245	**0.001***	0.648

Reaction Time

	User	Baseline [s]	Solution [s]
ATCOs	*TWR1*	X	10
	TWR2	*1*	3
	TWR3	14	0
	TWR4	*t<0*	*t<0*
	TWR5	X	10
	TWR6	*24*	7
ENAC Students	*TWR7*	11	2
	TWR8	X	2
	TWR9	12 (No action)	1 (No action)
	TWR10	1	1
	TWR11	6	3

Subjective assessment

- *Perceived Workload - NASA-TLX Questionnaire*
- *Usability Feedback*



Innovative & Potentially transformative

Ease of Use & Intuitive HMI

Enhanced Situational Awareness

Effective Alarm System

Physical Discomfort

Technical Issues

Usability Limitations

CONCLUSIONS

1. RT overlays **stimulate ATCOs in a "head-up" position**. Seamless multimodal interaction & safety warnings, **improved performance, situational awareness, efficiency** and **decision-making**.
2. XR system supports UAS integration in controlled airspace. Overlay **IAM traffic** data onto **ATCO's field of vision** allows for **simultaneous monitoring** of manned/unmanned traffic.
3. XR-based HMI's effectiveness, **reduced reaction times & improved task-switching**. Discomfort with prolonged use of HMD, need for **ergonomic improvements** despite the performance benefits.
4. **Recommendations documented** for improvement, seamless integration with existing ATC systems, **real-world trials** needed to validate performance, safety, and workload in live environments.

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