Towards a digital control tower: the use of augmented reality tools to innovate interaction modes

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***Abstract*—This paper describes the EU-funded project "Digital Technologies for Tower" (PJ05-W2 DTT) Solution 97.1 validation exercises by focusing on the simulation platforms and exploited technologies to demonstrate how Virtual/Augmented Reality along with Tracking Labels, Air Gestures and Attention Guidance can allow the air traffic controller to increase head-up time, even in low visibility conditions, to lower the time to react to critical or alerting situations, to reduce the workload, and to improve Situational Awareness and productivity. Important guidelines to further enhance the proposed solutions achieving higher levels of maturity can be drawn starting from the results obtained during the Sol 97.1 validation campaign.**

***Keywords*—Air Traffic Controller; Control Tower; Augmented Reality; Human Machine Interface; Multimodal interaction; Attention Guidance; Solution 97.1**

I. Introduction

In an airport control tower environment, when Extended Reality is used, additional auxiliary computer-generated visual information can be displayed as overlay over the real-world data and blended with the out-of-the-window (OTW) view to improve identification and tracking of aircraft especially in low visibility conditions. Moreover, with the introduction of these technologies, air traffic controller (ATCO) attention would not constantly be divided between two different perspective of the same environment (primary out of the tower visual field and auxiliary head-down equipment tools) with a benefit in terms of increased Situational Awareness (SA) and reduced workload.

Considering the possibility offered by Virtual/Augmented Reality (V/AR) applications to users of a multimodal interaction with the holograms, Air Gestures can be included in the control tower HMI to interact with the aircraft tracking labels and even to issue a set of clearances.

Furthermore, with the same aim of an enhanced safety and SA, airport safety nets can be used as a trigger to have synthetic elements integrated in the OTW view that guide the attention of air traffic controllers towards specific alerting events. According to the definition of a Virtuality-Reality continuum [1], the blend of virtual and real information can be tailored to different operational scenarios. Specifically, within the proposed solution more virtual information is shown when the low visibility conditions become more severe. As part of the EU-funded project "Digital Technologies for Tower" (PJ05-W2 DTT) [2], Solution 97.1 developed and validated novel HMI modes with related technologies in various airport control towers. To this aim, the project partners planned three different exercises on three different simulation and validation platforms assessing Tracking Labels, Multimodal interaction and Attention Guidance.

- **EXE-05.97.1-VAR-001:** ***Validation of AR Interaction Modes for Schiphol Tower with a Focus on Attention Guidance.***
  Carried out as a real-time simulation to address the use of attention capturing and guidance as new interaction modes for controllers in a customized environment representing the aerodrome control tower at Amsterdam Airport Schiphol (EHAM).
- **EXE-05.97.1-VAR-002:** ***Augmented Reality Multimodal Control Tower Interaction.***
  A real time simulation addressing Virtual/Augmented Reality Tower Tools, Tracking Labels, Air Gesture Interaction and Safety Nets/Attention Guidance at Bologna Airport (LIPE).
- **EXE-05.97.1-VAR-005:** ***Augmented Reality in the Tower Environment.***
  Shadow mode validation exercise to address Augmented

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Reality, Tracking Labels and Air Gestures at Vitoria-Gasteiz Airport (LEVT).

This paper describes the Solution 97.1 validation exercises by focusing on the simulation platforms and exploited technologies to demonstrate how V/AR along with Tracking Labels, Air Gestures and Attention Guidance can allow the ATCO to increase head-up time, even in low visibility conditions, to lower the time to react to critical or alerting situations, to reduce the workload, and to improve SA and productivity.

A. Validation of AR Interaction Modes for Schiphol Tower with a Focus on Attention Guidance

The Schiphol validation exercise VAR-001 is directed towards AR applications and Attention Capturing & Guidance (AC&G) for a conventional control tower environment of Schiphol Airport. The activity involved the reproduction of alerts currently provided at Schiphol Airport (for Runway Incursions and Go-around situations) to assess both the level of ATCO attention in comparison with the traditional environment and the advantages of the AC&G application. AR devices (Microsoft HoloLens 2) are used to expose the ATCOs to visual and aural alert information and different symbology. Different types of alerting with different levels of severity are included in the validation scenarios that are defined for the airport movement area with different amounts of traffic. In order to evaluate the most effective method for AC&G, a set of parameters is measured and compared. Attention distribution and decision-making effectiveness for the alerting situation to solve are evaluated by an operational expert, whilst the controller reaction times are assessed qualitatively using questionnaires and performing interviews. An increase in SA and operational effectiveness and a workload reduction are among the expected results to be observed.

Figure 1. NARSIM Tower Validation Platform at NLR Amsterdam.

B. Augmented Reality Multimodal Control Tower Interaction

The activity carried out in VAR-002 is aimed at the investigation and validation of the usage of Augmented Reality in conventional airport control tower environment of Bologna airport exploiting the results of an exploratory research campaign (RETINA Project [3], [4]) but focusing on some additional features and, in particular, Adaptive HMI and working positions, multimodal interaction and safety nets visualization. The validation exercise is provided for two different control working position, the Tower Ground (GND) and the Tower Runway (RWY), and therefore two different points of view have to be tracked to customize the different information provided to the two users in terms of CWP, current flight status and visibility condition. Moreover, the ATCOs are enabled to communicate with the system through a combination of voice and gestures; the GND controller has the possibility to deliver not-time-critical clearances by directly interacting with V/AR tracking labels via air gestures. Lastly, safety warnings related to runway incursions can be displayed thanks to overlays and directional alarms. The expected results of the introduction of an Augmented Reality Multimodal Interaction in control towers are mostly related to an increase of situational awareness and efficiency of the ATCOs together with a reduction of the workload and improved HMI and usability of the system.

Figure 2. University of Bologna simulation and validation platform (Virtual and Simulation Laboratory).

C. Augmented Reality in the Tower Environment

The Vitoria-Gasteiz VAR-005 exercise is the only one among the three to be conducted in shadow mode at an airport ATC tower to investigate the use of Augmented Reality in airport control towers. The selected airport is Vitoria which is a small airport without surface radar. The main objective is to demonstrate that an AR Head-up Interface could support the ATCO in the out-the-window (OTW) viewing by providing significant information and consequently reducing the changes to gaze from OTW to the controller working position, CWP. This support improves the situational awareness especially in low visibility conditions. Within the developed interface, the users are supported by AR technology which enhances visual information on the airport surface by merging real world images with computer-generated data. A Head Mounted Display (HMD) is exploited to provide configurable information such as Tracking Labels to identify the aircraft, location of runway, taxiway and key surface reference buildings/objects. Moreover, within the exercise, the user is enabled to adapt the displayed information through Air Gestures. Due to a lack of safety net system, no attention guidance was implemented in the exercise.

II. Validation Platforms

A. NARSIM Tower simulation and validation platform

The aerodrome tower simulation front-end of NLR ATC Research Simulator (NARSIM) environment, called NARSIM

Figure 3. Augmented Reality at Vitoria-Gasteiz airport.

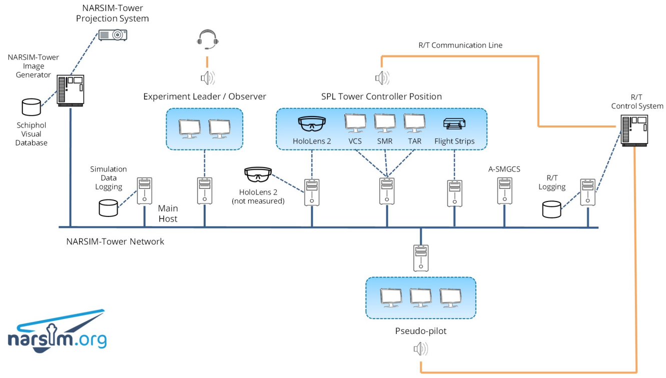

Figure 4. NARSIM Tower simulation and validation platform architecture.

Tower, is the simulation and validation platform used to conduct the Schiphol exercise VAR-001. NARSIM Tower is located at the Royal NLR premises in Amsterdam. NARSIM Tower is well known within the ATM research community as it has already been used in several SESAR and European Commission Framework Programme projects in the past. The platform was configured to simulate Amsterdam Airport Schiphol for Sol. 97.1, and it encompassed a highly realistic CWP and OTW view. For the aim of the VAR-001 exercise, which focused on alerts in approach, on the runway and on the taxiways, the simulation had a reduced scope with only one actively measured tower controller position. To simulate the tower environment with AR support, a Head Mounted Display (HMD) showing computer generated holograms of objects or information correctly positioned in the 3D environment, was integrated into the platform. Figure 4 gives an overview of the NARSIM Tower simulation platform architecture including the relevant Human Machine Interfaces (HMI) and roles involved. One tower ATCO was working on the measured position while another ATCO observed the situation on a second HMD device. Both controllers, an observer and a system engineer were present in the control room. Moreover, a supervisor and the experiment leader had access to the control room and to the pseudo-pilot room. In the pseudo-pilot room there were two pilot positions, each one with a dedicated HMI for the interaction with the aircraft. The pseudo-pilot positions were connected to the tower controller frequency. Observers were present to give instructions to trigger specific alerting events.

B. University of Bologna simulation and validation platform

The Bologna validation campaign VAR-002 is performed at UNIBO's real-time Humans-in-the-loop simulation and validation platform located at the Virtual Reality and Simulation Laboratory of the University of Bologna in Forlì. The platform, already used during the SESAR Exploratory Research Project RETINA, encompasses all the necessary components to integrate the following features which are under investigation within the exercise VAR-002 of Solution 97.1.

Adaptive HMI and CWP: two different working positions, namely Runway and Ground controllers, are involved in the validation. Two different points of view have to be tracked in order to customize the view of each user and to allow the system to deliver the information based not only on visibility conditions and flight status, but also to the specific CWP.

Multimodal Interaction: the ATCOs are enabled to interact with the system by a combination of voice and air gestures. In this specific exercise, datalink messages regarding not time critical clearances can be issued by means of multimodal interaction.

Safety net: safety warnings related to runway incursions and conflicting clearances are displayed through V/AR overlays to guide the attention of the controllers towards the critical events.

The exercise platform architecture consisting in five modules feeding three different role's posts (ATCO GND, ATCO RWY and Pseudo-pilot) is depicted in Figure 5. The core system of the platform is a 4D model of the reference scenario which integrates the data sources, responds to user inputs and manages events. This module is also in charge of the communication with five subsystems: 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). The OOT provides the controllers with a photorealistic and consistent scenario of the out of the tower scene of the Bologna aerodrome while the AR Overlay Applications (GND App and RWY App) which are tailored with reference to specific working position in terms of both point of view and necessary information, derive and deploy the AR overlays on two second generation Microsoft HoloLens2 head mounted see-through displays. Each one of the two CWP includes an HDE presenting a set of data similar to that given to the ATCOs via the actual head down equipment in the control tower. It derives data from the 4D model and presents it to the ATCO on a screen. Lastly, the PP App enables the pseudo-pilot to monitor and update the state of 4D model module according to the instructions provided by the controllers. Moreover, the pseudo pilot posts includes an additional interface for the Controller–pilot data link communications (CPDLC). This interface which is used for the scenario related to Air Gestures, allows the user to send specific clearance requests and to receive datalink-like messages from the ATCO.

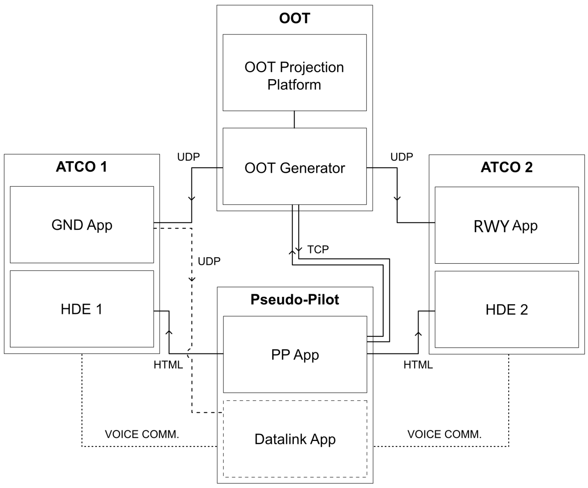

Figure 5. University of Bologna simulation and validation platform architecture.

C. *Vitoria-Gasteiz ATC tower platform*

The exercise VAR-005 is performed in shadow mode in the Vitoria-Gasteiz ATC tower using an operational paper strip CWP not being used at the time of the exercise where a V/AR device is provided as support tool for the ATCO. As previously indicated, Vitoria-Gasteiz ATC tower does not have surface radar or other surface surveillance device. The AR prototype module is composed of the following subsystems.

- A Microsoft HoloLens device to display the information over the real out of the tower view, the controller is enabled to interact with some of the holograms through air gestures recognised by the HMD.
- A software installed in the HoloLens used to consume ADS-B services and airport data and to provide the information required.
- A real-time service to process ADS-B-like signals and to provide information to the HMD device.
- An ADS-B transmitter is mounted over a vehicle driving through the aerodrome movement area to allow the execution of use cases and technical test.

III. Validation exercises

In this section, the validation exercises conducted by the different solution partners are presented according to the specific feature under investigation. An overview of the validation exercises is depicted in Table I. The Schiphol exercise VAR-001 is a Real-time Simulation addressing two different features, Tracking Labels (TL) and Attention Guidance (AtGu), in the simulation scenario of the large category airport of Schiphol. Bologna exercise VAR-002 deals with the development of a novel HMI including TL, AG (Air Gestures) and AtGu. During the Validation exercise, five teams of GND and RWY ATCOs were involved in a Real-time Simulation (RTS) with Humans-in-the-loop (HITL) in a scenario which replicated the Bologna aerodrome. In order to assess the introduction of the specific feature, each simulation scenario in which the GND and RWY controllers were supported by the technical solution, was preceded by a reference one with same amount of traffic and visibility conditions. Five teams, each one composed of one GND and one RWY controller, were involved in the validation. To allow the ATCOs to experience all the three technologies from the same position and make a good comparison between the reference and solution scenarios, there was no rotation of the ATCOs among the two CWP. The total of five users in each ATCO position ensured a thorough evaluation of the concept under investigation for different aspects and from different perspectives. Lastly, within the exercise VAR-005, the Vitoria-Gasteiz Airport ATC tower is exploited to perform a Shadow Mode validation to evaluate the usage of V/AR TL and AG in conventional control towers. Four different controllers were asked to wear the V/AR device and perform their tasks in front of a spare CWP located at Vitoria-Gasteiz tower control. Being Vitoria-Gasteiz a small airport, one controller performs all the roles, GND and RWY. Due to the shadow mode nature of the exercise, traffic and visibility conditions differed from one controller to another. The different light conditions tested included day, sunset and night. When there was no traffic and the operational controller allowed it, a vehicle with the ADS-B transmitter moved along the platform and taxiways following the mandate of the validation controllers.

TABLE I. Overview of Validation exercises.

Exercise	TL	AG	AtGu	Airport - Category	Validation technique
VAR-001	X		X	Schiphol - L	RTS
VAR-002	X	X	X	Bologna - M	RTS
VAR-005	X	X		Vitoria - S	SM

A. *Tracking Labels*

In Schiphol exercise, tracking labels are generated by the A-SMGCS servers inside the NARSIM environment and visualized inside the HoloLens. Generally, the AR symbology correlates accurately with the objects in the simulated outside view and tracking labels follow the aircraft without noticeable deviations.

The Bologna simulation exercise concerning only the usage of V/AR Tracking Labels is based on a solution scenario where the AR overlays are tailored according to CWP (GND and RWY), phase of flight and specific visibility condition. Each tracking label is linked to the associated aircraft with a bar and can present two different colour, light blue for departures and yellow for arrivals. The information reported on the tracking lables are of two types, permanent (Call Sign and Afc Type/WCAT) and adaptive (EOBT, CTOT, Push Back, Taxi, Hold position, Take off for departure label and Distance from touch down, Altitude and Speed for arrival label). Moreover, as the visibility condition decreases, airport layout overlays appear. In order to assess the introduction of the specific feature, the first exercise run was always performed on a reference scenario including eleven movements (7 departures and 4 arrivals) and a gradually decreasing visibility for a total amount of 40 minutes to be compared with the following 40 minutes solution exercise with the same amount of traffic and visibility conditions of the reference one. Within the solution exercise, the two ATCOs were provided with two HoloLens2 devices which allowed to display the different overlays on aircraft, runway and taxiways through the AR App (see Figure 6).

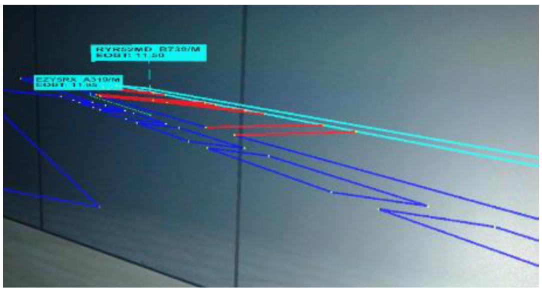

Figure 6. VAR-002: Tracking labels and airport layout overlays in low visibility condition. The colour of the runway follows the same coding of the aircraft TL.

Vitoria-Gasteiz exercise displayed V/AR tracking labels that used the ADS-B information to follow the aircraft or vehicle over the airport surface and on air. The label associated to a flight presented its callsign information, the horizontal speed, distance to the tower and altitude (if it is on air). The labels were linked to a bubble that was orange if the aircraft was on air and green if it was on ground or very near it. Another V/AR element that the exercise device presented to the controller was a low visibility condition (LVC) block that covered the runway. It indicated if the runway was occupied (in red) or not (light green). The occupancy or not of the runway (R) was also displayed on a square that was always in the controller line of vision (See Figure 7).

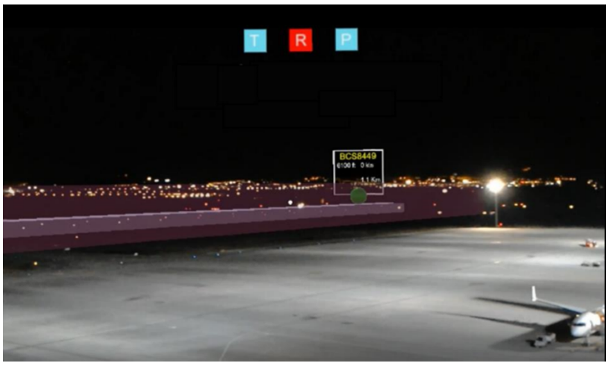

Figure 7. LVC block and R square in red indicating an aircraft on the runway-VAR-005.

B. Air Gestures

Solution 97.1 explores different usage of the Air Gestures recognised by the AR HMD devices, and in particular, clearances release (VAR-002) and information customization (VAR-005).

Within the VAR-002, the multimodal interaction of voice and gestures was implemented for the GND ATCO. The GND controller, who is responsible for the maneuvering area, is enabled to interact with the AR overlays to manage not-time-critical tasks such as Departure, Start-up and Push back clearances release. In order to avoid a too crowded out-of-the tower scene, each aircraft TL is activated five minutes before the EOBT; the user is allowed interact with the specific label, which is first coloured in gray and then turns to light blue when the pseudo-pilot sends the departure clearance request through the CPDLC interface. Once the GND controller acknowledges the request by clicking on the label, a datalink-like message is sent to the pseudo-pilot who can issue a push-back and start-up request. This request triggers two buttons (Pushback and Startup) to appear above the aircraft label. With the same type of AG already used for the departure clearance, the controller interacts with the two holograms allowing the electronic messages to be sent to the pseudo-pilot who updates the state of the aircraft through the PP App.

Figure 8. VAR-002 Air Gestures solution exercise: ATCOs can simultaneously see both the out of the tower view and the AR overlays through Hololens2. The personal view of the GND controller who is interacting with the overlays is depicted in the blue square.

Considering the lower level of maturity of this particular solution, the exercise related to the AG HMI interaction was assessed only in good visibility condition and with a reduced amount of traffic for a total of 15 minutes. To evaluate the impact of the introduction of the Air Gestures into the novel HMI in airport control towers the solution scenario was compared with a reference one where the AR applications were disabled.

In VAR-005, controllers are able to change the information virtually displayed using two air gestures, air tap and air tap and hold [5]. They have access to different menus and performing air gestures they have the possibility to:

- pick, drag and drop AR elements;
- navigate between a list of aircraft displayed on the V/AR;
- increase/decrease the number of aircraft displayed;
- select an aircraft by its callsign from an aircraft list;
- enable/disable Low Visibility Conditions display;
- calibrate the device (if needed).

C. Attention Guidance

The Schiphol exercise mainly focused on a concept for Attention Capturing and Guidance (AC&G) [6]. The operational concept for AC&G in the AR device is based on visual and auditory cues. In order to find relevant events that would trigger the AC&G process, two existing Schiphol runway controller alerting systems are considered, the Runway Incursion Alerting System (RIAS) and the Go-around Detection System (GARDS). Both systems are available in the NARSIM environment. A team of Simulation and Human Performance experts at Royal NLR elaborated the basic AC&G operational sequence for safety-relevant events and designed the necessary cues inside the HoloLens2 to be presented to the tower controller for each of the alerts. They consist of different types of symbols for information display and user guidance. Different shapes and colors were tested, but also different information content. Aircraft labels generated by the A-SMGCS servers inside the NARSIM environment were also visualized inside the HoloLens and used as attention getters and as guidance elements, increasing the Situational Awareness of the tower controller. In the operational sequence, the A-SMGCS safety

Figure 9. Tower Controllers with HoloLens2 (NARSIM).

net servers detect an event and relay that information to the attention guidance logic. A non-intrusive text element (i.e. being transparent and not blocking the view) is then displayed in the center of the HoloLens field-of-view indicating the type of alert and the most important information for that event. The event, and thus the attention capturing activity, has to be acknowledged by the user and both an intrusive (air gesture) and a non-intrusive (direction of view detection) method are tested to that end. At the same time, a pointer guides the user towards the area in which the event is taking place (depending on the type of event that could be an approach area, a runway, or a part of the movement area) and the callsigns of the involved subjects are highlighted in boxes resembling aircraft labels on a radar display. The boxes are connected to the subjects in question (i.e. an aircraft, vehicle or tow) in a so-called rubber band mode, meaning that they would be drawn towards their subjects until they reached the end of the display. When the user looks towards the location of the event, the callsign boxes snap to their respective subject and their outline changes to indicate alignment of view. Furthermore, the attention capturing process is accompanied by an auditory cue. Updates of the event would occur after a given time interval. They depend on acknowledgment of the user that the event has been noted, the direction of view of the user (i.e. whether the user followed the guidance cues or not), and the severity of the indicated event (or conflict). In case of an update, different cues are used with the interface to raise the attention of the tower controller to a higher level. Different settings for the mentioned time interval and the severity of the event were tested. The test programme was designed in accordance with the SESAR-adopted European ATM research methodology for validation (E-OCVM) and consisted of several events and combinations of events (with different or equal priority) that happened while two experienced tower controllers carried out routine work in the NARSIM environment for Schiphol airport. Pseudo-pilots were in control of aircraft movements and communicated with the tower controllers. Traffic scenarios being similar in configuration and traffic volume were used to compare working with and without the HoloLens. In the reference scenario, ATCOs were working with traffic that was comparable to the traffic used in the scenario including the technical solution, but they were not using the AR device and the symbology that developed for AC&G. Alerts from the A-SMGCS servers were shown on the Traffic Situation Display (radar screen) instead. The results of the reference scenario were used for comparison between ATCO behavior and performance with the solution scenarios which included the use of the AR device. The experiment structure was based on 14 different events offered in pseudo-randomized order for both ATCOs and conditions.

The attention guidance given by the introduction of safety nets and directional audio sources in the novel HMI developed for Bologna airport scenario is assessed through a technical test. A safety event, and more specifically a runway incursion, is simulated in both the reference and solution scenario. For the reference scenario, the ATCOs operate with the basic equipment whilst in the solution one they are supported by a directional acoustic alarm and AR tools (the TL of the aircraft involved in the event turns to red) to visualize the safety events. Given the reduced augmented field-of-view of the HMD devices, the directional alarm is present to drive the attention of the controller if he/she is not looking in the direction of the V/AR safety nets. In order to trigger the alarming event, the pseudo-pilot starts a runway inspection when the runway is occupied by one of the take-off aircraft (reference) or when an aircraft has already obtained the permission to land and its distance is less than 4 miles from the runway (solution).

IV. Results of validation exercises

The results concerning the VAR-001 exercise are gathered by using questionnaires after each test run and performing debriefings and interviews. Questionnaires include a set of standardized rating scales to assess ATCO workload, Situational Awareness, system usability and acceptability (Bedford [7], CARS [8], SHAPE [9], SUS [10]). Dedicated questions with a specific operational context are also formulated to retrieve detailed information from the ATCOs about how they appreciate the Attention Guidance cues and what could or should be adjusted.

To assess the introduction of Tracking Labels, Air Gestures and Safety Nets in the HMI of VAR-002 simulation platform, different data are collected anonymously in the form of objective quantitative measurement derived online by the platform (Head up time and number of switches head up/head down and number of vocal communications, time to react to the safety events) and subjective qualitative assessment such as workload, acceptability, trust, usability, human error, user comfort and throughput obtained through questionnaires and/or interviews.

When dealing with the VAR-005 validation exercises, data are gathered by means of anonymous questionnaires and debriefing sessions with the validation team. The information collected include workload, situational awareness, trust and acceptability, human error, HMI and perceived safety.

A. Tracking Labels

The results obtained for the introduction of Tracking Labels and airport overlays demonstrate that the prototype concept developed and implemented into UNIBO'S platform has a positive impact on the ATCOs' performance. Feedback from the users assigned to both GND and RWY working positions, showed that the prototype for V/AR TL supports controllers in maintaining an acceptable level of workload and efficiency of ground operations. Situational awareness, potential for human error, trust, acceptance, job satisfaction, and perceived safety, especially in low visibility conditions, improved, leading to a beneficial effect for the cost efficiency performances. Nevertheless, in the future, a further improvement of these factors could be achieved by increasing the synthetic field of view and enhancing the label design and positioning. Most of the controllers suggested that the background color of the TL should have some degree of transparency to avoid to obscure important areas of the aerodrome and that it should be possible to customize some of the information displayed. Lastly, assessing the objective data, the proposed solution proved to be helpful to the ATCOs in reducing the time spent in Head Down position looking at the HDE with respect to the reference scenario (Figure 10).

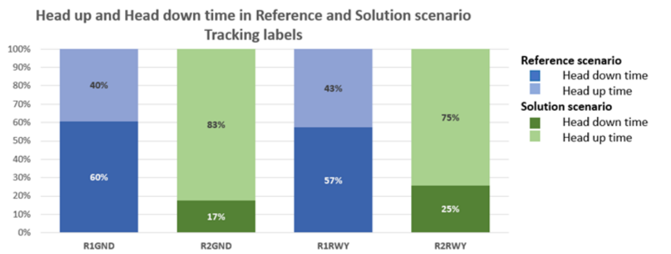

Figure 10. VAR-002: Head up and head down time in reference and solution scenario - Tracking Labels

These data are strictly related to the number of switches head-up/head-down, a number which was drastically reduced with the introduction of TL and airport overlays. 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 [11].

Controllers are very interested in the solution at Vitoria-Gasteiz exercise. Their feedback indicates that the use of V/AR glasses are beneficial to safety specially at night or LVC in airports that do not have surface surveillance systems. ATCOs' Workload and perceived safety improved, job satisfaction, trust and acceptability had high rates and human error did not vary. Situational Awareness did not improve in the exercise which was linked to ergonomics (use of a heavy first-generation HoloLens V/AR device) and data processing (need of data smoothing between ADS-B position reports and an antenna coverage study). Controllers provided feedback to improve the size of the tracking label and fonts used. Due to the nature of the airport, small size, overlaps were not an issue although some opacity adjustments were performed following ATCOs feedcback. The LVC block was considered as very useful and supportive. All signs point to a feasible implementation of the solution, but the mentioned issues need to be addressed.

B. Air Gestures

From a technical perspective, the solution exploring the introduction of V/AR Air Gesture HMI interaction into the VAR-002 interface proves to be operationally feasible when dealing with not-time-critical tasks but, in order to achieve a higher level of maturity and have a positive impact on human performance, some usability improvements shall be considered. The users assigned to the GND position experienced some difficulties in the correct usage of the AG currently recognised by the Microsoft device. The controllers observed an increase in the physical workload associated with usability and ergonomics issues that can have an impact on the situational awareness. Nevertheless, the perceived potential for human error, the trust level and the acceptance and job satisfaction level were not impacted by the introduction of a multimodal interaction encompassing V/AR Air Gestures and voice. Moreover, the investigated solution demonstrates to be helpful for the GND ATCOs in increasing the time spent in head up position looking at the out-of-the-tower environment rather than at the HDE. When dealing with the AG, one of the most important parameter to evaluate is the number of vocal communications. The possibility to interact with the pseudo-pilot through gestures can lead to a reduction in vocal communications. The average percentage reduction of this number between the reference and solution scenario is about 56% (Figure 11) and, as some controllers pointed out, it was also reduced the associated risk of miscommunication.

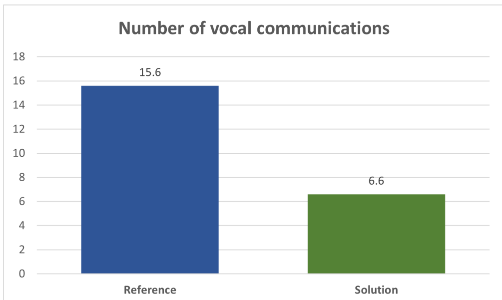

Figure 11. VAR-002: Average number of vocal communications in reference and solution scenario

The air gestures used at Vitoria-Gasteiz airport support the controller to obtain the desired information. Controllers indicated that the air gestures used to control the menu could be a bit more intuitive, but after some time practicing them, they are easily understood and accomplished. Controllers provided feedback on the information menus (e.g. an altitude filter should be available) with no further comment on the AG themselves.

C. Attention Guidance

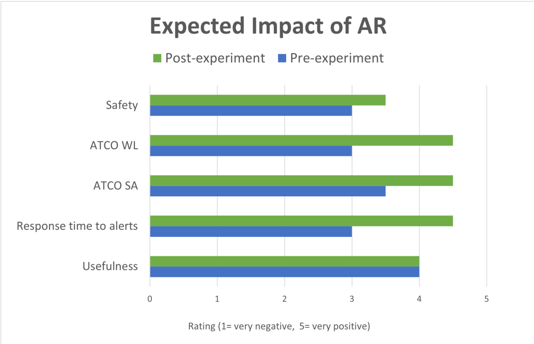

Figure 12. VAR-001:Expected AR Impact (Mean Values).

In the results of VAR-001, controller workload, was rated "positive" to "very positive" after the experiment with respect to the impact of the AR device, both during normal operations and in case of an alert being given (see also Figure 12, showing mean questionnaire results). The post-run ratings of workload, however, show no significant differences between baseline and advanced condition. This could be attributed to the fact that controllers were already working in a smaller operational scope with comparable traffic volume levels under both conditions. Future investigations should therefore concentrate on experiments with larger controller teams for Schiphol or smaller airports with higher levels of diverse traffic to find corroborating evidence for workload reduction. The impact of AR on controller Situational Awareness (SA) was rated "positive" to "very positive" as well after the experiment, both during normal operation and in case of an alert. Again the post-run ratings of SA show no significant differences between baseline and advanced condition. While it is thus safe to say that a sufficient level of SA could be maintained, the positive outcome at the end of the experiment can not be corroborated. The fact, though, that controllers stated during debriefings that it is a substantial improvement that they do not have to search for information about the location of the conflict and the relevant aircraft callsigns, indicates that they were indeed anticipating such improvements. The absence of controller errors when using AR may support this argument. Again, different environments with a larger operational scope or more complex traffic situations may help to find more compelling evidence. The ATCO ratings of expected influence on the response time to alerts was neutral before the experiment and rated "positive" to "very positive" at the end of the experiment. This was substantiated by the ATCOs during the debriefing. ATCOs stated that reaction times might decrease when using AR guidance, because controllers would not have to look down onto displays for information. While this was not objectively measured in the experiment, ATCOs commented that it is efficient and convenient having callsigns in view and not being constrained by information displayed on the TSD or the flight strips which would force them to work in a head-down mode. After the experiment, the expectation was that safety will increase because controllers could give instructions more efficiently when using AR device (based on the information received from the safety nets). No negative effects on workload or SA were found during the experiment. Furthermore, the outcome of the experiment did not give reason to believe that using AR would have a negative effect on controller error rates due to the consistency of the information provided in the AR device. While the subjective evidence thus supported the assumption that AR had a positive impact on the work of the tower controller in terms of performance and safety, the current prototype did not reach a development stage yet that would have been sufficient to gain a stable level of automation trust or acceptance ratings from the controllers. Accordingly, the measured system usability scores are low (between 40 and 52.5 on the SUS) and acceptance ratings range between 1 and 7, as one of the controllers made several assumptions regarding the potential for improvement of the prototype. Generally, the reasons given for the low ratings concern the presentation of the alert notification, which is considered too intrusive, the inappropriate re-appearance of alerts in some of the alerting conditions and some of the hardware limitations (restricted field of view, visor reflections, low contrast in simulator). Despite the fact that ATCOs addressed technical performance improvements (mostly related to user comfort and general adjustments), the HoloLens was considered a technically useful device for implementing prototypes for AC&G with aural and visual cues. According to the controllers, the AR device has a high potential and deserves more attention. Tracking labels are not only used for provision of basic aircraft information but also as attention getters and as guidance elements, increasing the Situational Awareness of the tower controller. The controllers could provide instructions immediately as they are quickly guided towards the location of an alert. Furthermore, the aural alerts also indicate that location and the relevant callsigns are visible in the AR device as soon as there is an alert. There is no need for the controllers to look down at the flight strips. The experiment with the AC&G prototype led to two issues that are recommended to be considered when designing an updated version. It concerned the re-capturing of controller attention and the symbols used. Controllers stated that, once they had been alerted of a serious event, such as a runway incursion or a go-around, they would not need to be alerted again for the same event. Instead, only solid guidance is needed as soon as the event is detected. In a nutshell, controllers do not like support from a system that monitors their own actions. Accordingly, some of the symbols were considered as distracting with too much interference. This could be changed easily in a new prototype set-up but may lead to different results in a real tower environment due to different lighting conditions in a real-world tower cabin. As regards the tracking labels, controllers generally appreciated that the labels of all aircraft were visible. No showstoppers or technical problems were identified here.

The results of the qualitative assessment of VAR-002 simulation related to the Attention Guidance feature demonstrate how the proposed concept solution is highly appreciated. The controllers agreed that the safety net tool, helping them to immediately recognise a hazard, positively impacted the potential for human error and it was also a benefit for the Situational Awareness and the acoustic alarm was very effective in guiding their attention. Moreover, since the safety nets and the acoustic alarm were triggered and notified for the two AR App, there was no need to communicate the event and therefore the team Situational Awareness was enhanced. Analysing the quantitative measurements, the introduction of safety nets proves to be very helpful in reducing both the time spent in Head-up position and the time needed by the RWY ATCO to notice and react to a safety event which was reduced of almost the 65% in the solution scenario with respect to the reference one (Figure 13).

Figure 13. VAR-002: Time to react to the safety event in reference and solution scenario

V. Conclusion

This paper introduces the validation exercises conducted by different partners in the framework of the EU-funded project "Digital Technologies for Tower" (PJ05-W2 DTT) Solution 97.1 to investigate the introduction of novel HMI modes with related technologies in various airport control towers. In particular, V/AR tracking labels, air gesture interaction and attention guidance features have been assessed, from both an objective and a subjective point of view, according to the proper maturity level and validation technique. As expected, the obtained results show how the usage of V/AR technologies, by displaying additional information over the actual out of the window view, could lead to a reduction of the mental workload, and an improvement of situational awareness and productivity of the ATCOs. However, further improvements, mainly related to the ergonomics of the AR device, should be implemented in order to achieve higher levels of maturity of the solutions.

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