Could Augmented Reality take over Air Traffic Control?

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ABSTRACT

There are only a handful of professions that require computers and their operators to work perfectly together such as in Air Traffic Control (ATC). Luckily, there have been rarely any incidents in the past originating from faulty systems and failure within human-computer-interactions. But operating an airport with over a thousand arrivals and departures every day has always been a huge challenge for the ATC operators (ATCOs) and to increase the efficiency isn't desired but required to prevent potential crashes and system failures. Many efforts were taken into the direction of digitizing the old systems, but the core of the workflow of an ATCO remained the same. Since the late 1990s a new approach rapidly gained interest, due to its ability of using old analog, tangible systems, while incorporating digital advantages. Augmented Reality (AR) has been a topic ever since and several prototypes and studies were conducted. My goal within this systematic literature review is to show the current state of said research, review its literature and summarize its contents to positively answer the self-imposed question. AR could substantially change the way controllers operate at the largest airports in the world, for the better.

CCS CONCEPTS

• **Human-centered computing → Touch screens**.

KEYWORDS

systematic review; augmented reality; air traffic control; paper strips

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1 INTRODUCTION

To secure the safety of aircraft (A/C) and especially their passengers, a supervising instance is needed to control the airspace and the traffic that surrounds modern airports. Especially large airports like Paris' Orly or Amsterdam's Schiphol are facing immense challenges everyday with increasingly dense air traffic. The first recorded occurrence of an ATC building was in 1920 and since then, ATC systems evolved radically during the past century due to the high demand for safety and efficiency. Which already illustrates a critical concern, the idea of maximum safety and maximum efficiency are somewhat contradictory [15]. To guarantee maximum safety, no A/C would be allowed to depart any airport resulting in no air traffic. This ultimately leads to trade-offs that allow air transport to be possible but still hold precise standards and protocols to get close to eliminating any room for error.

Apart from sensory or other machine inaccuracies, the human yet remains to be the weakest part of an ATC system, since 95% of runway incursions are related to human error [6]. ATCOs need immense multi-tasking and situation assessment skills to quickly solve high density air traffic scenarios, while still being aware of the state of their sector. Before the first air navigation service providers started to use different systems in 2005, flight progress strips made of paper were still the standard interaction media to track and hold relevant info of flights.

Each strip stands for a flight, or rather the flight's A/C, and can differ in layout and content, but generally contains the flight number and the A/C type with its corresponding assigned flight level, departure, destination and other information.

Anytime an A/C enters the airspace of an Air Traffic Control Tower (ATCT) a paper strip gets automatically printed, inserted into a plastic strip holder and subsequently sorted into a strip board. The position of the flight strip often represents the order in which A/C are approaching and departing the airport. Since such strips are made out of paper, it's easy to move them around, building a strong tangible connection between the ATCO and the strip to support the memorization of interactions. Additionally, strips can be updated using a pen. Especially the mentioned reasons stagnated the development of other ATC systems and even the digitized systems today often use interfaces that emulate the analog workflow.

Since the core of the idea of a flight progress strip seemed to persist, researchers started to explore an Augmented Reality (AR) approach to solve many of the problems with both, the digital and physical representation of a flight and increase the operator's efficiency by merging tool capabilities instead of replacing or eliminating existing systems and workflows. This is a critical part of the proposed solutions and could change the tools that ATCOs work with in the near future, improving the Air Traffic Management (ATM) drastically to support future air traffic with higher densities.

To my knowledge, a systematic literature review about the use of AR in ATCTs is non-existent to date, which could be a lost opportunity to show the potentials and risks of AR in ATC. To pursue this matter, I gathered all research regarding this topic and analyzed them to a point where I can confidently say that AR is able to benefit ATC [2, 3, 5, 12, 14] and there are still unexplored facets to this field. There is still a lack of data and studies about current-gen and next-gen AR devices which might paint a clearer picture in the future, but the practice of centralizing information using AR showed to be beneficial for ATCOs. Even small improvements

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Table 1: Search Result Distribution

Source	Results (No.)
ACM DL	76
IEEE Xplore	18
NTRS	41
Total	135

might have a great impact in the large scale of an air navigation service provider and should be explored.

2 METHODOLOGY

I searched three well known databases to gather all relevant research publications of all AR related topics in ATC. The ACM Digital Library (ACM DL), the IEEE Xplore digital library (IEEE Xplore) for content published by IEEE and its publishing partners; and the NASA STI Repository (NTRS) which provides access to aerospace-related publications created or funded by NASA.

The search terms remained the same throughout all of the databases being:

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"augmented reality" AND "air traffic control"
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The search results accounted to 135 papers in all databases. The distribution can be reviewed through Table 1.

The search terms were chosen to be this narrow to focus on the ATC aspect instead of including other research fields like AR in cockpits or AR in A/C production. The goal was to find the type of paper specifically, that focused on the AR part of new design approaches for ATC.

The resulting 135 publications were reviewed by first, reading each title of the paper and discarding the ones that did not fit into the category at all. This step was done very reluctantly to not discard any useful information. If I wasn't sure whether to keep the paper in scope, I read the abstract and decided using my own interpretation of the topic of each publication. After filtering by the title and abstracts 25 papers remained. Lastly, selected parts (e.g. concluding sections, introductions, etc.) were analyzed and the amount of papers were reduced to 16 by discarding a portion again. The remaining 16 papers were then read and summarized individually to get a better scope of the problems and advantages of AR in ATC. There were also two papers added later on. The first [6] was referenced by [2] to further understand the distribution of responsibility between operators and machines, but I could not fully connect the paper's statements to the reference it lead to. Instead, I searched for the source of the statement using the Google search engine and the search term:

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human factors committee us national research council
 loa decision-making action implementation
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The second search result lead me to www.researchgate.net where I found the paper with the original statements and findings I was looking for [16] and added it to my selection of now 18 publications. I did not study both of the papers [6, 16] thoroughly, since they are not part of the "AR in ATC" research field and literature, and only served for additional data.

Notably, within the 16 original papers only three of them did not feature a prototype in any way. It was hard for me to distinguish between the number of prototypes used, because sometimes it was the same team with the same or similar prototype, working for another organisation. But I could conclude that within the selected publications, at least six different prototypes were built, tested and/or discussed.

3 AUGMENTED REALITY USE CASES

According to [13] the first AR system using live radar data had been studied at Moffett Tower, California in 2005, but there are far earlier approaches to AR in aerodrome towers; such as electronic paper strips and projection systems, which will be discussed in the following among other types of AR tools that were described in the retrieved publications.

3.1 Electronic Paper Strips

The earliest record I found of a study about an AR prototype regarding ATC was from 1998, which already used a variety of systems but introduced a new kind of augmented paper strips.

These paper strips were augmented using embedded resistors with different resistances in the plastic holders, so the digital system would know the location of each individual paper strip on the strip board and was able to display additional information next to the paper strip [9, 10].

3.2 Projecting Information onto Strip Board

In the same studies, which featured the electronic paper strips [9, 10], projectors were already being tested to be a viable option to project dynamic information onto static paper. But even though the projection technique was mentioned a lot in the context of electronic documents and augmented paper [5, 7, 9, 10, 18], interestingly only the oldest paper raises the concern of blocking the light source of the projector with body parts or similar [10].

3.2.1 Digital Pens. All of the prototypes that featured a projection system also used some kind of digital pen. One of the first prototypes implemented a graphics tablet solution, where a standard pen input signal was used [10]. Another prototype called Ariel used a barcode reader to identify drawings [9]. While this prototype was not aimed at ATC, it was part of a paper which offered augmented paper solutions for ATC as well. The prototype called Strip'TIC uses an infrared digital camera to locate itself on the strip board and send this information to the AR system [5, 7, 18].

3.3 Monitoring Data on see-through Displays

There was only one prototype that wasn't aimed specifically at Head Mounted Displays (HMDs). The particular study used a tower simulator which already emulated the outside view of a tower using displays. The study conveniently placed their Computer Generated Imagery (CGI) on top of the simulator's image of the outside world to emulate the experience of AR without being bound to an HMD to focus more on the visual modality [3].

3.3.1 Head-mounted Displays. Apart from this single occurrence, which doesn't contradict the use of an HMD, all other prototype papers used some form of HMD. While some only described a concept of such a system [2] and other studies had fully functional prototypes to test with [11–15]. Especially an HMD from NASA was studied thoroughly regarding the field of view (FOV) and its importance in an ATC context [15].

4 RISK ASSESSMENT OF AUGMENTED REALITY IN ATC

As stated in [1]: "risk assessment starts with the identification of what can go wrong". And in novel technologies like AR, a lot can go wrong. AR is a very interesting tool, because it challenges the user in a completely different way. Thus, new fail scenarios can occur that cannot be assessed with more traditional fault taxonomies. To oppose the missing elements, researches of the School of Innovation, Design and Engineering in Sweden, proposed to extend an already existing metamodel which targets socio-technical systems called SafeConcert [1]. But there are far more failure scenarios than are worth mentioning here, so I will refer only to the ones that stood out to me.

4.1 Do-It-All Systems

When introducing new technologies and/or approaches we need to be careful not to implement it everywhere. Especially in a safety critical environment like ATC, a system capable of juggling multiple tasks at once seems tantalizing, but is usually prone to failure.

4.2 Automated Decision-Making

To eliminate sensory and machine errors, the decision-making and action implementation should always be the responsibility of a human being, so every data will go through a human filter of experienced ATCOs. This conforms to the statement that in ATC only the information acquisition and analysis should be automated on a high level, compared to the decision selection and action implementation [16].

4.3 Loss of Tacit Information

While workflows are getting improved and updated, it is essential to remember the subconscious information that might get lost when interactions between humans are replaced by machines. It is crucial for the ATCO to be able to quickly assess the pilot's condition and react accordingly. This cannot be done with current technology, especially to the extent that an ATCO is capable of listening to two conversations at once or pick up on his colleague's insinuations [4].

4.4 Impossibility of Non-Standard Work Practices

According to [4], controller's work practices can be divided into two main categories: a standard and a non-standard work practice. While the standard work practice promises high security, especially in high traffic density situations, the non-standard work practice offers high efficiency with low traffic density. There are controllers who only practice the standard procedures and others who sometimes work on their own, but they all default to the standard practices as soon as the traffic gets denser, since the standard workflow showed to be mentally less demanding [4].

4.5 Low Tracking Update Rates

Latency between the position of the A/C and its digital representation were observed to be above two seconds [14]; this might not be enough for accurate positional tracking, especially close to ATCTs.

5 RESULTS AND DISCUSSION

5.1 Results

Even simpler AR concepts are often not easily implemented, like the AR display concept for ATCOs showed that even displaying relevant information on an HMD, similar to an additional display, faces challenges. One of these challenges is over-cluttering of information, i.e. displaying multiple lines of text on top of each other. The readability of the text decreases drastically resulting into the AR HMD being not usable for the safety critical nature of ATC [2].

In contrast, there are lots of opportunities for AR to help ATCOs in their everyday workflow. Tavanti describes a list of potential benefits of AR [17] that contains, but is not limited to, the following:

- Allowing an extent of weather independence due to reduced air traffic density
- Improved visibility, therefore reducing the number of visual sources needed
- Centralized info, leading to increased awareness and reduced mental effort
- Potential of missing critical events decreased in proportion to Head Down Time (HDT)

The mentioned HDT is a large topic mentioned among many papers that contained the risks of usual ATC workflows [1–3, 6, 17]. Between 51 and 57% of the working hours of an ATCO are spent with the head down [6]. Important visual cues and critical situations might be recognized too late or missed entirely. To combat this issue, NASA researched several HMDs to gain knowledge about how different degrees of FOV influenced the performance of ATCOs. They suggest that using an FOV of 47° or greater will compromise the abilities of an operator only in a minor manner [15].

And while this seems to be specific information that usually emerges over an extended period of research, this particular paper of the NASA was published in 2002. Only three years after the first paper, to my knowledge, about the proposal of augmented paper in ATC [8]. "Is Paper Safer?" [8] is a very well known publication about the different types of analog and digital systems and concepts used in ATC and while it does not conclude its self-imposed question into a single answer, it suggests that the radical change in work practice and the elimination of paper strips might be the wrong approach.

Over two decades later, another publication studied the "Changes and Similarities in Air Traffic Control Work Practices" [4]. Now, with paperless systems implemented, the study shows that the documentation speed with digital flight strips is faster than the analog approach [4]. But even after decades of evolving tools and practices, the radio communication remains to be a bottleneck [4]. All of the pilot's interactions with the ATCT get funneled into one lane of communication, resulting in less multitasking possibilities, therefore leading to a lower efficiency. Automating this part of the interaction is not feasible due to the potential loss of tacit information that is exchanged between operators and pilots [4].

Instead, ATCOs reviewed multiple AR prototypes and concepts and often mentioned their usefulness and benefits for ATC [2, 3, 5, 10, 12]. Especially AR systems, like the already described electronic flight strips and digital pens for selecting A/C on radar or strips, were rated as very useful [5, 10]. Other parts of certain prototypes, however, were heavily criticised. Such as impractical prototypes that visually impaired [12] or over-cluttered [2] the operator. Additionally, the data that was delivered to the AR tools wasn't consistently reliable and caused the risk of over-trust [2, 3]. Which could also be due to low update rates of the positional tracking systems that took in some cases 4.8 seconds to update the CGI of the AR interface [12]. Whenever projectors were used in prototypes, the argument, that operators could easily block the light source of the projection, was quickly made by the ATCOs [10] and was stressed to be not usable as an AR implementation.

Some ATCOs expressed additional concerns that weren't always part of the researchers' respective study. Precise and reliable head tracking and FOV requirements were among these demands [2].

Generally, AR seems to be a viable option to increase situational awareness [3], but to further interpret these results they will be discussed in the next section.

5.2 Discussion

It is not possible for me to give an exact number on how many ATCTs use paper today, due to the lack of empirical data, but it is a concept that seems to have moved far into the background during the last two decades [4]. Although even modern systems still use representations and workflows similar to the analog systems, the world of modern air transport has gone digital. This poses questions, such as whether electronic flight strips or projected AR tools are even justifiable in the present. I would argue, that while the electronic flight strips were perceived very positively by ATCOs [10], they would reintroduce old systems and might lead to regressions in air traffic systems. Although, tangible AR interfaces proved themselves as useful in the past, there is not enough data to support any claims in this direction.

On the other hand, systems that are able to centralize all of the important data into the FOV of an ATCO seem like a very good option to reduce the mental effort needed to make important decisions and educated guesses that are sometimes needed in ATC. AR glasses should deliver these types of capabilities rather soon, especially with next-gen interfaces.

There is a drawback, though. Over-cluttering is a constant problem [2], specifically with smaller display areas. Therefore I would argue that while the potential of AR HMDs is very important to the work of an ATCO, the goal of an AR HMD should not be to replace a system or change it in any way. I would advise to rather duplicate the most crucial information of the "inside area" of an ATCT and place it inside the FOV of the operator looking outside of the tower's windows; refocusing the attention of the ATCO onto the airport runway and reducing the HDT. This should improve the workplace environment by reducing mental efforts to gather information. This part of system benefits is sometimes overlooked, since the speed of the operation is not altered in a significant way, but it introduces less stress for the operators and should therefore contribute positively to the system safety.

Having this context in mind, I agree with [4] to answer the question "Is Paper Safer?" [8] negatively. While this does not contradict arguments into the direction of tangible user interfaces, the next step in the development of AR tools for ATC should be centralizing and speeding up the process of information gathering for the ATCO to quickly make decisions and implement actions based on the data delivered by the system. The more convenient, the better. Especially systems with abilities to issue warnings will be essential for the safety critical nature of ATC.

Another key argument is the level of automation that would be introduced by new systems. As mentioned before, the decision-making and action implementation should always be the responsibility of a human being. ATCOs use multiple sources of data, such as flight plans, radar, digital flight progress strips and more to assess situations and react accordingly. The assessment is based on standard procedures, experience and educated guesses, but the sources of data might not be reliable. Sensory errors are a possibility that must always be considered, which is currently not possible to my knowledge. This is why it's suggested to only highly automate the information acquisition and analysis, but refrain from any decision selection or action implementation automation. The human filter is crucial for the safety of the A/C and their passengers.

6 CONCLUSION

I choose to answer the self-imposed question "Could Augmented Reality take over Air Traffic Control?" positively, since the literature revolving around this topic showed to be consistent in the matter of whether AR might be used in ATC in the future [2, 3, 5, 10, 12].

But this systematic literature review also revealed that there is still a great need for further studies in this area. The latest study I found that featured a new prototype in this matter is from 2016, while AR technology has already reached the consumer market.

Especially the implementation of AI, while contradicting some of the statements concerning automation levels [16], could introduce new facets as to suggesting recommended action implementations to ATCOs and should be explored.

During the review I discovered that AR in ATC was a far earlier concept than I expected, with a publication describing a prototype in 1998 [10], but this only amplifies the call for new research around this topic due to the low number of prototypes and the few empirical studies within the last two decades.

AR in ATC is a missed opportunity that could enhance the workflow of operators of aerodrome towers, increase the safety of passengers, pilots and airport personnel and potentially save lifes.

REFERENCES

[1] S. S. Bahaei and B. Gallina. 2019. Extending SafeConcert for Modelling Augmented Reality-equipped Socio-technical Systems*. In *2019 4th International Conference on System Reliability and Safety (ICSRS)*. IEEE, School of Innovation, Design and Engineering, Mälardalen University, Västerås, Sweden, 275–282. https://doi.org/10.1109/ICSRS48664.2019.8987702

[2] H. Gürlük. 2016. Concept of an adaptive augmented vision based assistance system for air traffic control towers. In *2016 IEEE/AIAA 35th Digital Avionics Systems Conference (DASC)*. IEEE, German Aerospace Center (DLR), Braunschweig, Germany, 1–10. https://doi.org/10.1109/DASC.2016.7777975

[3] H. Gürlük, O. Gluchshenko, M. Finke, L. Christoffels, and L. Tyburzy. 2018. Assessment of Risks and Benefits of Context-Adaptive Augmented Reality for Aerodrome Control Towers. In *2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC)*. IEEE, German Aerospace Center (DLR), Institute of Flight

Guidance, Braunschweig, Germany, 1–10. https://doi.org/10.1109/DASC.2018.8569859

[4] Stephan Huber, Johanna Gramlich, and Tobias Grundgeiger. 2020. From Paper Flight Strips to Digital Strip Systems: Changes and Similarities in Air Traffic Control Work Practices. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW1, Article 028 (May 2020), 21 pages. https://doi.org/10.1145/3392833

[5] Christophe Hurter, Rémi Lesbordes, Catherine Letondal, Jean-Luc Vinot, and Stéphane Conversy. 2012. Strip'TIC: Exploring Augmented Paper Strips for Air Traffic Controllers. In *Proceedings of the International Working Conference on Advanced Visual Interfaces* (Capri Island, Italy) *(AVI '12)*. Association for Computing Machinery, New York, NY, USA, 225–232. https://doi.org/10.1145/2254556.2254598

[6] Toshiyuki Inagaki. 2001. Adaptive Automation: Sharing and Trading of Control. *The Proceedings of the Transportation and Logistics Conference* 2001.10 (12 2001). https://doi.org/10.1299/jsmetld.2001.10.79

[7] Catherine Letondal, Christophe Hurter, Rémi Lesbordes, Jean-Luc Vinot, and Stéphane Conversy. 2013. *Flights in My Hands: Coherence Concerns in Designing Strip'TIC, a Tangible Space for Air Traffic Controllers*. Association for Computing Machinery, New York, NY, USA, 2175–2184. https://doi.org/10.1145/2470654.2481300

[8] Wendy E. MacKay. 1999. Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control. *ACM Trans. Comput.-Hum. Interact.* 6, 4 (Dec. 1999), 311–340. https://doi.org/10.1145/331490.331491

[9] Wendy E. Mackay. 2003. The Missing Link: Integrating Paper and Electronic Documents. In *Proceedings of the 15th Conference on l'Interaction Homme-Machine* (Caen, France) *(IHM '03)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/1063669.1063671

[10] Wendy E. Mackay, Anne-Laure Fayard, Laurent Frobert, and Lionel Médini. 1998. Reinventing the Familiar: Exploring an Augmented Reality Design Space for Air Traffic Control. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Los Angeles, California, USA) *(CHI '98)*. ACM Press/Addison-Wesley Publishing Co., USA, 558–565. https://doi.org/10.1145/274644.274719

[11] Ronald Reisman and Stephen Ellis. 2003. Augmented Reality for Air Traffic Control Towers. In *ACM SIGGRAPH 2003 Sketches & Applications* (San Diego, California) *(SIGGRAPH '03)*. Association for Computing Machinery, New York, NY, USA, 1. https://doi.org/10.1145/965400.965426

[12] Ronald J. Reisman and David M. Brown. 2009. *Augmented Reality Tower Technology Assessment*. Technical Report 20110014045. NASA Ames Research Center, Moffett Field, CA, United States. 15 pages. https://ntrs.nasa.gov/citations/20110014045

[13] Ronald J. Reisman and Stephen R. Ellis. 2005. Air Traffic Control Tower Augmented Reality Field Study. In *ACM SIGGRAPH 2005 Posters* (Los Angeles, California) *(SIGGRAPH '05)*. Association for Computing Machinery, New York, NY, USA, 52–es. https://doi.org/10.1145/1186954.1187014

[14] Ronald J. Reisman, Steven K. Feiner, and David M. Brown. 2014. Augmented Reality Tower Technology Flight Test. In *Proceedings of the International Conference on Human-Computer Interaction in Aerospace* (Santa Clara, California) *(HCI-Aero '14)*. Association for Computing Machinery, New York, NY, USA, Article 8, 8 pages. https://doi.org/10.1145/2669592.2669651

[15] Joelle R. Schmidt-Ott, Stephen R. Ellis, Bernard D. Adelstein, Jimmy Krozel, Ronald J. Reisman, and Jonathan Gips. 2002. *Augmented Reality in a Simulated Tower Environment: Effect of Field of View on Aircraft Detection*. Technical Report 20030005687. NASA Ames Research Center, Moffett Field, CA, United States. 54 pages. https://ntrs.nasa.gov/citations/20030005687

[16] Thomas Sheridan and Raja Parasuraman. 2005. Human-Automation Interaction. *Reviews of Human Factors and Ergonomics* 1 (06 2005), 89–129. https://doi.org/10.1518/155723405783703082

[17] M. Tavanti. 2007. Augemnted reality for tower: using scenarios for describing tower activities. In *2007 IEEE/AIAA 26th Digital Avionics Systems Conference*. IEEE, Linköpings University, Dept. of Science and Technology (ITN), Norrköping, Sweden, 5.A.4–1–5.A.4–12. https://doi.org/10.1109/DASC.2007.4391928

[18] Jean-Luc Vinot, Catherine Letondal, Rémi Lesbordes, Stéphane Chatty, Stéphane Conversy, and Christophe Hurter. 2014. Tangible Augmented Reality for Air Traffic Control. *Interactions* 21, 4 (July 2014), 54–57. https://doi.org/10.1145/2627598