THE USE OF SYNTHETIC VISION TOOLS IN THE CONTROL TOWER ENVIRONMENT: THE RETINA CONCEPT

Sara Bagassi*, **Francesca De Crescenzio***, **Sergio Piastra***
*Department of Industrial Engineering, University of Bologna, Italy

Keywords: *Synthetic Vision, Augmented Reality, Airport Control Tower, Air Traffic Control*

Abstract

The Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision (RETINA) project is one of the selected Single European Sky ATM Research (SESAR) exploratory research projects on High Performing Airport Operations and it investigates the potential and applicability of Virtual/Augmented Reality (V/AR) technologies for the provision of Air Traffic Control (ATC) service by the airport control tower. The project assesses whether those concepts that stand behind tools such as Head-Mounted Displays (HUDs), Enhanced Vision Systems (EVSs) and Synthetic Vision Systems (SVS) can be transferred to ATC with relatively low effort and substantial benefits for controllers' Situational Awareness (SA). In doing so, two different augmented reality systems are investigated: Spatial Displays (SD) that, potentially, can be made to coincide with the tower windows and See-Through Head-Mounted Displays (ST-HMD). In this context the RETINA concept will enable the Air Traffic Controller to have a head-up view of the airport traffic even in low visibility conditions, similar to the vision currently provided in the cockpit with Head-Up displays. In the two-year project, the RETINA concept was developed, implemented and validated by means of human-in-the-loop simulations where the external view is provided to the user through a high fidelity 3D digital model in an immersive environment.

1 General Introduction

As a matter of fact, Augmented Reality is nowadays one of the most important enabling technologies for innovation in a number of sectors and it is becoming more and more competitive with respect to its more known counterpart that is Virtual Reality. This is mainly due to the possibility offered by AR to enhance the real world with synthetic information with no need to isolate the user from the real environment. On the other hand, such isolation is one of the contributing factors to the sickness often experienced by VR systems users.

Modern Augmented Reality tools offer the possibility to improve the user interaction with the real environment by adding information to it in the form of synthetic overlays that enhance the user perception of the surrounding world. A number of AR applications are currently being developed in different industrial sectors and they concern the use of such technology to improve the way the user interacts with the system he/she is designing, producing, operating, controlling, or maintaning.

The RETINA project takes the idea of augmented vision and investigates its application to on-the-site control towers through the use of synthetic vision. It investigates the placement of additional information such as flight tags, runway layout, and warning detection over the actual out the window view that the controller has. The project ambition is to provide a significant contribution to the long-range vision for the future Single European Sky which includes objectives for operating as safely and efficiently in low-visibility conditions as in high-visibility conditions [1] [2] [3].

1.1 State of the art

On the airside, the research on all-weather operations cockpits is already far advanced and Head Up Displays (HUD) technologies are widely being applied both in civil and military flight operations. HUDs are based on displaying data on a transparent layer allowing pilots to simultaneously look outside and see the projected data. Data that are commonly displayed on HUDs are speed, altitude, optimal flight path and, in general, some information which is usually displayed on the Primary Flight Display. A considerable interest is currently being focused on the possibility of displaying conformal symbols, intended as geo-referenced graphics that supports the operator in the comprehension and projection of the operational environment [4]. In this case the HUDs are also called Spatial Displays, since they allow implementing AR in panoramic views. This made the HUDs popular for applications in car dashboard while applications in Air Traffic Control have also been reported [5].

On the groundside, a task that is still largely dependent on the visual observation of the surrounding area is the Air Traffic Control (ATC) service provision by the control tower. Indeed, results of controllers' task analyses under past and present day working conditions have shown the importance of the outside view for establishing controllers' Situation Awareness (SA) [6] [7] [8] [9] . Therefore, the airport capacity is limited, under certain conditions, by the number of flights that controllers can safely manage visually. When bad weather impairs the visibility from the control tower, huge economic and operational costs for both carriers and ANSPs are incurred. In larger airports, the traffic density and the complex aerodrome layout further complicate this issue.

Fig. 1 The RETINA concept is based on the superposition of synthetic overlays onto the real out-of-the-tower view

1.2 RETINA concept

The RETINA concept consists in superimposing synthetic overlays to the out of the tower window view (Fig.1). Those overlays allow to visualize - in a comprehensive head-up view - the information that is currently available on head down displays. Figure 2 shows one of the overlays that were designed within the RETINA concept. It is a label registered to each aircraft that shows the most relevant information for each flight. The system automatically filters the information that is relevant for the specific phase of flight assigning also a colour code to the associated billboard, according to the colour coding used in the current head down interface.

Overall, the RETINA project target is to bring the concept of visual augmentation for Air Traffic Control in the Airport Control Tower from TRL 1 to TRL 3. The project is in line with the ATM Master Plan and it builds upon the technol- ogy previously developed in SESAR providing new overlays as well.

2 Design Methodology

In Air Traffic Control, operators must deal with easy tasks and familiar events, as well as with unfamiliar, time consuming and unexpected events. Besides talking to pilots, controllers need to extract information from the radar display, check

Fig. 2 RETINA label overlay: a label registered to each aircraft shows the most relevant information for each flight

weather, look at Flight Strips (FS), elaborate long term strategies, detect potential conflicts, make tactical decisions, coordinate with each-other and look out of the tower window. In addition, controllers need to balance cognitive resources and carefully timetable actions. Under these circumstances, human-computer interaction designers cannot only focus on the user but must consider the complexity of the work domain. Within the RETINA project, the interface design draws from the Ecological Interface Design (EID) approach and in this context the application of Skills, Rules, Knowledge (SRK) framework to the ATM work domain has been investigated for the purpose of RETINA project providing relevant results.

The Skills, Rules, Knowledge (SRK) framework defines three types of behaviour or psychological processes which are present in the operator information processing. The three categories essentially describe three possible ways in which information can be extracted and understood from a human-machine interface. The categories can be weighted according to the user needs. For example, by supporting skill and rule based behaviour in familiar tasks, more cognitive resources may be devoted to knowledge-based behaviour, which are important for managing unanticipated events. Analyzing the ATC work domain we can see that a large portion of the expert controller's observable behaviour is skill-based. When low visibility or adverse working conditions occur, the entry in force of limitations preserves or improves the type of cognitive behaviour at the expense of throughput and efficiency.

According to the RETINA concept, exposing and moving relevant information onto the outside window, making constraints visually perceivable and providing the user with an improved situation awareness even in low visibility conditions would imply fewer limitations with an increased capacity. This is performed by means of a first S-R-K taxonomy applied to nine tasks typical of the control tower environment, in three different visibility conditions [10]. The identification of shifts in the cognitive behaviour as low visibility procedures apply allows to understand which information should be moved or exposed. This constitutes an input for the design of the overlay that allows to guarantee the same cognitive behaviour in low visibility conditions and without limitations. The cognitive behaviour deriving from the RETINA concept is assessed once again by means of S-R-K-taxonomy in an iterative process.

3 The Validation Process

3.1 Scope and activities overview

The validation target was to demonstrate the positive impact of the Augmented Reality tools proposed by RETINA, namely See-Through Head-Mounted Displays and Spatial Displays (which potentially could be made to coincide with tower windows), in terms of human performance (situational awareness and the human factors), safety (the capability to detect some typical hazardous situations such as runway incursions) and efficiency (workload and maintenance of capacity in poor visibility conditions).

The RETINA concept was validated in a laboratory environment by means of human-in-the-loop real-time simulations involving ATCOs, who were placed in an immersive 3D virtual environment represented by 3 rear projected screens, simulating a high-fidelity and photorealistic out of the window view from the Bologna Airport Control Tower. The operators were also provided

Fig. 3 The green frame highlights the augmented tower windows in Spatial Display solution

with head-down equipment replicating the current one in the control tower and with a voice communication with a pseudo-pilot located in a control room, with the role of monitoring and updating the traffic on the airport model according to the clearances given by the controller.

The technical solutions considered during the validation are based on two different AR technologies. The first one is a commercial head mounted display (HMD) while the second one is based on Spatial Displays (SD) which are large Conformal Head Up Displays that are supposed to coincide with the tower windows. Being Spatial Displays less mature than Head-Mounted Displays, it was necessary to simulate Spatial Displays via software, as the big formats of this type of technology are not yet on the market nowadays, so that it was not possible to integrate the hardware in the simulation loop. The Spatial Display augmentation was considered for 9 out of 32 Control Tower windows. The highlighted green frame depicted in Fig.3 represents the selected windows.

The subjects were asked to perform all tasks as Tower and Ground controller during the same exercise, as no distinction of roles between Tower and Ground position was necessary due to the simplicity of the selected airport scenario. The validation exercises were characterized by:

- two different real observed traffic conditions: medium traffic and medium-high

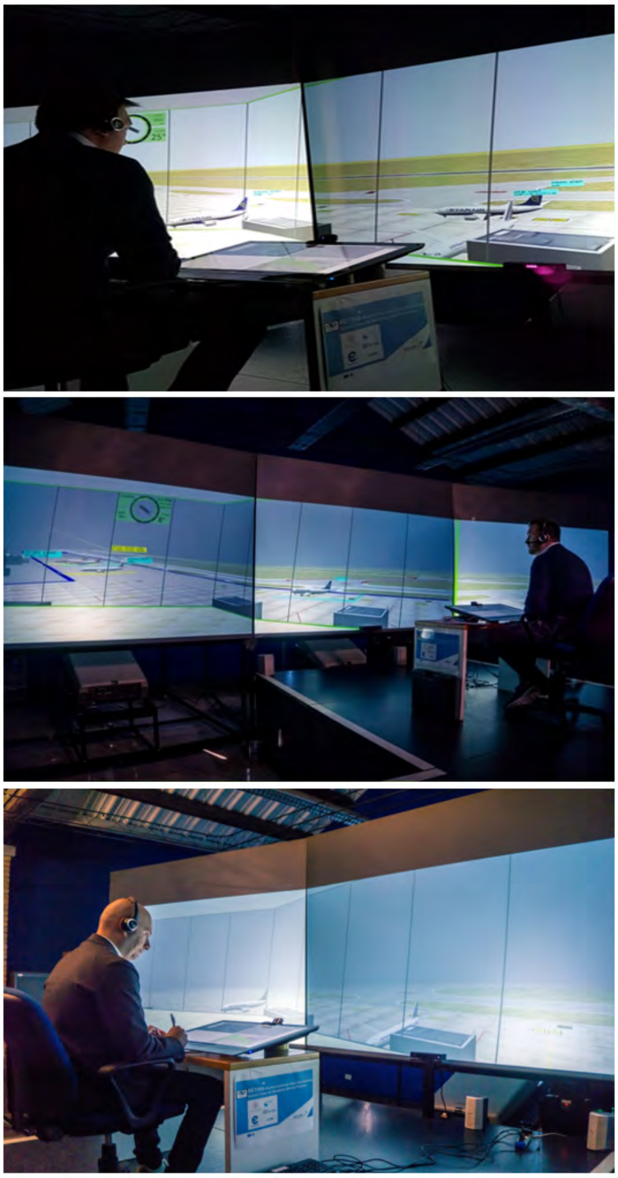

Fig. 4 The three different visibility conditions considered in the validation process: CONDI VIS 1, CONDI VIS 2 and CONDI VIS 3 from top to bottom (from good weather condition to extremely bad one)

traffic;

- three different visibility conditions (from good weather condition to extremely bad one), namely CONDI VIS 1, CONDI VIS 2 and CONDI VIS 3, as reported in Fig.4.

For each exercise performed using Augmented Reality tools, a similar exercise was conducted adopting the baseline equipment, in order to compare data obtained in terms of the human performance, safety and efficiency validation targets. Since the EID results show that the introduction of Augmented Reality technologies balances the shift to the knowledge-based behaviour in low visibility conditions, meaning that RETINA solutions provide safe operations at high capacity even in low visibility conditions, CONDI VIS 3 exercises include a specific RETINA solution exercise in which the restrictions due to low-visibility procedures (such as larger separations among aircraft and restricted access to some taxiways) were removed, providing a very valuable and significant comparison with the baseline solution characterized by restrictions.

3.2 Validation Platform Architecture

The validation platform architecture consists of five main modules (Fig. 5). The core system is the 4D model of the Bologna Airport reference scenario represented in Fig.6. This model integrates all data sources and is able to manage events and respond to user inputs. It was developed using Blender software and it includes most of the airport static features and ground signs, a library of aircrafts and ground vehicles, an interface for managing aircrafts and ground vehicles, approving pushbacks, assigning taxi routes, starting and stopping the movements, clearing takeoffs and landings.

The model communicates through data exchange protocols with the following four subsystems:

- Out-of the Tower View Generator (OOT) represented in Fig.7: it derives a rendered view of the reference scenario from the 4D model and displays it on the RVE (Reconfigurable Virtual Environment). It provides the controller with a semi-immersive, consistent and photorealistic view of the out of the tower scene. The Reconfigurable Virtual Environment is a CAVE-like virtual environment designed to recreate a sense of immersion by means of three, rear-projected, flat screens. The screens can be arranged in three different configurations, closed, semi-closed and wide open. A stereoscopic 3D effect is obtained by means of active shutter glasses (NVIDIA 3D Vision) and compatible projectors. Head tracking is obtained by means of a Microsoft Kinect sensor. In the OOT a custom rendering pipeline generates images based on the viewerâĂŹs position providing the user with a good sense of immersion.

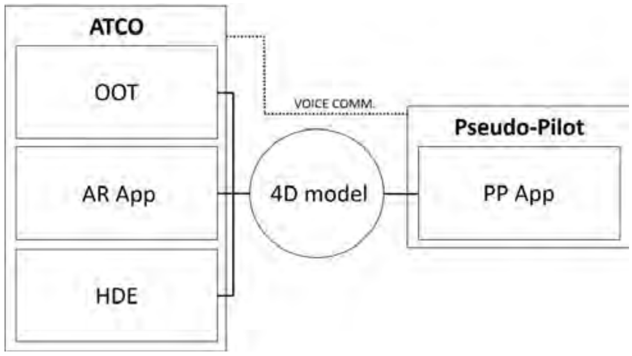

Fig. 5 The platform architecture

- Augmented Reality Overlay Application (AR App): it derives the relevant Augmented Reality overlays from the 4D model and deploys them on the appropriate controller head-up interface (being either Spatial Display or Head Mounted Display), providing the controller with a unique conformal representation of all the needed information correctly registered in time and space with the static and dynamic objects of the 4D model: vehicle and flight tags, aircraft bounding boxes, airside and runway layout, runway status, forbidden taxi-

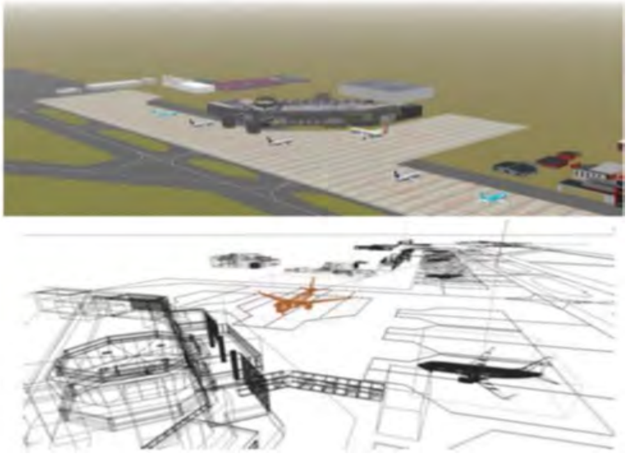

Fig. 6 The 4D model of the Bologna Airport reference scenario

ways, meteorological data and warning detection (see Fig.8).

- Head-Down Equipment (HDE): it consists in a simplified interface that replicates the actual head-down equipment in the control tower, reporting meteorological data, radar interface and departure and arrival lists with flight status and significant times.

- Pseudo-pilot application (PP App): it allows the pseudo-pilot to monitor and update the state of the 4D model according to the commands provided by the controller.

3.3 Data collection

In order to assess the impact of the introduction of RETINA solutions on the controllers working methods three Key Performance Areas, namely human performance, efficiency and safety were considered. During the validation campaign the following data were collected in the form of either subjective qualitative assessment or objective quantitative measurement:

- Head-Down Time (time the user spent looking at the the head down interface along the single exercise)

- Number of Switches Head Down/Head Up

- SA levels

Fig. 7 Out of the Tower view generator: screenshot (top) and deployed and the Reconfigurable Virtual Environment equipped with tracking system (bottom)

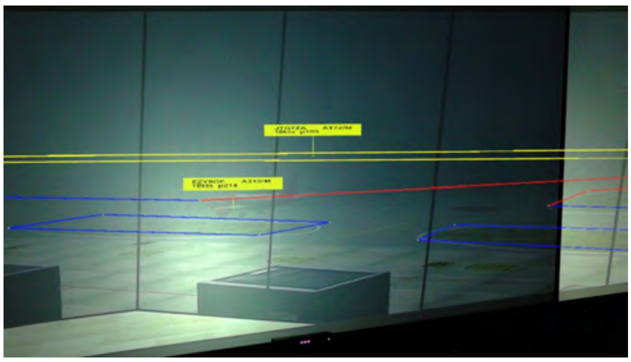

Fig. 8 Hololens generated overlays registered in time and space with the static and dynamic objects of the 4D model: flight tags (yellow labels for the arrivals), airport layout (blu lines), runway status (yellow lines when runway is occupied by an arrival), forbidden taxiways (red lines)

- Workload levels
- User Comfort
- Information Accessibility (time needed to access a specific information while performing a task)
- Throughput/Capacity

The Head-Down Time and the Number of Switches Head Down/Head Up were collected through objective quantitative measurement. SA levels, Workload levels and User Comfort were collected by means of subjective questionnaire (NASA Task Load Index (NASA-TLX)) and interviews during debriefing in offline conditions, while Information Accessibility and Throughput were mainly collected online during the simulation .

3.4 Validation Results

This section captures the main results related to the validation of the RETINA concept in comparison with current tower operations:

- the RETINA concept has a clear effect in stimulating the ATCO to work in a head-up position more than in a head-down position. It is worth noticing that the solution based on HMD reduces head down time in normal visibility conditions by a factor of 5 compared to the baseline equipment and the reduction factor rises to 6.5 in very low visibility conditions. Similar figures apply to the number of switches between head-up and head-down positions.
- The ATCO is provided with a unique conformal representation of all the needed information that is currently provided by means of several visual inputs.
- When low visibility conditions apply, the use of RETINA tools provides the ATCO with a head up conformal view of all needed information, leading to the reduction of current restrictions due to LVP, with consequent increased throughput.
- The proposed solutions provide quantified benefits in terms of mental workload, temporal workload, performance, effort, frustration, information accessibility.
- The operational benefits provided by the two conceptual solutions explored, namely HMD and SD, are comparable.
- RETINA tools proved to preserve safety. Moreover they lead to safety improvement as they enhance situational awareness.

4 Conclusions

The results obtained through the validation of the RETINA concept are fully demonstrating the soundess for the introduction of Augmented Reality in the Airport Control Tower. Major benefits are related to the use of such technology in low visibility conditions to restore the same level of airport capacity as in normal visibility conditions, with positive impact on the whole ATM system in terms of safety, efficiency and resilience. Moreover, it is worth noticing that the validation activity performed on the RETINA concept achieved TRL3.

Although several benefits were observed/recorded or inferred by the simulation activities, a few issues were also noted, which, if the concept were to be developed, would need to be addressed. These include but are not limited to:

- In its present version, the Head Mounted Display used for the validation should not be used continuously for a long time. Further study should investigate what time limit, if any, should apply for the continuous use of such a device in the control tower.
- The AR technology for Spatial Display is not yet mature. The main limitations for this technology are screen size, costs, and the possibility to provide AR holograms to multiple users looking at the same device. While the first two issues will be

likely overcome in the next decade, the latter might take more time to get over. This being said, further testing of the concept should continue in a simulated environment to further develop the concept.

References

[1] Office for Official Publications of the European Communities, *Single European Sky - Results from the transport research programme*.

[2] SESAR JU, *Enhanced Ground Controller Situational Awareness in all Weather Conditions* [Online]. Available: https://www.atmmasterplan.eu/oisteps/AO-0201.

[3] Clean Sky JU, *Clean Sky 2 - Joint Technical Programme*.

[4] Bimber Oliver and Ramesh Raskar, *Spatial augmented reality: merging real and virtual worlds* 2005.

[5] Peterson, Stephen, and Pinska, *Human Performance with simulated Collimation in Transparent Projection Screens* in Proceedings of the Second International Conference on Research in Air Transportation (ICRAT), 2006.

[6] R. Reisman and D. Brown, *Design of Augmented Reality Tools for Air Traffic Control Towers* in Proceedings of 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Wichita, KS, 2006.

[7] Monica Tavanti, *Control Tower Operations: A Literature Review of Task Analysis Studies* EEC Technical/Scientific Report No. 2006-013, Jul. 2006.

[8] Ella Pinska, *An Investigation of the Head-up Time at Tower and Ground Control Positions* in Proceeding of the 5th Eurocontrol Innovative Research Workshop, 2006, pp. 81-86.

[9] M. Schmidt, M. Rudolph, B. Werther, C. Mohlenbrink, and N. Furstenau, *Development of an Augmented Vision Video Panorama Human-Machine Interface for Remote Airport Tower Operation* in HCI (9), 2007, vol. 4558.

[10] Mohamed Ellejmi, Sara Bagassi, Sergio Piastra, Alfredo Persiani, *Evaluation of Augmented Reality Tools for the provision of Tower Air Traffic Control using An Ecological Interface Design*, 2018 Modeling and Simulation Technologies Conference, AIAA AVIATION Forum, (AIAA 2018-2939) pp. 1119-1128.

5 Contact Author Email Address

RETINA Project Coordinator
Sara Bagassi
University of Bologna, Italy
mailto:sara.bagassi@unibo.it

Copyright Statement