A roadmap for the implementation of augmented reality solutions for airport control towers in an operative environment

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Abstract. This paper describes how augmented reality has been recently exploited to define novel concepts for helping control tower operators in the aerodrome traffic zone. Starting from solutions developed within the SESAR research framework through real-time simulations, the paper describes the work done so far in transferring the developed solutions to an operative scenario (i.e. an actual control tower), exploiting ADS-B data and a HoloLens2^{TM} head-mounted device. Finally, a roadmap covering the missing steps for completing the operational concept is proposed, orderly defining the missing steps and possible solutions.

Introduction

In a global scenario of constantly increasing air traffic volumes [1], the aviation sector's main actors are redefining the entire air traffic management (ATM) concept, researching mitigating solutions to the current air-mobility issues, mainly related to crowded routes. A major bottleneck of the flight chain is aerodrome traffic, managed through the airport control tower, whose operators are responsible for the aerodrome traffic zone and on-ground, arrival, and departure operations. Aerodrome controllers comply with many aircraft manoeuvring with short time and space separations, relying on the direct out-of-the-window view to provide flight crews with essential clearances and flight instructions. Meanwhile, they retain important information from an increasing number of interfaces and coordinate with other controllers from the same or contiguous airspace sectors. Their work is thus characterised by a high – and still increasing – workload, while they need as much situational awareness as possible. Moreover, the requirements for improved safety of operations clash with the need for increased airport capacity and fluidity of traffic flow. Following the dictates of the fourth industrial revolution [2], research has focused on exploiting modern advanced human-machine interfaces – especially augmented/mixed reality (AR). AR exploit the superposition of an overlay of digital elements over the real world, providing the user with tailored information about the surrounding environment (thus “augmented” reality). Since AR usefulness requires matching the digital overlay and the physical world behind it, a critical aspect of AR techniques is the registration process, i.e. the continuous and real-time projection of the holograms in the correct position relative to the real world and the user’s gaze.

By exploiting AR, operators should experience a decrease in the workload and an increase in situational awareness due to the possibility of directly retaining the information needed without gazing away from the outside view. This should result in an overall increase in the safety and fluidity of the traffic, also speeding up operations in low-visibility and hazardous conditions.

The first studies on the use of AR in airport control towers were conducted by Reisman in 2006 [3] and Tavanti [4] in 2007. They stated the need to include users in the design of AR tower applications while recognising that the technologies were still lacking in maturity. In 2015, following a considerable increase in AR maturity, Silva et al. [5] compared and integrated multiple surveillance sources (radar and ADS-B) to point the aircraft position on a video-based AR interface. In 2016, Gürlük [6] evaluated the beneficial effects of AR on situational awareness, recognising some critical aspects of the ergonomics of the devices and the data organisation and visualisation. In 2018 [7], Gürlük et al. tested the implementation of AR in a virtual traffic scenario simulation involving tower controllers.

Starting in 2016, research campaigns have also been conducted at the University of Bologna. In 2019 and 2020, Bagassi et al. [8-10] presented the results of the SESAR-founded RETINA project, validating in a simulated scenario a fully operational concept which allowed the controllers to retrieve all the needed surveillance information in a head-up position, with an increase in task performance and situational awareness and reduction in workload. The concept tested two different projecting technologies – head-up displays and spatial displays – and identified see-through HMD displays as the best technology, with spatial displays still not presenting the needed maturity for dealing with multiple controllers. Simulations were selected for their cost-effectiveness, risk-safeness, and controllability, as already proven in many aerospace applications, including aircraft and helicopter flight simulators [11].

Following RETINA, the SESAR DTT project [12] evolved the developed concept, evaluating different solutions in simulated airport scenarios between 2021 and 2023. The proposed solutions included a label pinpointing the aircraft's position and presenting the needed surveillance information to the tower controller. The research assessed the adaptation of the interface to different environmental conditions and controller roles and validated different interaction modes with the surveillance infrastructure. Exhaustive validation campaigns were conducted using a human-in-the-loop methodology, employing several tower controllers in real time. The overall feedback confirmed a reduced workload and increased situational awareness. The DTT project increased the RETINA TRL, reaching level 4, thus preparing the developed concepts for operational implementation. This paper summarises the work done at the University of Bologna in transferring DTT solutions to an operational tower environment, hence defining a roadmap for the upcoming development and pointing out the technical challenges.

Challenges of AR application for real-time data in the control tower

In dealing with AR devices, the actual "augmentation" of the physical world implies an adequate matching of the holographic information with the user's view of the physical world. AR devices such as the Microsoft HoloLens 2^{TM} head-mounted display (HMD), used at the University of Bologna's Virtual Reality and Simulation Lab, establish a visual link with the circumstancing environment through an array of cameras and depth sensors and place holograms accordingly to the scanned, detectable surrounding. While this is easier for a simulated scenario, where aircraft are visualised on screens locally placed in the room, real aircraft are usually detected through radar or transponder, which provide a global reference for the aircraft's position.

Similarly, much surveillance information, as particular indications of flight phases (push-back, taxiing…), is usually decided "a priori" somewhere alongside the simulation span rather than computed from available data. In real cases, the available information is limited, and the elaboration of surveillance data is mandatory to extract some precise information.

Also, the environmental conditions change between a simulated environment and actual airport rooms, with their out-of-the-window view and changing light and visibility conditions.

These considerations bring a new set of requirements. The user must retain its ability to move through the environment, so the AR device must track the user's gaze and position as well as the environment in real-time, repositioning the holograms simultaneously (real-time registration). Concurrently, the AR visualising device must be able to track aircraft based on global positioning data (usually related to an Earth-based reference system). These data should be converted to the AR device reference frame. Also, a source for the aircraft's surveillance data is needed, be it an antenna or a live link with third-party surveillance databases. These data come at uncertain rates, and missing data is possible. Sources for other relevant information, such as weather data and flight plans, are needed. Furthermore, unprecedented scenarios are possible, including unexpected/hazardous traffic events or discrepancies in data flow content, aspect, etc. Finally, application development depends on the available traffic at the testing location.

Methodologies for AR implementation in the control tower. Due to the different implementation challenges, two methods are needed to design and validate the solutions developed for an operational tower environment. Technical checks and extended testing are required to ensure the conformal behaviour of the AR platform logic. A user-centred approach is needed instead for the interface design (view management, design of the graphics). This iterative method builds on previous validations, starting from the concepts assessed within the RETINA and DTT validation campaigns, and requires controllers' involvement in every design stage.

The current state of the physical-world implementation of AR in the control tower. Fadda et al. [13] developed a preliminary platform including initial solutions for many of the stated challenges. They designed a system for detecting the aircraft state vector and its positioning and rendering in the virtual world through the ADS-B surveillance technique, together with a primary organisation and representation of the information provided by the ADS-B in the digital tracking labels. The system is responsible for the correct superposition of the digital overlay onto the real-world scenario using a HoloLens2 see-through HMD. The central aspect of this solution - the capability of tracking aircraft in real-time and positioning the label with reasonable accuracy – has been validated with a technical check and the supervision of a tower controller. In addition, databases for airport weather and flight information are queried, and simple analysis of positional data for flight status detection (landing, take-off, taxiing or parked aircraft) is performed.

The developed application is thus capable of detecting aircraft movement and correctly collimating the holographic aircraft pointers and the surveillance information with the user's and aircraft's respective positions. The application can filter airport-relevant traffic among all the signals detected by the ADS-B antenna. It can also distinguish landing and departing aircraft, recognise their position in the airport and current flight status, and detect when they have parked.

An on-site validation of the concept developed so far has been recently performed at the Bologna Marconi airport (Fig. 1). The validation demonstrated the feasibility and reliability of the solution. Feedback from tower controllers was collected to guide future development.

Figure 1. User's view from the Bologna Marconi airport control tower.

A roadmap for future work in AR platform implementation

Starting from initial feedback collected during the demonstration at the Marconi airport, a roadmap is proposed to guide the future transfer to the physical world of the concepts developed in a simulated and fully controllable environment.

Preliminary feedback from tower controllers was on the device maturity (label visibility, display transparency), the interface design (missing adaptivity of label content, relevant information saliency, dimension of far aircraft pointer and visual clutter/label overlapping), and the data quality (system calibration, aircraft positional information delay).

The proposed future work collects feedback and identifies some known limitations. It should be organised as follows.

Improvement of the registration process for real-time data. The first task should be to improve the registration performance. This can be accomplished by working on the calibration procedure for aligning the local and global reference frames and on the accuracy and timeliness of the surveillance data. The calibration accuracy depends on determining the user's position inside the room, the room's position in the world, and the aircraft's position in the world. For the tracking of the user, marker and markerless methods should be compared. Room geodetic position can be determined through GPS sensor measures. Once the room registration accuracy has been perfectioned, room position and orientation can be passively improved by manually aligning reference holograms with known points. Finally, the live aircraft positioning quality depends on the accuracy of the ADS-B data received, and improvements are to be made to the conversion method between geodetic data and the AR device reference frame. Further progress comes from corrections for data transmission delay and predictive algorithms for data holes in the data feed.

Integration of surveillance and traffic management information. A significant aspect of the application development is integrating all the needed surveillance information, usually provided to controllers through the control tower's head-down interfaces. In addition to the challenging acquisition of this information, all the data should be managed to provide the controller with a usable and practical interface, choosing the correct data and extrapolating advanced information as ground flight phases, potentially implementing AI-based solutions. This step falls into a user-centred design, requiring an on-site validation with tower controllers. In contrast, the actual design of the interface could still take advantage of the rapid development allowed by simulated scenarios.

Integration of novel airport traffic control solutions. Tracking labels, attention guidance, and safety nets are novel concepts developed within the SESAR research framework. They should be integrated into the platform with concepts developed for DTT in a simulated scenario, such as ground phase recognition (push-back, start-up), air gestures, attention guidance and multimodal interaction [12]. This task will parallel the previous one since it requires reworking the available surveillance data.

Conclusion

The proposed roadmap highlights the main tasks identified for the completion of an operative platform to validate AR technologies inside the airport control tower. Further work could consider integrating Advanced Air Mobility traffic within the controller's workflow. This will require high levels of automation and proper management of the data provision to the controllers.

Finally, considering the recent advancements in the digital/remote tower concept, it is worth highlighting how the solutions proposed in this paper will still be valuable for a remote tower when considering multiple control roles (and thus points of view) and particular environmental conditions, such as low visibility.

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