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Innovative Ideas for the Use of Augmented Reality Devices in Aerodrome Control Towers

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Abstract. In recent years Augmented Reality (AR) has become one of the major focus points of user interface development. With the rapidly increasing computing power and developments in software and hardware applications during the last two decades, it has moved from theoretical approaches towards industry-wide application and mass production.

The Royal Netherlands Aerospace Centre, NLR, tested several devices in the past, but only recent developments made it possible to effectively use them in an Air Traffic Control (ATC) working environment for Aerodrome Control Towers. In 2021 NLR carried out innovative technology experiments on their high-fidelity real-time air traffic control simulation and validation platform, NARSIM. These experiments were part of the SESAR 2020 project Digital Technologies for Tower (DTT) and focused on advanced HMI interaction modes for aerodrome tower controllers. A proposed Attention Capturing and Guidance concept with an AR device was evaluated inside an aerodrome control tower environment for Amsterdam Airport Schiphol.

This paper reflects on the technology development activities that took place at NLR during the last decade and describes the different steps taken to apply the technology in a conventional control tower environment. It is shown that the recent technology developments must be seen as a big step forward in practical application of AR devices for ATC.

Furthermore, an outlook into the expected future use of AR devices in conventional control tower environments will be given that goes beyond abovementioned concept elements. This outlook considers additional developments for standardization of digitized airport information and communication between different stakeholders and general performance improvements for AR devices.

Introduction

The technology used for AR combines virtual objects or information generated by a computer with the real world. These computer-generated overlays enhance user perception of the physical environment and, with added sensory input technology, lead to an interactive and immersive user experience.

The history of AR devices already dates back several decades, with the technology evolving and advancing over time. In early developments, Head-up Displays (HUDs) were used by the military since the second half of the last century. They were primarily employed in aircraft to improve weapon aiming and provided pilots with critical information without requiring them to look away from their primary field of view. This functionality soon moved on to general piloting displaying basic aircraft state parameters in the field-of-view to improve situational awareness (SA), especially under low-visibility conditions, and became a more common technology in commercial aviation in the 1980s [1].

More complex interface developments based on HUDs were taken up by the gaming industry at the beginning of this century. With technological advancements in the areas of power supplies, display and sound elements, and gyros for orientation, a major step from a simple display of data towards the inclusion of 3D-images in the real-world view could be achieved. Especially the developments in handheld computing devices, and eventually mobile phones and dedicated AR devices, such as the Microsoft HoloLens™, which is a head-mounted display (HMD) or headset, opened up the world of AR computing to more sophisticated developments. Such dedicated devices are currently also referred to as Mixed Reality (MR) devices, as they allow the user to interact with and manipulate physical and virtual elements and environments via advanced sensor and imaging technology [2].

Developments at Royal NLR

For over a decade, Royal NLR has been actively exploring applications for the use of HMD devices in the aerodrome tower ATC environment (Fig. 1). Initial research began in 2010 when NLR tested the nVisor ST™ HMD from NVIS in the NARSIM Tower environment, the in-house developed platform for highly realistic real-time simulations of ATC tower operations. The HMD device served as a demonstrator, displaying basic flight strip information that could either be static or change depending on the controller's line of sight. While feedback from controllers highlighted concerns about the device's ergonomic discomforts in terms of weight and freedom of movement, and about the accuracy/availability of sensor data, the concept of enhancing visual information through HMDs showed promising potential.

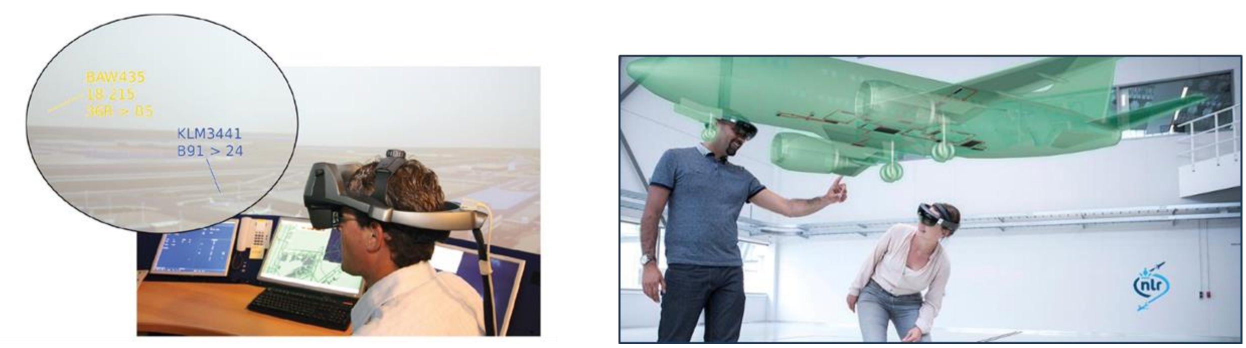

Fig. 1: Experiments at Royal NLR with Different Visual Enhancement Devices

In 2016, NLR integrated a Google Glass™ device (now known as Glass™) into the NARSIM environment to showcase additional capabilities with improved comfort to a selected group of air traffic controllers from ATC The Netherlands (LVNL). The device streamed video feeds from remote cameras. These feeds were then displayed on Google Glass and switched automatically based on the user's direction of view, which was continuously tracked. This demonstration aimed to illustrate how tower controllers could gain visibility into apron areas by looking beyond physical obstructions in the line of sight, such as buildings. While controllers acknowledged the promising capabilities, they identified limitations in how the glasses incorporated virtual elements. The video feeds were perceived as an additional monitor rather than an integrated component of the provided outside view.

In late 2019, with the arrival of the Microsoft HoloLens 2™ in the AR device market, NLR acquired two of these units. Although NLR had previously used HoloLens devices between 2016 and 2019 for various purposes like aircraft maintenance training, simulation debriefings, and projecting simulation results onto aircraft components, the potential of AR devices in the context of air traffic management and control had not yet been explored.

Evaluation of an AR Device for Attention Capturing and Guidance

With abovementioned development steps in mind, NLR continued the goal of investigating the possibilities of AR devices for enhancing the effectiveness and efficiency of tower ATC operations. In 2020 NLR joined a consortium for carrying out a project that focused on advanced HMI interaction modes for aerodrome tower controllers. That project was part of SESAR 2020, the second Single European Sky Advanced Research Programme, and was called Digital Technologies for Tower, DTT [3].

While the display of weather-adaptive static information (buildings and outlines) and flight phase-adaptive traffic labels as well as air gestures to interact with the labels and the system was carried out by other partners of the consortium, NLR focused this activity on the evaluation of an Attention Capturing & Guidance (AC&G) concept [4]. To that end, the HoloLens 2 AR device was integrated into the NARSIM Tower environment (see Fig. 2). This meant that…

- …the HoloLens had to be aligned with the real world environment, in this case the (real-life) tower control cabin of NARSIM, using its World Anchoring system,
- …data had to be collected on the NARSIM side and communicated as XML messages via TCP/IP with the HoloLens application, and
- …the HoloLens application had to use the simulation data in its own world model to generate the necessary visualizations.

One of the encountered difficulties in that set-up was the fact that the real world was actually the simulated tower outside view of NARSIM, which was projected onto a 360-degree circular screen with diameter of 11m, surrounding the real-life tower cabin environment. Thus, aircraft movements on taxiways had to be observed to perfectly align both simulation worlds.

The most realistic and detailed airport model available for NARSIM was its Amsterdam Airport Schiphol (EHAM) environment which is also used as training environment for LVNL controllers. In order to prevent that the complexity of that environment would distract from the actual goal of evaluating the AR interface, the operation at Schiphol was scaled down to an off-peak runway configuration that could be handled by one ground controller, also acting as runway controller.

The AC&G concept was then demonstrated in 2021 based on visual and auditory cues displayed in the AR device to alert and guide controllers in case of critical events. In order to find relevant events that would trigger that process, two existing Schiphol runway controller alerting systems were considered, the Runway Incursion Alerting System (RIAS) and the Go-around Detection System (GARDS). Both systems were previously prototyped on NARSIM and thus available in the simulation environment. Additionally, an experimental algorithm for Taxiway Conflict Detection (TCD) was integrated that added alerts with lower priority that could be perceived as minor disturbances when compared to potential high-impact runway alerts. They served as a distraction to actually be able to surprise controllers when concurrently generating more relevant situations and events.

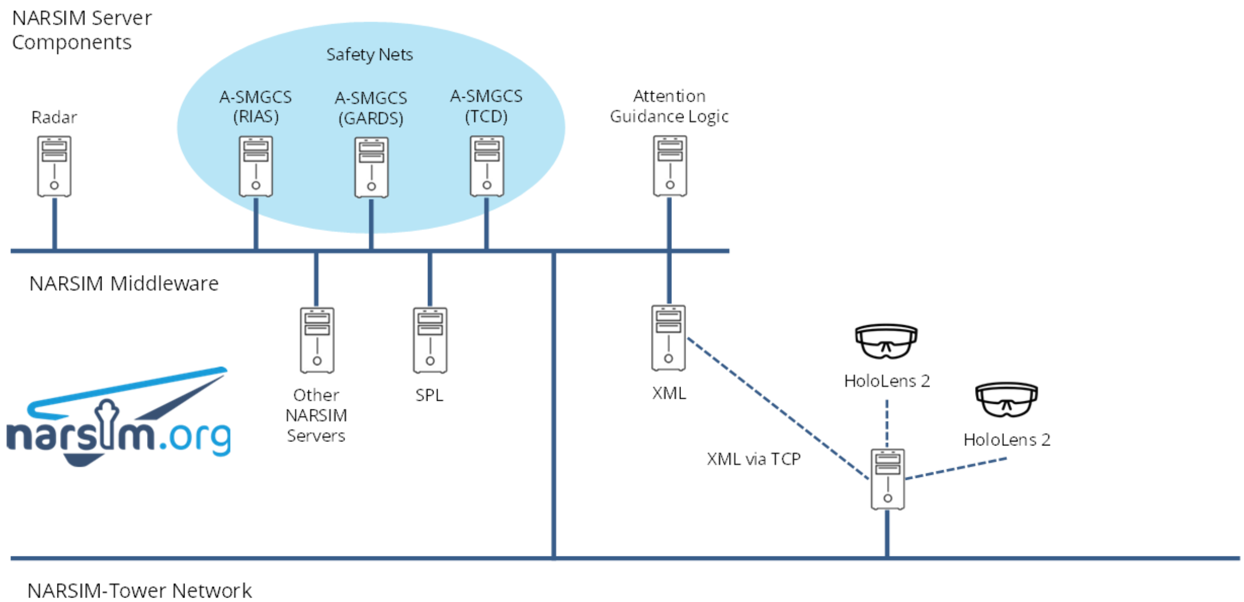

Fig. 2: NARSIM Architecture Elements with Integrated AR Devices

Different cues for each type of event were designed within the HoloLens application with different types of symbols for information display and user guidance (Fig. 3 and Fig. 4). Various shapes and colours were tested, but also different information content. Aircraft labels available from the NARSIM A-SMGCS servers were also visualized inside the HoloLens and were used as attention getters and guidance elements, increasing the SA of the tower controller.

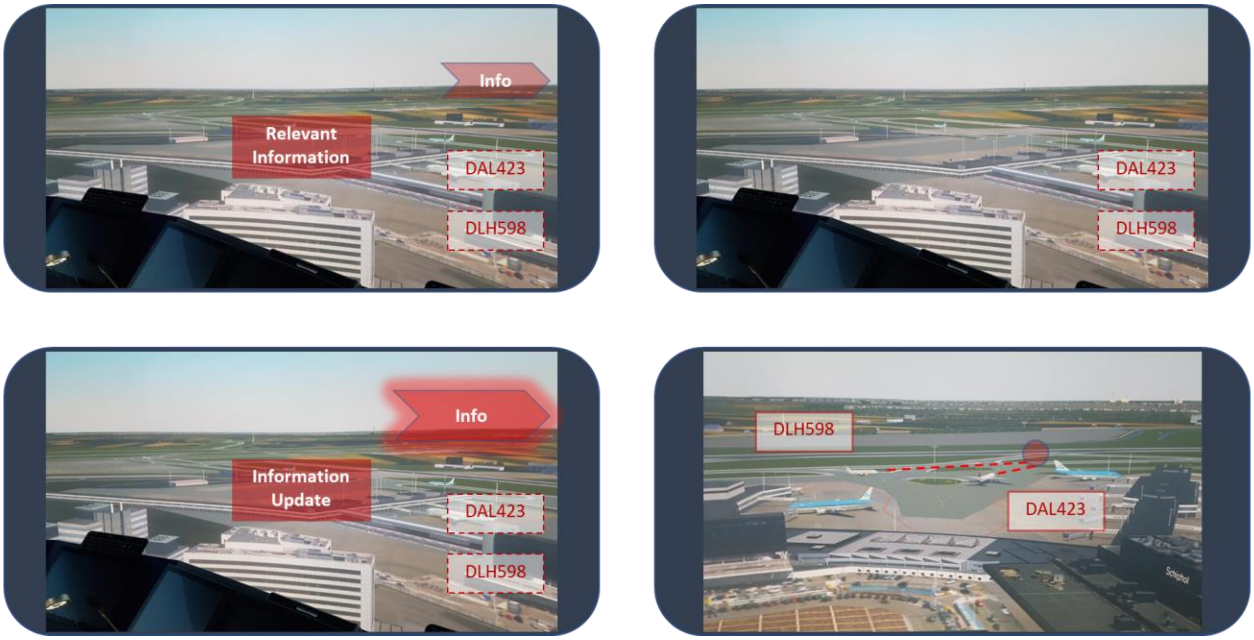

Fig. 3: Prototype Sketches of Virtual Elements Indicating Operational Sequences in NARSIM

Generally, the operational sequence played out as follows:

- *Detection of a safety-critical situation*: A-SMGCS safety net servers detected an event and relayed the associated alert information to the AC&G server. The AC&G server then triggered an attention capturing event in the HoloLens application for display of a non-intrusive text element in the AR device indicating the type of alert and relevant information (upper left in Fig. 3). The attention capturing process was also accompanied by an auditory cue.
- *Controller acknowledgement of the safety-critical situation*: the user of the AR device had to acknowledge the attention capturing event (upper right in Fig. 3) by either an intrusive method (air gesture) or a non-intrusive method (direction-of-view detection).
- *Guidance of controller attention towards safety-critical situation*: instantly following the attention capturing event, attention of the controller was guided via a pointer towards the area in which the safety-critical situation was taking place (e.g. taxiway, apron) and the callsigns of the involved subjects (displayed in the AR device by default) were highlighted. The callsigns were connected to the subjects (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 (lower left and right in Fig. 3).
- *Detection of alignment of direction of view with safety-critical situation*: when the user looked towards the location of the safety-critical situation, the callsigns snapped to their respective subject and their outline changed to indicate alignment of view.
- *Detection of triggers for AC&G situation updates*: updates for the safety-critical situation would occur after a given time interval and depended on user acknowledgement, the direction of view of the user (i.e. whether the user followed the guidance cues or not), and the severity of the indicated conflict. Different timer and severity settings were tested.

The test programme consisted of different events and combinations of events 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. Similar traffic scenarios were used to compare working with and without the HoloLens. Results were gathered in different ways, using questionnaires after each test run and performing debriefings and interviews.

Fig. 4: Go-around Detection Alert as Seen through the AR Device

Evaluation Results

Based on the described evaluation experiment, it was determined that the AC&G operational concept for aerodrome tower controllers using an AR device is feasible and has potential. Although the experiment had a limited operational scope, and feedback was provided for improving certain aspects of the concept, the general outcome was positive. The feedback primarily focused on enhancing the symbology and timing of attention guidance cues. Overall, this result provided us with a solid foundation to further advance and refine the concept moving forward.

Technical integration issues for the AR device were not encountered in the NARSIM environment. However, it is important to note that this does not guarantee the absence of such issues in a real tower environment, e.g. due to noise in the surveillance data or the lighting conditions in the tower cabin. Nonetheless, the positive results obtained have instilled confidence that activities performed with the HoloLens 2 in real towers will likely yield similar conclusions.

From a Human Performance perspective, not too many conclusions could be drawn when comparing experiments with and without use of the AR device [5]. This was mainly due to the fact that both controllers were already very familiar with the current environment and were confronted with a device that had a large impact on the operation, as safety net alerts were presented and perceived differently. Thus, the fact that no significant difference in perceived safety and workload were found was already a positive aspect. However, it was also clear from the current development stage, that the prototype did not reach a level yet that would have been sufficient to gain stable results for automation trust or acceptance ratings from the participants. This meant that they were well aware that the presented prototype was not the end of the development, and therefore they accepted some of its shortcomings. In the end, the post-experiment ratings therefore exceeded the expectations that controllers had before starting the experiment, which is shown in Fig. 5.

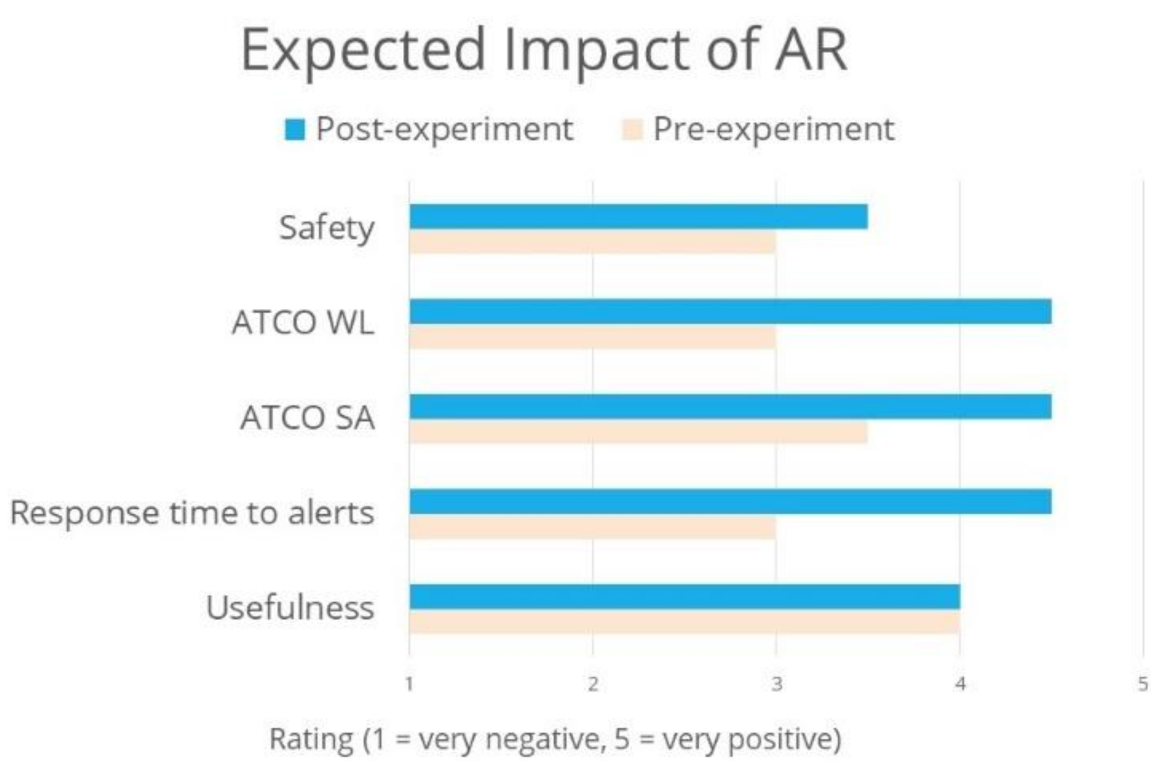

Fig. 5: Comparison of Pre-experiment and Post-experiment Human Performance Ratings

During and after the experiments (Fig. 6), the two participating tower controllers provided positive feedback on both the AR device and the operational concept. The device was considered a favourable addition to the tower controller working environment. Although the suggested technical improvements related to user comfort and general adjustments and will thus depend on vendor development, the HoloLens used in the experiment proved to be a technically useful device for implementing prototype applications with aural and visual cues for AC&G. According to the controllers, the AR device demonstrated high potential and deserves further attention.

It is important to note that the experiment validated a rather generic operational set-up, without distinguishing between runway and ground controllers. In reality, each role may require a more customized presentation of necessary information. Additionally, team working aspects and coordination activities among different controllers or roles were not yet considered. Despite these limitations, which prevented the identification of objective evidence for operational improvements, the controllers still held a favourable opinion regarding workload reduction and enhanced SA and rated both aspects positively. They expected a positive impact on safety through a more efficient and timely presentation of the safety-critical situation which should lead to a better understanding of the situation. Similar conclusions were drawn regarding head-up and head-down times, even though objective measurements were not feasible. An increase in head-up time, particularly during alert situations, was deemed highly likely. Notably, no controller errors were observed as a result of using the device.

Fig. 6: NARSIM Tower Simulation Experiment with Air Traffic Controllers

The operational application of the technology still faces several challenges, predominantly stemming from hardware constraints. Addressing these concerns, vendors should prioritize improvements in the key areas of device weight and screen size. The latter poses constraints on the virtual elements that may be observed by peripheral vision, making device adjustments challenging. Lastly, the coating used on the device diminishes visibility, akin to wearing sunglasses in a dark simulator room. Resolving these hardware limitations will significantly enhance the feasibility and usability of the technology in an operational setting.

Through discussions with the simulation participants, additional ideas emerged regarding potential future development steps and a vision for tower controller work with AR devices was developed. The recommendations emphasized the importance of not solely concentrating on alerts related to high-impact events. Instead, it was suggested that other avenues should be explored to enhance SA, reduce workload, and facilitate knowledge sharing to improve controller efficiency and capacity.

One potential next step could involve focusing on enhancing tower controller awareness of specific airport and approach operations. By analysing the type of information that controllers frequently reference and presenting that information in a more intuitive manner, controllers can enhance their SA with reduced effort. In other words, by providing adapted and relevant information in a readily accessible manner, controllers can build their SA more effortlessly.

These ideas and recommendations highlight the broader potential of AR devices beyond alerting systems and attention guidance, extending their utility towards creating a more efficient and effective working environment for tower controllers. When considering them, further advancements may be possible to optimize controller performance, enhance SA, and improve overall controller efficiency and capacity. Some of these aspects and avenues will be addressed in the last section of this paper.

Additional Ideas about the Future Use of AR Devices in the Aerodrome Tower

For the future, different development paths for the use of advanced technology in aerodrome control towers may lie ahead. Depending on already existing approaches and applied technology, the potential of AR could actually be reduced or even be eliminated. The latter would certainly be the case if the goal was to reach full automation of tower controller tasks using so-called Artificial Intelligence algorithms. The idea would be to completely eliminate the human operator from the tower environment and thus the need for an out-the-window view. Such developments are in fact a part of current air traffic management (ATM) research, perhaps a bit less prominent for conventional manned traffic operations, but certainly in the area of unmanned traffic management [6]. Nevertheless, for now, they should be seen in the context of research on automation work that still needs to progress in several areas of human perception and cognition before safe and efficient operations are achieved.

In the current environment, full AI automation is definitely a bridge too far, and emphasis is laid on the fact that the use of AI in the foreseeable future does not have the objective to eliminate human operators from the process but rather to integrate the strengths of both computational methods and human intelligence. AI-enabled applications are intended to become a valuable aid for air traffic controllers, significantly alleviating their workload by presenting them with the best possible options for complex situations in terms of traffic flows, sequences, and safety-critical situations. This collaborative approach between human and machine is expected to lead to an enhanced provision of services without eliminating human actors [7].

Further digitalization steps of tower operations and certainly the introduction of remote tower operations, however, are not a pipe dream but represent the current state of the art for quite a number of airports. These operations still require the presence of human operators and therefore may include different visualization concepts with the aim of integrating a picture of the outside world with relevant information for tower controllers. Current set-ups vary in scope and size, depending on the complexity of the operation that is carried out. For smaller airports or operational settings, the additional system support and information provision will already lead to benefits, such as a reduction in the number of controller roles or other improvements regarding work efficiency. However, if several controller are supposed to work with the outside view at the same time and if each controller would need to see different information content in the outside view due to a specific controller role, AR devices could offer an alternative to the current solutions. These current solutions usually add different screens to a panoramic view or split the remote controller working position into several smaller and role-dependent working positions. The most prominent example for such an operation is the HungaroControl set-up at Budapest International Airport (LHBP) that has been in operation since 2017 as a contingency facility [8].

Advantages of using AR devices in such set-ups might increase if attention capturing and guidance mechanisms are added. This would not only be the case for single remote tower set-ups, but, to a larger degree perhaps, for multiple remote tower set-ups, where one or more controllers need to maintain a mental picture of the operational situation at two different airports. Clearly, AR technology alone would not be enough to improve the situation, but it could certainly offer additional possibilities in combination with planning features, as indicated in [9] Ch. 6.2, and alerting features, as tested in the earlier described DTT experiment.

In the more conventional context of improving existing visual operations within tower buildings, the inclusion of AR technology holds significant promise. AR presents the opportunity to enhance the outside view for controllers without the need to add further equipment to the working position and without forcing controllers to look down at the working position to acquire vital information for a safe and expeditious operation. The latter means that head-up time is increased.

The augmentation of relevant information in the outside view including integrated 3D aural cues allows for several attention capturing and guidance capabilities that more effectively improve operations than non-AR technology. Intelligent virtual augmentation could include aspects, such as highlighted stop bars and their statuses, enhanced runway- and taxiway edges, indicated cleared routes for taxi operations, building contours and the outlines of other static obstacles or restricted areas. Such augmentation could be adapted automatically to the current visibility condition.

Traffic labels and their appearance and contents could be adapted to visibility conditions, the role of the controller, or the currently known flight status as well [10]. Taking it one step further, it could be investigated whether adaptation of what is shown or highlighted to support a controller could also take place in terms of the amount of traffic controlled or any signs of stress or high workload situations. This would mean that attention guidance would not only occur in case of a safety-relevant event already taking place, as in the case of safety net alerts being triggered, but much earlier in order to prevent such safety-critical situations in the first place.

Other technology additions may be considered as well, such as air gestures or automatic speech recognition. Air gestures generally would help in terms of system interaction, such as pulling up menus to change various settings, or system input operations, such as the selection of a route or a clearance limit as label information. Speech recognition, while generally meant to improve system input by itself, could be used together with AR to also highlight the labels of pilots calling in or, vice versa, callsigns being addressed by the controller, thus increasing SA and reducing workload once again.

Additionally, AR has the potential to redefine the roles and responsibilities of controllers, with the AR system being informed of the sequence of operations and actions required by each individual in the tower and guiding human actions in accordance with the expected procedures. Naturally, such innovative arrangements would necessitate a high level of automation and a well-defined delegation of authority, particularly during system failures or contingencies. Nonetheless, a potential future milestone could involve a complete redefinition of all existing working arrangements in the pursuit of an optimal operation (see Fig. 7).

Fig. 7: Innovative Use of AR Devices in the Aerodrome Tower (e.g. EFS, Adaptive Labelling)

Research organizations are entrusted with the task of exploring innovative concepts without being confined by existing structures of air navigation service providers or limitations imposed by industry. Such an approach would yield fresh perspectives on technology utilization and serve as a catalyst for breaking away from conservative developments of the past, such as electronic flight strips (EFS). Many EFS implementations merely replaced the traditional paper strips with electronic counterparts while retaining existing operational procedures, roles, structures, and rules of responsibility and authority. Although the ability of these electronic strips to display additional information can be seen as a significant advancement, it fails to address the fundamental question that could revolutionize airport operations: Why do we rely on strips and bays as structural aids for aircraft control on airports?

Concluding

In summary, the potential of using AR devices in the aerodrome tower operational context is very promising but has not fully been investigated yet. Many innovative ideas and functions have not been addressed yet or even been conceived. Of course, given the sensitive nature of the job of tower controllers in terms of required safety and the reliability and ease-of-use of supporting equipment, technical improvements in terms of weight reduction and display quality may still be required.

Nevertheless, initial experiments in different operational environments carried out for the SESAR 2020 project DTT, have shown that the use of these devices has a potential to improve controller SA and workload, leading to safer and more expeditious operations.

For the future, research with an exploratory character should be carried out to show the full potential of the functionalities sketched above, perhaps even from scratch, i.e. without being constrained by current working concepts and organisational structures. The focus of such research should be directed at the main capabilities of AR devices in terms of improvements in safety and operational efficiency, namely to augment controller vision by highlighting operationally relevant elements in an adaptive fashion inserting the most important information directly into the field-of-view. Other functionality exploiting the availability of different sensors (e.g. surveillance and video streams) could be added to also guide controllers in carrying out operations using different kinds of visual and auditory cues. Last but not least combinations of AR and automated system interaction and input technologies should be investigated further.

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