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V/A-R AIR GESTURES HMI INTERACTION IN AIRPORT CONTROL TOWERS

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Abstract

In 2019, the SESAR JU Project *Digital Technologies for Tower (PJ05-W2 DTT)* has been founded to exploit and advance the concept, already investigated by the Exploratory Research Project *RETINA*, of an augmented reality-based interface for ATCOs in airport control towers. The work introduced is part of one of the DTT Project solutions conducted by the University of Bologna (UNIBO). This paper describes the experimental campaign performed at UNIBO's real-time Humans-in-the-loop simulation and validation platform to asses the introduction of V/A-R Air gestures HMI interaction in airport control towers. During the validation exercises, the Ground controller, who is responsible for the maneuvering area, is enabled to interact with AR overlays to release some not-time-critical clearances through Air Gestures. To evaluate the impact of the V/A-R tracking labels and Air Gestures HMI interaction introduction in airport control towers the solution scenario is compared with a reference one where the AR applications are disabled. Feedback from the ATCOs are collected to assess the validation objectives in specific key performance areas and in particular Human Performance and safety. The analysis method, by detecting the differences between reference and solution scenario in terms of Key Performance Indicators, allows to determine the overall soundness of the concept against different solution success criteria.

Keywords: V/A Reality, Air gestures, HMI interaction, Airport control towers

1. General Introduction

In recent years, innovative and advanced visualization tools for Air Traffic Control Operators (ATCOs) such as movement maps, conflict detection and conformance monitoring, have been designed to improve the operational safety of airports. However, the increased information required and displayed on the monitors, e.g. radar displays, FDP and weather displays, lead to more time in head-down position watching at the screens rather than focusing on the out of the window view. The continuous switching between two different perspectives of the same environment would lead to a reduction of the situational awareness [1]. To address this problem, Lloyd Hitchcock from Federal Aviation Administration (FAA), introduced the idea of using Augmented Reality (AR) in the control tower almost three decades ago [2] and since then, a few experiments [3, 4] with modern AR hardware have been conducted to provide air traffic controllers with useful spatially conformal information [5, 6, 7, 8]. In 2019, the SESAR JU Project *Digital Technologies for Tower* [9] has been founded to exploit and advance the concept, already investigated by the Exploratory Research Project *RETINA* [10], of an augmented reality-based interface for ATCOs in airport control towers.

Figure 1 – Retina Concept [10].

The work introduced is part of the activities conducted by the University of Bologna, which addresses the development of novel human machine interface (HMI) interaction modes and technologies at the Controller Working Position. Different validation exercises have been performed through a real-time Humans-in-the-loop simulation and validation platform [11] to assess, respectively, the introduction of V/A-R tracking labels, air gestures interaction, and safety nets visualisation.
For each one of the validation exercises, to determine if the solution success criteria in terms of Human Performance and Safety have been fulfilled, different data have been collected in the form of subjective qualitative assessment and objective quantitative measurement.
This paper focuses and describes one of the experimental campaigns conducted in this framework to assess the introduction of V/A-R Air gestures HMI interaction in airport control towers.

1.1 Digital Technologies for Tower Project

The *Digital Technologies for Tower* (DTT) project aims to contribute to Air Traffic Management (ATM) digitalisation objectives in two ways. On one hand, by proposing the development of a remote aerodrome air traffic service in which services from various aerodromes are combined in a centralised control room independent of airport location. On the other hand, it intends to validate innovative human-machine interface modes and related technologies in different airport towers. The final goal of the project's is to provide shorter travel times and better point-to-point connections, as well as an increasing of flight safety and controller productivity. Therefore, the DTT international partners are focusing on three solutions to be validated and progressively matured for the benefit of the ATM network in terms of safety, capacity, efficiency and flexibility. One of these solutions, *Virtual/Augmented reality applications for tower*, addresses the use of tracking labels, air gestures and attention guidance thanks to the development of new human machine interface (HMI) interaction modes and technologies at the Controller Working Position (CWP), with the aim to minimise the load and mental strain on the tower controllers (especially under high traffic density situations, low visibility conditions, etc.) in several airport sub-operating environments. To this aim, a multicentered validation is planned to be performed by the different partners all over Europe [12]. In particular, a specific validation campaign is performed on Bologna Airport scenario.

2. Virtual/Augmented Reality Control Tower Concept

The objective of the validation campaign is to investigate the use of V/A-R in a conventional control tower environment at Bologna airport with specific focus on adaptive HMI, working position, multimodal interaction, and safety nets visualisation. Virtual and augmented reality along with tracking labels and air gestures, by presenting digital data, is expected give the controller the possibility of an increased head-up time of the airport traffic, even in low visibility conditions. Furthermore, in good visibility, some of the limitations regarding the display of information (e.g. planning times and warnings) that might be missed due to increased focus on the outside view, can be mitigated. In addition, attention guidance can support the controller in reacting to critical situations when needed and where needed. By means of this solution, the controllers will no longer be limited by what the human eye can physically see out of the tower windows. This is expected to lead to an increased ATCO situational awareness, increase of controller's productivity and a reduction in reaction times.

2.1 Simulation and validation platform

The campaign is conducted as a real time human in the loop simulation exploiting a validation platform encompassing all the components needed in order to integrate the following features.

Adaptive HMI and working positions: the exercise is conducted for two different working positions (i.e. Runway RWY and Ground GND Controllers). Two different points of view are tracked to customize the view for each one of the two controller and therefore allowing the system to provide specific information based on working position, visibility conditions and flight status to the users;

Multimodal Interaction: the users can interact with the system by a combination of gesture and voice. Datalink messages (start-up, pushback, and departure clearances) can be issued by means of multimodal interaction;

Safety net: the V/AR overlays can be used to display safety warnings such as runway incursions and conflicting clearances.

The core of the platform is a 4D model of the reference scenario integrating all the data sources and which is able to manage events and respond to user inputs. This module communicates with five subsystems, namely, Out of the Tower View Generator (OOT), Ground Augmented Reality Overlay Application (GND App), Runway Augmented Reality Overlay Application (RWY App), Head Down Equipment (HDE) and Pseudo-pilot application (PP App). While the OOT provides the users with a consistent scenario of the out of the tower view of Bologna airport, the GND and RWY Applications, tailored with respect to the user point of view and the specific information based on the working position, deploy the necessary AR overlays on two head mounted Microsoft Hololens2 displays. The ATCOs can simultaneously see the out of the tower view and the AR overlays (Figure 2). The HDE is the same for the two controller working positions (CWP) and replicates in a simplified interface the actual HDE of the control towers. Lastly, through the PP App, the pseudo-pilot is able to update the state of the 4D model in accordance with the ATCOs instructions. Moreover, for the scenario related to Air Gestures, an additional Controller–pilot data link communications (CPDLC) interface is present to allow the pseudo-pilot to both send specific clearance requests and receive datalink-like messages from the ATCOs.

Figure 2 – The ATCOs can contemporarily see both the out of the tower view and the Augmented Reality Overlays through Hololens2. The personal view of the user during the V/A-R Air Gestures HMI interaction validation exercise is depicted in the blue square.

3. V/A-R Gestures HMI interaction validation exercise

The validation technique to perform the specific validation campaign is a Real-time Simulation (RTS) with Humans-in-the-loop (HITL). In this case, the HITL concerns the Bologna Tower Ground and Tower Runway Controllers and pseudo-pilots. Bologna airport is chosen as reference scenario for the validation; it has a moderately complex layout (one runway, several taxiway, more than one apron) with a moderate traffic (between 200 and 300 movements per day). Bologna is a single Runway (12 and 30) airport with a main taxiway T and several taxiway and aircraft stand taxilane. The runway has orientation 12/30 with an asphalt strip of 2803x45 m. Moreover, the airport is often affected by low visibility conditions.

Within the validation scenario addressing the Air Gestures solution, the GND controller, who is responsible for the maneuvering area, is enabled to interact with AR overlays to release some not-time-critical clearances (Departure Clearance, Start-up, Push back) through Air Gestures and more specifically the hand ray and air tap gesture recognised by Hololens2 devices. To avoid a too crowded OOT scenario, the aircraft tracking labels are not displayed all at once, but each of them is activated five minutes before the Estimated Off Block Time of the specific aircraft. At first, the label is coloured in gray but, once the pseudo-pilot sends the clearance request to the ATCO through the CPDLC interface, the colour switches to light blue and a button *Departure Clearance* appears below the tracking label. Once the GND controller acknowledge the request by clicking on the button which disappears, the pseudo-pilot receives a message and issues a push-back and start-up request. This request triggers two buttons *Pushback* and *Startup* to appear above the tracking label. As before, the GND ATCO can interact with the two holograms through the air gesture allowing the datalink-like messages to be sent to the pseudo-pilot who can proceed with the required actions through the PP App.

To evaluate the impact of the V/A-R tracking labels and Air Gestures HMI interaction introduction in airport control towers the solution scenario is compared with a reference one where the AR applications are disabled as depicted in Figure 3.

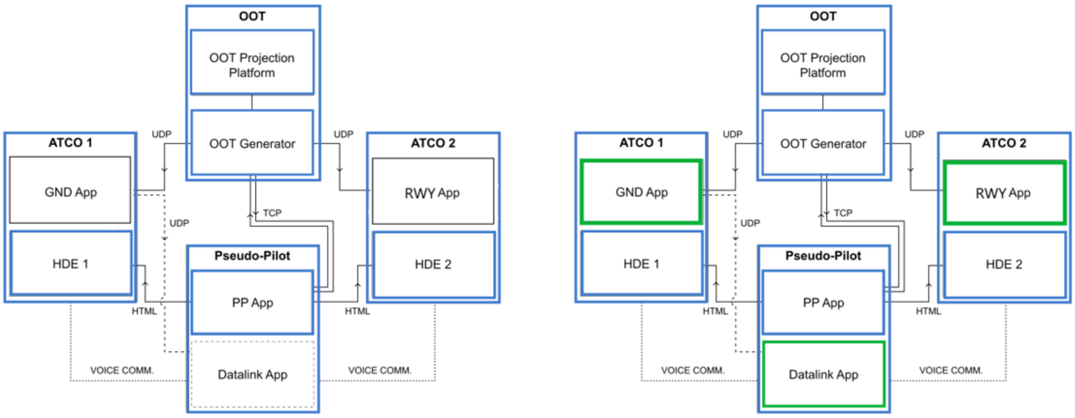


Figure 3 – Validation platform architecture in reference scenario (left) and solution scenario with air gestures implementation for GND controller (right).

In the solution scenario ATCOs are operating a scenario that is comparable as the reference scenario, but in the solution scenario both the V/AR and the Air Gestures are available, in addition to conventional CWP. In fact, the subjects are in almost the same situation but in the solution scenario the controller is supported by the technical solution. The main difference between reference and solution scenario is the additional presentation and supplementary possibility to interact offered by V/AR and Air Gestures respectively. Thus, if performance is influenced in either positive or negative way, this can be attributed to the solution offered.
During the validations, each batch of exercises is repeated five times by five different teams of GND and RWY ATCOs. The average years of experience of the GND controllers is 18.4 years, with a minimum of 10 and a maximum of 25 years. One GND ATCO is between 30 and 39 years old, three between 40 and 49 and one between 50 and 59. Moreover, four of them are working at Bologna Airport, whereas the other one is currently working at Torino Airport. When considering the RWY controllers instead, the average years of experience of the RWY operators is 18.4 years, with a minimum of 6 and a maximum of 33 years. Two RWY ATCOs are between 30 and 39 years old, one between 40 and 49 and two between 50 and 59. Moreover, two of them are working at Bologna Airport, whereas the other three are currently working at Forlì, Rimini and Ancona Airports.

Table 1 – ID, Age, Years of experience and Current airport of the ATCOs involved in the validation campaign.

ID	AGE	YEARS OF EXPERIENCE	CURRENT AIRPORT
GND1	30-39	10	Bologna
RWY1	40-49	12	Bologna
GND2	40-49	19	Torino
RWY2	30-39	6	Forlì
GND3	40-49	19	Bologna
RWY3	30-39	16	Bologna
GND4	50-59	25	Bologna
RWY4	50-59	33	Ancona
GND5	40-49	19	Bologna
RWY5	50-59	25	Rimini

For the purpose of the validation, each ATCO is either assigned to the ground controller or the runway controller position. There is no rotation of the ATCOs amongst the positions because it is important for the ATCO to experience the different technologies (tracking labels, air gesture) from the same position in order to make a good comparison between reference and solution. Although one ATCO only occupies one position, the total of five ATCOs in each controller position, ensures a comprehensive assessment of the concept from different perspectives and for different aspects. The first exercise run is always performed on a reference scenario including eleven movements (7 departures and 4 arrivals) for a total amount of 40 minutes and it is followed by the 15 minutes of solution exercise with a reduced number of movements. Moreover, whilst for the reference scenario the visibility conditions are progressively reduced, the Air Gestures solution considers only a good visibility condition. At the end of each run and of each exercise, the feedback from the GND ATCOs are collected to assess the validation objectives in specific key performance areas (KPA) and in particular Human Performance and safety. The analysis method, by detecting the differences between reference and solution scenario in terms of KPI (Key Performance Indicators), allows to determine if the solution success criteria have been fulfilled.

4. Results and Discussion

During the validation campaign different data are collected anonymously in the form of objective quantitative measurement (Head up time and number of switches head up/head down and number of vocal communications) and subjective qualitative assessment such as workload, acceptability, trust, usability, human error, user comfort and throughput. Head up and head down time and the number of switches between head down and head up are measured by the validation platform through a camera. SA levels, Workload levels and User Comfort are collected by means of subjective questionnaire and interviews during debriefing at the end of the run and at the end of the exercise.
For sake of completeness, the quantitative data related to the Air Gestures solution (Run3) are compared not only to the ones of the first 15 minutes of good visibility conditions of the reference scenario (Run1) but also to a 15 minutes exercise performed with the same visibility conditions and the introduction of AR overlays (Run2). The decision to include the Run2 in this evaluation has been taken to assess whether and how the introduction of multimodal interaction could be an added value to the augmented reality-based interface in control towers.

Looking at Figure 4 and comparing the data related to Run1 and Run3, it is possible to notice a sensible increase of the time spent in Head Up position in the Air Gesture solution scenario with respect to the reference scenario. However, this improvement is not entirely given by the introduction of the air gestures but first and foremost by the introduction of the V/A-R tracking labels.
A more realistic evaluation of the benefit in terms of Head Up time given by the air gestures can be obtained by computing the percentage of improvement in Head Up time of Run3 vs. Run2. Four out of five GND ATCOs show from a minimum of 3% to a maximum of 15% of improvement in the Head Up time, whereas for one of the GND ATCOs these data present a downgrade of the 21%. When taking into account this last negative number, it is important to know that the operational method has not been the same in the two exercises. Unlike all the other controllers, the ATCO GND2 has decided to operate the Run2, without the aid of paper stips spending less than the 3% of the run time in head down position.

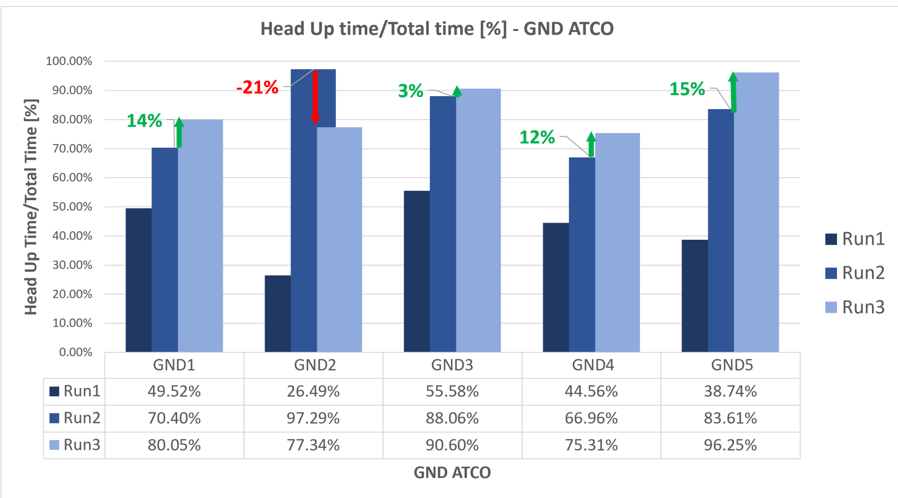
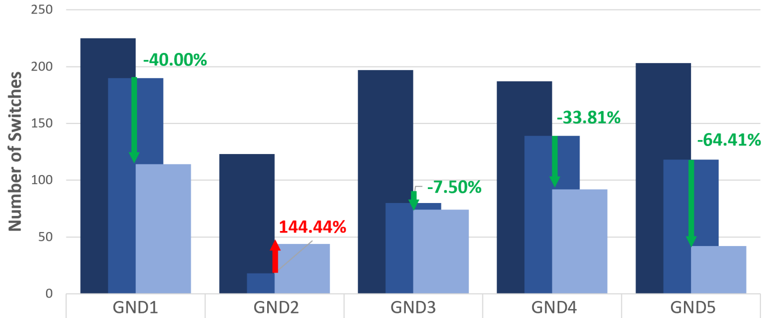


Figure 4 – Head Up Time/Total time [%] - GND ATCO

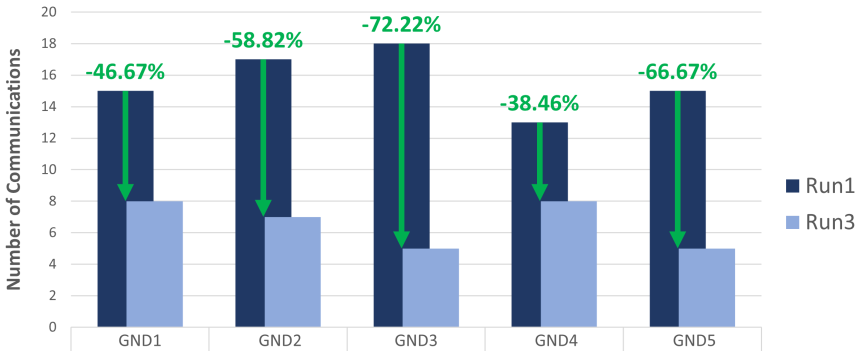
As can be seen from Figure 5, the Number of switches between the head up and the head down position is decreased in the solution encompassing the air gestures. Even in this case, to assess the benefit of the multimodal interaction introduction, a comparison with an intermediate solution is produced. When comparing the data of Run2 and Run3, it is possible to see how the introduction of the air gestures leads to a gain in terms of number of switches. As highlighted, it is possible to appreciate a decrease in the number of switches ranging between -64,41% and -7,50%. As expected, even in this case, the results obtained from the ATCO GND2 are bucking this trend.



	GND1	GND2	GND3	GND4	GND5
Run1	225	123	197	187	203
Run2	190	18	80	139	118
Run3	114	44	74	92	42

Figure 5 – Number of Switches - GND ATCO

When dealing with the introduction of V/A-R Air Gesture HMI interaction, one of the most important parameter to consider and to evaluate is the number of vocal communications. The possibility to interact with the Pseudo-pilot through gestures, allows the GND ATCO to reduce the number of vocal communication (see Figure 6). The percentage decrease of the number of vocal communications of the GND controller during this validation exercise ranges from a minimum of 38,46% to a maximum of 72,22%.



	GND1	GND2	GND3	GND4	GND5
Run1	15	17	18	13	15
Run3	8	7	5	8	5

Figure 6 – Number of Communications - GND ATCO

Considering all the objective quantitative measurements presented, the proposed solution proves to be helpful to the GND ATCOs in reducing the time spent in Head Down position looking at the HDE not only with respect to a reference scenario but also with respect to the solely introduction of V/A-R tracking labels. These data are strictly related to the number of switches Head Up-Head Down, a number which is drastically reduced with the introduction of the Air gestures interaction. This reduction is particularly relevant since the continuous change of perspective on the same out-of-the-tower environment would lead to a decrease in situational awareness. Moreover, thanks to the possibility to communicate with the Pseudo-pilot through gestures, the average number of vocal communications of the controllers are reduced by about 56% and, as pointed out by some of the GND ATCOs, is also reduced the associated possibility of miscommunication.

From a technical perspective, the introduction of V/A-R Air Gesture HMI interaction in airport control towers proves to be operationally feasible in the release of not-time-critical clearances. During the debriefing, the five GND controllers involved in the exercise have provided observations and suggestions to qualitatively assess the solution under investigation. As a whole, the presented concept of multimodal interaction encompassing gestures and voice received positive feedback from all the users, however some improvements shall be considered to achieve a higher level of maturity of the solution. Most of the ATCOs have experienced some difficulties in correctly using the air gesture function currently implemented within the Hololens2 device. These difficulties that could be mitigated to the point of being totally eliminated through a specific training, in this phase of the validations, have negatively impacted the human performances of the GND ATCOs. In particular, the controllers have experienced an increase of the physical Workload mostly due to Usability and Ergonomics issues and, as a consequence, a reduction in Situational Awareness. Even considering these downsides, no impact on the perceived potential for Human Error is reported by the users. On the contrary the 80% of the controllers (4) observe that the V/A-R Air Gestures have no or a positive impact on trust level and on Acceptance and Job satisfaction level.

5. Conclusion

This paper introduces the experimental campaign conducted at the University of Bologna real-time Humans-in-the-loop simulation and validation platform addressing the introduction of V-A/R Air Gestures HMI interaction in airport control towers. Within the evaluated solution, the Ground Controller is enabled to release not-time-critical clearances such as *Departure Clearance*, *Start-up* and *Push back* through Air Gestures interaction with V/A-R overlays. To estimate either a positive or negative impact of the proposed multimodal (Voice and Air Gestures) interaction, the solution scenario is compared with a reference one where the presentation and supplementary possibility to interact offered by V/A-R and Air Gestures respectively are disabled. Therefore, different objective quantitative and subjective qualitative data related to the GND CWP are collected anonymously during the validation campaign. Through the objective measurements the proposed solution proves to raise the time spent in Head Up position looking out of the tower, to reduce the number of switches Head Up-Head Down, and lastly to decrease the number of vocal communications of the GND controller with the Pseudo-pilot. All these factors lead to the conclusion that the introduction of this novel V/A-R Air Gesture Human Machine Interface could be beneficial to increase the Situational Awareness and the Safety in control towers. However, as emerged from the subjective data collected through user feedback, the level of acceptability of Human Performance is not completely met. Usability and Ergonomics issues, mostly related to the AR device used, lead to an increase of the Workload and, as a consequence, a reduction of the Situational Awareness of the GND ATCOs, which nevertheless have expressed very positive opinions on the concept of a multimodal interaction in their working position.

It is possible to conclude that, even if some improvements shall be considered in order to achieve a higher level of maturity of the solution, from a technical perspective, the introduction of V/A-R Air Gesture HMI interaction in airport control towers proves to be operationally feasible in the release of not-time-critical clearances.

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Copyright Statement

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