Chapter

Applications of Mixed Reality for Smart Aviation Industry: Opportunities and Challenges

Trung Hieu Tran, Yirui Jiang and Leon Williams

Abstract

Nowadays, mixed reality has improved operational efficiency and enhanced passenger experience in the aviation industry. Integrated with advanced machine learning and artificial intelligence techniques, mixed reality can easily deal with tons of aviation data to support decision-making processes in this industry. The chapter presents the state-of-the-art applications of mixed reality in smart aviation industry. Opportunities and challenges of integrating mixed reality with advanced machine learning and artificial intelligence techniques into the aviation industry are introduced. This chapter focuses on how the integrated mixed reality can improve the quality and reliability of maintenance, operation, piloting, training, and product design in smart aerospace engineering. It also describes autonomous, self-service, and data visualization systems in smart airports to enhance passenger experience. Finally, this chapter discusses airline's digital-based responses to the COVID-19 crisis.

Keywords: artificial intelligence, aerospace engineering, machine learning, mixed reality, passenger experience, smart aviation

1. Introduction

Along with the contribution of technology, data science (e.g., machine learning and artificial intelligence techniques) and mixed reality have brought much benefit into intelligent industrial revolution [1–3]. One of their significant impacts is to redefine the business models in intelligent aviation industry. In the aviation industry, mixed reality-based applications such as digital twin, aerospace design, manufacturing, verification, validation, and services have been widely implemented [4]. In addition, applications of smart visualization, mobility, robotics, and analytics were developed and integrated into the passenger journey [5].

Airlines have used mixed reality not only for efficiency improvement of staff operations but also for maximization of passenger satisfaction. For example, airlines are experimenting with mixed reality in smart maintenance in which repair works are transformed from manual to digital assistant to increase the efficiency of maintenance operation [6]. When applying mixed reality for training, virtual instructions are overlaid on physical items, allowing employees to gain hands-on experience [7]. For market, airlines use mixed reality for indoor navigation, advertising recommendations,

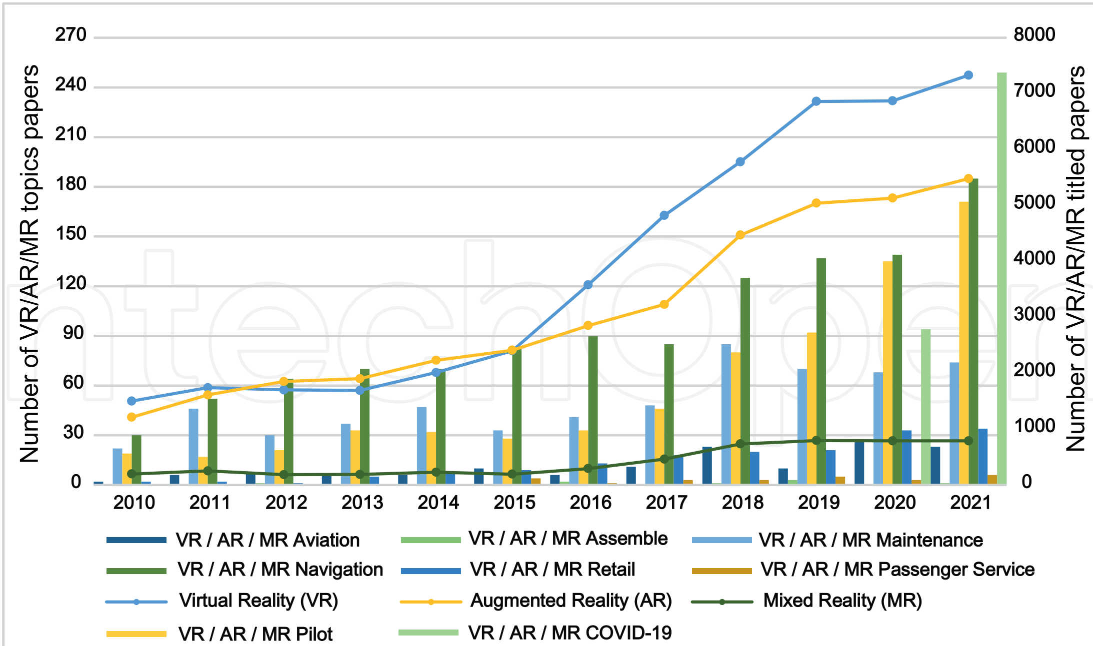

Figure 1.
The evolution of VR/AR/MR applications during the period of 2010–2021.

information notification, and immersive entertainment [8, 9]. Toward an automation industry, there is no doubt that mixed reality can transform the aviation industry by accelerating operator efficiency, developing staff skills, and improving the passenger experience.

The chapter provides a comprehensive review of existing works to understand the integrated mixed reality opportunities and challenges in the intelligent aviation industry. The keywords such as virtual reality (VR), augmented reality (AR), mixed reality (MR), VR/AR/MR aviation, VR/AR/MR design, VR/AR/MR assemble, VR/AR/MR maintenance, VR/AR/MR pilot, VR/AR/MR navigation, VR/AR/MR retail, VR/AR/MR passenger service, and VR/AR/MR COVID-19 were used to capture the most relevant literature published over the last decade from academic databases. Hundreds of papers that applied mixed reality for the aviation industry are then selected to review in the chapter. In addition to the opportunities and challenges of mixed reality in the smart aviation industry, the chapter also discusses a roadmap for intelligent aviation's future and the role of digital technologies in overcoming COVID-19 challenges. **Figure 1** shows that the number of papers published on VR/AR/MR has significantly increased over the last decade. It can be seen that the number of such papers has strongly developed since 2015 when the VR/AR/MR concept gradually received public attention, and its enormous potential for future development is widely acknowledged. Research works that proposed VR/AR/MR solutions to deal with the challenges of COVID-19 have also been concerned since 2020.

The rest of the chapter is structured as follows: Section 2 reviews MR-based aerospace engineering applications. Section 3 discusses how to apply MR to improve the passenger experience. Section 4 presents digitalization solutions implemented during and after COVID-19. Finally, Section 5 provides conclusions and future works.

2. Mixed reality for smart aerospace engineering

MR plays an integral role in the product design stage of manufacturing. Advanced interfaces and visualization systems are developed for product design, complex assembly, accurate maintenance, assisted piloting, and staff training. Engineers leverage MR to rapidly make improvements and changes before the product goes into manufacturing. Product designers overlay digital features onto the physical product and adjust it accordingly [10]. MR can thus shorten the development cycle and reduce the associated cost. For example, designers create a visualization of product hypotheses and prototypes and overlay virtual embodiment onto the real environment [11]. Engineers can interact with their designs using immersive tools to create a convincing product lifecycle [12]. The PJSC Scientific and Technical Council has recently created two VR sets and two mobile applications that received the highest rating and were recognized by aircraft simulator manufacturers, educational institutions, and aircraft operators [13].

Other application of MR in smart aerospace engineering is to assemble thousands of parts accurately and quickly [14]. Traditionally, manual instructions are painstakingly studied and constantly referred to as product assembly. Since the introduction of MR, detailed 3D instructions for hands-free and voice-controlled operations are provided to support product assembly efficiently [15]. Although installing electrical wires on an aircraft is an impossible task that requires zero error, interactive 3D wiring diagrams have made it possible [16, 17]. Airlines developed AR to provide technicians with hands-free, real-time 3D interactive wiring systems. Engineers' works have also been altered by MR. 3D manufacturing can improve 90% in first-time quality and reduce 30% in time cost than 2D manufacturing [18–20]. Gattullo et al. [21] reviewed 1757 papers to study the benefits of industrial augmented reality (IAR) in assembly, to demonstrate how MR can support manipulation, inspection, and positioning, and to build future research directions. Lai et al. [22] created a worker-centric system that uses Faster R-CNN in MR-based mechanical assembly. With CAD models as datasets, the authors successfully deployed the system for detecting simple tools. Hořejší et al. [23] compared MR-based instruction with traditional assembly one on 60 subjects. Staff turnover and proficiency can be improved by converting complex assembly manuals into on-screen virtual instructions. Alves et al. [24] compared the requirements, performance, and user satisfaction of various MR application products (i.e., handheld mobile AR, indirect AR that displays augmented scenes on a monitor, and see-through head-mounted displays) during assembly in a variety of industrial scenarios. Through 30 participants, user preference aspects, the advantages and disadvantages of each method, and the potential benefits of specific use cases were reported.

MR-based maintenance enables faster and more accurate operations [25, 26]. Mechanics have traditionally relied on paper manuals to assist with thorough maintenance. MR overlays instructions on top of the actual product, allowing operators to see machine status in real-time [27]. Quality screenings are essential for product maintenance. Identifying problems early on is beneficial for reducing machine downtime, and associated costs incurred by airlines [28]. On the other hand, human-based defect detection cannot guarantee optimal quality assurance because human errors are unavoidable. MR-based projects overlay over the product, allowing defects and inefficiencies to be identified with high accuracy and speed [29]. Maintenance technical documentation is becoming more visual. The most common maintenance operations in the manuals are integrated into remote maintenance support applications. Scurati et al. [27] created a glossary of graphic symbols to use in mixed reality. Mourtzis et al. [30] designed an AR-based remote maintenance framework that allows technicians and engineers to use real-time feedback by creating appropriate communication channels. The applicability of the developed framework was tested in the laboratory and real-world industrial scenarios with good performance. Verde et al. [31] combined the Internet of Things (IoT) and MR to create a dependable predictive maintenance system for off-site service. With IoT, engineers can share diagnostic information, and experts can monitor and guide maintenance operations remotely via the controller. Heterogeneous sensors integrated with AR visualization can improve operator safety in complex and dangerous plants. Liu et al. [32] proposed a multi-service collaborative machine intelligence predictive maintenance approach for fault prediction that combines CNN and LSTM. MR guides the visualization through the maintenance process, integrating massive amounts of data into the machine. Runji et al. [33] reviewed advanced MR research in manufacturing maintenance, focusing on analyzing user needs in applications via ergonomics, communication, situational awareness, intelligence sources, feedback, safety, motivation, and performance evaluation.

MR is used not only for navigation on the ground but also for assisting pilots [34]. MR creates visuals of terrain, navigation, air traffic, weather, instruments, and airspace information by overlaying information on demand. The MR-based application provides situational awareness in a user-friendly 3D format. Furthermore, a head mount display (HMD) guides pilots during the flight, takeoff, and landing. The MR systems show a corridor overlay to display pilots the proper path, ensuring their safety from takeoff to landing. The air-traffic visualization aids pilots in keeping an eye on the traffic and so increases passenger safety [35, 36]. Extensive training is required for airline personnel before they work in a real-world environment. However, preset manual training is insufficient to meet operators' growing needs. MR is thus developed to support training operators. It enables them to gain practical experience. When training and execution are combined, the equipment is easier to learn and use [37, 38]. Remote MR assists in lowering training and execution costs. It gives experts a view through the technicians' eyes, allows remote expert support, and performs inspections without regard for distance. In addition, remote MR makes the support process highly convenient and significantly reduces travel costs [39, 40]. Han et al. [41] conducted a systematic review of MR-based professional training applications to assess their overall effectiveness. Kaplan et al. explored the effectiveness of VR, AR, and MR for training through a meta-analysis and identifies that MR-based training can achieve as similar results as the traditional methods, but with less than time and cost. Moesl et al. [42] used MR for advanced pilot training in turbine engine aircraft and detailed the most challenging elements of the course that can be addressed with AR. A survey of 31 pilots and 22 instructors was conducted to evaluate MR-based pilot training tools thoroughly. To help pilots learn new flight panel layouts for different aircraft, Füchter et al. [43] developed MR as a human-machine interface for training. The system employs Human Centered Design (HCD), integrating a multi-disciplinary process involving flight instructors, students, and pilots, and has been tested in Brazil with positive user feedback. These MR applications show that it has the potential to transform aerospace engineering procedures toward reliant automation in the future.

3. Mixed reality for passenger experience enhancement

At the present, airports have implemented several initiatives to accelerate the development of commercial MR services in the aviation industry. HMD provides passengers with customized audio-visual options as the virtual entertainment market expands. Indoor navigation and sign guides based on MR technology significantly improve passenger travel efficiency. Passengers can see advertisements and targeted recommendations while walking. The virtual tags allow for faster baggage claims and reduce mishandled baggage. Real-time live dashboards display waiting times, flight arrangements, and weather information for passengers. The use of boarding reminders and real-time notification systems reduces the number of missed flight events and makes passengers feel more at ease at airports. Such MR-based initiatives demonstrate that the era of MR applications for improving passenger experience has arrived. **Figure 2** illustrates how airports utilize digital and MR to improve passenger experience.

Traditionally, airports installed beacons in terminals to provide passengers indoor navigation services that help new passengers navigate easily. However, this method is unreliable [44]. Recently, AR wayfinding displays directional prompts by superimposing digital information onto a real-world setting. It is a visual treat that makes life easier for visually impaired passengers by improving turn-by-turn audio prompts. An MR navigation system can locate late-running passengers and send them text reminders [45]. An AR-powered navigation app can even display points of interest along the way. The merchants send promotional messages to nearby passengers, informing them of current ongoing promotions. The app collects passenger information to create "people density" map in different areas that support airport queuing management by directing passengers to a less congested area. Passengers can use MR navigation to get through the airport quickly, accurately find their way, and avoid missing their flight. At the same time, it improves passenger flow management efficiency, promotes consumption, and increases airport and retail store revenue. [46] investigated the application of MR-based indoor positioning technology in airports and train stations. ARBIN was created to help passengers navigate through a user interface and navigation commands. The system was tested on nearly 1800 m^2 in 35 destinations and points of interest. The system performed very well and proved to be a practical indoor

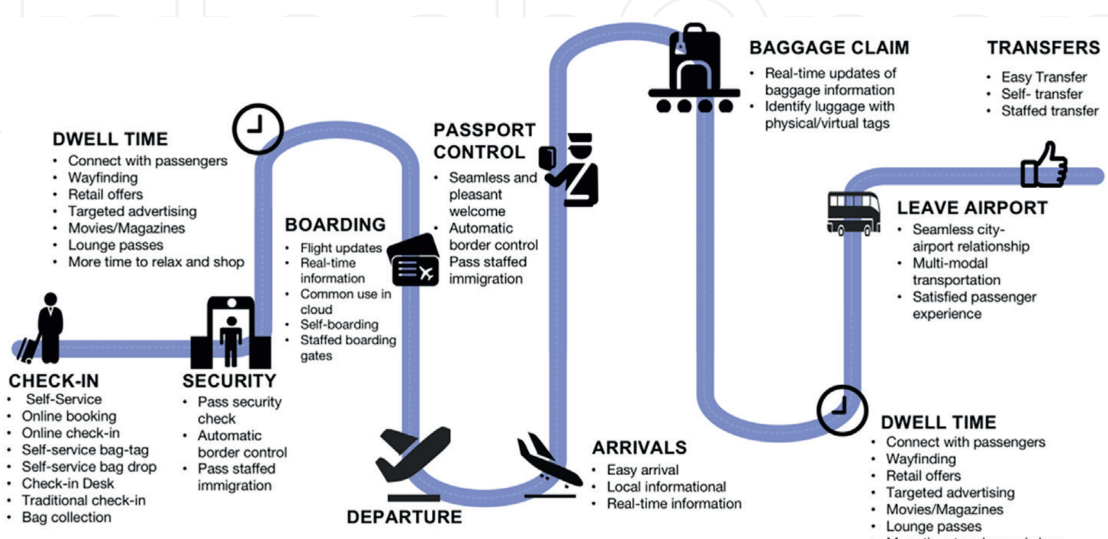

Figure 2.
The application of digital and MR to the entire airport passenger journey.

navigation solution for large buildings. [47] made it easier for visually impaired people to navigate in indoor environments. The app "Clew" provides intuitive guidance along a route by recording the user's previous route and then using haptics and voice. Ayyanchira et al. [48] developed a collaborative, cross-platform, real-time MR-based navigation system. The system uses visualization and interactive methods to support common tasks in buildings through device sensors and image markers. Gladston and Duraisamy [49] developed an indoor navigation solution based on computer vision and MR to assist navigation for users in any new or unknown environment.

Retail contributes significantly to airport revenue. MR retail boosts in-store and online sales and alters customer purchasing habits. Customers, for example, can make better decisions with virtual try-on for wearable products, eliminating the need to measure and verify dimensions [50]. Nike customers are able to try on different colors and finishes in an immersive environment. It makes shopping more exciting and enjoyable. MR retail increases customer satisfaction while decreasing product returns. AR in retail has effectively converted potential leads by increasing engagement. The use of MR features allows the audience to interact with products. Customers can scan AR markers on print advertisements to access interactive augmented videos rather than plain old print ads. In addition, AR wayfinding can be combined with retail advertisements. Airports, for example, can show passengers the best shops along their route. Airports direct passengers through the airport based on their preferences and previous purchasing habits. Airports, for example, provide information on various product prices and guide customers to the correct location with guided arrows. According to recent research, MR is inspiring new traveler engagement. [51] presented a systematic literature review of MR retailing, analyzing technical features, user behavior, and experience. Tan et al. [52] outlined four broad usages of MR in the retail environment, assessing the potential of such applications and empirically examining their impact on sales. Janssen [53] tested MR-based shopping app as a solution for retailers to engage consumers and enhance their shopping experience. The study investigates consumer acceptance of mobile AR (MAR) shopping apps using the Technology Acceptance Model (TAM) and potentially external factors.

Airport incidents such as lost baggage or missed flights have received much attention by passengers. Implementing MR in airports has not only improved customer experience but also been beneficial in generating a return on investment (ROI). Before passengers boarding, airports use MR systems to notify them of the best boarding time and direct them to the right gate. Gatwick Airport deployed AR to provide personalized flight updates to travelers with a frictionless experience. Despite the importance of baggage in the passenger journey, baggage operations in airports continue to have many flaws [54, 55]. Many airlines are working to improve their baggage handling procedures. Singapore's Changi Airport uses smart glasses for baggage handling. Staff can instantly scan QR codes on baggage and cargo containers to obtain weight and unit data. MR has reduced the loading time from 60 to 45 minutes. MR has really increased the efficiency of airport operations, delivered more streamlined experiences, and, ultimately, provided more enjoyment for passengers.

4. Opportunities and challenges during and post COVID-19

Digital technologies are critical in assisting airports' recovery worldwide following the COVID-19 crisis. Most airlines are undergoing a digital transformation, resulting in cost savings, increased productivity, automation, streamlined operations, and

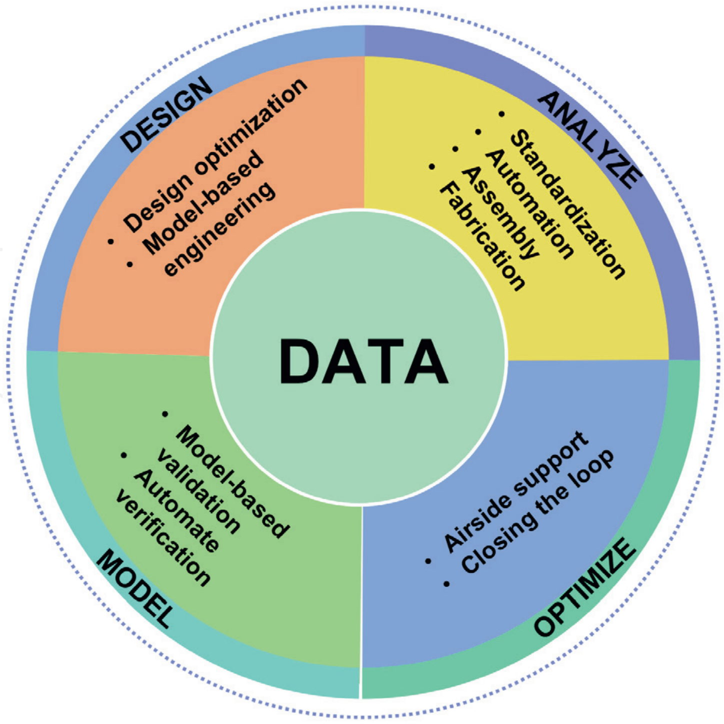

Figure 3.
The application of digitalization in the aviation industry.

reduced risk to smart airports [56]. **Figure 3** shows how to fully utilize data to drive the digital transformation of the aviation industry after COVID-19.

The length of time passengers spend at airports is critical in reducing the possibility of pandemic infections. Airlines are attempting to achieve seamless, touchless, and frictionless travel [57, 58]. Online ticketing, seat selection, and check-in reduce contact and queuing time. Automated check-in and boarding, self-service systems such as biometric enrollment, facial recognition, and finger scanning are applied. To reduce passenger anxiety, airports deploy notification systems to communicate with passengers and provide real-time traffic information. The airports can use mobile app to optimize queuing management and maintain a safe distance between passengers.

During the COVID-19 crisis, health screening and certificates are special operations [59]. To assist customer service representatives, airports use the web, mobile, social media, kiosk, email, smartphone apps, and chatbots. Each passenger's health is digitally recorded, and machine learning is used for abnormal data identification, identifying infected suspects in real time. Real-time data analytics ensure that potential patients are not overlooked. In addition, data science manages airport sanitization, ensuring high hygiene standards, which decreased human intervention and increased fidelity, accuracy, and observations.

Although airports will incur short-term losses during COVID-19, renewed digital aviation investments will increase long-term benefits [60]. It is not only necessary to promote airport digitization, but also to prioritize environmental protection [61, 62]. Passengers' modes of transportation to and from the airport have significantly changed in recent years. Airports need to prepare for an increase in passenger traffic in the future and a faster recovery of the leisure passenger segment [63]. Public airport transportation necessitates substantial support, such as route subsidies [64, 65]. Commercial air taxi services have been expanded at some airports. The Volocopter completed the first human-crewed flight over Singapore. Boeing, Bell, Embraer, Safran, Uber, Fraport, and Groupe ADP, among others, have announced plans for urban air mobility solutions. Airports are working together to reduce their environmental impact.

An innovative travel ecosystem has emerged in the air transport industry. Based on WHO and UNWTO guidelines, Mohanty et al. [66] investigated the possibility of using MR to support the restart of tourism after COVID-19. The study explored the role of MR for social distance and lower mobility norms based on a systematic review of secondary data. Kerdvibulvech and Chen [67] summarized models and tools that use MR in responding to the COVID-19 crisis. For example, MR-based thermal imaging glasses are used to detect virus symptoms and passenger temperatures. Airport personnel is remotely trained by using MR educational applications. Priyan et al. [68] designed a MR-based standard operating procedure (SOP) for detecting and controlling social distance on a large scale. The application aims to help people control physical distance, accelerate social distance, and flatten the increasing case curve.

5. Conclusion

This chapter did a comprehensive review and provided a road map for MR applications in the intelligent aviation industry. Opportunities and challenges for implementing advanced MR in aerospace design, manufacturing, testing, and service are presented. MR technology helps smarter product design, safer assisted piloting, more flexible manufacturing, and more efficient staff training. The ongoing development of MR significantly impacts the passenger experience in the aviation industry, including visualized real-time information, AR wayfinding, virtual baggage tags, and AR retail. Furthermore, this chapter analyzed and discussed opportunities and challenges that the aviation industry can face during and after the COVID-19 pandemic. With the breathtaking array of new data-enhanced technologies, the aviation industry will open a new era of “touchless, seamless, and secure” operations and services in which the importance of machine learning and artificial intelligence techniques are concerned.

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References

[1] Zhu L, Yu FR, Wang Y, Ning B, Tang T. Big data analytics in intelligent transportation systems: A survey. IEEE Transactions on Intelligent Transportation Systems. Apr 23 2018;**20**(1):383-398

[2] Siegel JE, Erb DC, Sarma SE. A survey of the connected vehicle landscape—architectures, enabling technologies, applications, and development areas. IEEE Transactions on Intelligent Transportation Systems. 4 Oct 2017;**19**(8):2391-2406

[3] Menouar H, Guvenc I, Akkaya K, Uluagac AS, Kadri A, Tuncer A. UAV-enabled intelligent transportation systems for the smart city: Applications and challenges. IEEE Communications Magazine. 13 Mar 2017;**55**(3):22-28

[4] Brunton SL, Nathan Kutz J, Manohar K, Aravkin AY, Morgansen K, Klemisch J, et al. Data-driven aerospace engineering: Reframing the industry with machine learning. AIAA Journal. Aug 2021;**59**(8):2820-2847

[5] De Crescenzio F, Fantini M, Persiani F, Di Stefano L, Azzari P, Salti S. Augmented reality for aircraft maintenance training and operations support. IEEE Computer Graphics and Applications. 2010 Dec 23;**31**(1):96-101

[6] Henderson SJ, Feiner SK. Augmented Reality for Maintenance and Repair (Armar). New York, USA: Columbia University, Department of Computer Science; 1 Aug 2007

[7] Eswaran M, Gulivindala AK, Kumar Inkulu A, Bahubalendruni MR. Challenges and opportunities on augmented reality-based guidance in product assembly and maintenance/repair perspective: A state of the art review. Expert Systems with Applications. 7 Oct 2022;**213**:118983

[8] Pucihar KČ, Coulton P. Exploring the evolution of mobile augmented reality for future entertainment systems. Computers in Entertainment (CIE). 2015 Jan 28;**11**(2):1-6

[9] Safi M, Chung J, Pradhan P. Review of augmented reality in aerospace industry. Aircraft Engineering and Aerospace Technology. 16 Jul 2019;**91**(9):1187-1194

[10] Shen Y, Ong SK, Nee AY. Augmented reality for collaborative product design and development. Design Studies. 2010 Mar 1;**31**(2):118-145

[11] Ng LX, Wang ZB, Ong SK, Nee AY. Integrated product design and assembly planning in an augmented reality environment. Assembly Automation. 23 Sep 2013;**33**(4):345-359

[12] Mourtzis D, Zogopoulos V, Vlachou E. Augmented reality supported product design towards industry 4.0: A teaching factory paradigm. Procedia Manufacturing. 1 Jan 2018;**23**:207-212

[13] Neretin ES, Kolokolnikov PA, Mitrofanov SY. Prospect for the application of augmented and virtual reality technologies in the design, production, operation of aircraft and training of aviation personnel. Journal of Physics: Conference Series. 1 Jun 2021;**1958**(1):012030. IOP Publishing

[14] Tang A, Owen C, Biocca F, Mou W. Comparative effectiveness of augmented reality in object assembly. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 5 April 2003. pp. 73-80

[15] Gavish N, Gutiérrez T, Webel S, Rodríguez J, Peveri M, Bockholt U, et al. Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. Interactive Learning Environments. 2 Nov 2015;**23**(6):778-798

[16] Yin X, Fan X, Wang L, Qiu K, Liu R. Augmented reality training system for aerospace product assembly process guidance and its application. Aeronautical Manufacturing Technology. 2018;**61**(1):48-53

[17] Wang X, Ong SK, Nee AY. A comprehensive survey of augmented reality assembly research. Advances in Manufacturing. Mar 2016;**4**(1):1-22

[18] Davies P, Sivich L. Augmented reality and other visualization technologies for manufacturing in boeing. SAE International Journal of Aerospace. 2011;**4**(2):1133-1139

[19] Barfield W, Caudell T. Boeing's wire bundle assembly project. In: Barfield W, Caudell T, editors. Fundamentals of Wearable Computers and Augmented Reality (1st ed.). Boca Raton: CRC Press; 1 Jan 2001. pp. 462-482

[20] Baird KM, Barfield W. Evaluating the effectiveness of augmented reality displays for a manual assembly task. Virtual Reality. 1999 Dec;**4**(4):250-259

[21] Gattullo M, Evangelista A, Uva AE, Fiorentino M, Gabbard JL. What, how, and why are visual assets used in industrial augmented reality? A systematic review and classification in maintenance, assembly, and training (from 1997 to 2019). IEEE Transactions on Visualization and Computer Graphics. 6 Aug 2020;**28**(2):1443-1456

[22] Lai ZH, Tao W, Leu MC, Yin Z. Smart augmented reality instructional system for mechanical assembly towards worker-centered intelligent manufacturing. Journal of Manufacturing Systems. 1 Apr 2020;**55**:69-81

[23] Hořejší P, Novikov K, Šimon M. A smart factory in a smart city: Virtual and augmented reality in a smart assembly line. IEEE Access. 14 May 2020;**8**:94330-94340

[24] Alves JB, Marques B, Ferreira C, Dias P, Santos BS. Comparing augmented reality visualization methods for assembly procedures. Virtual Reality. Mar 2022;**26**(1):235-248

[25] Palmarini R, Erkoyuncu JA, Roy R, Torabmostaedi H. A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing. 1 Feb 2018;**49**: 215-228

[26] Hincapié M, Caponio A, Rios H, Mendívil EG. An introduction to augmented reality with applications in aeronautical maintenance. In 2011 13th International Conference on Transparent Optical Networks. 26 June 2011 (pp. 1-4). IEEE.

[27] Scurati GW, Gattullo M, Fiorentino M, Ferrise F, Bordegoni M, Uva AE. Converting maintenance actions into standard symbols for augmented reality applications in Industry 4.0. Computers in Industry. 1 Jun 2018;**98**:68-79

[28] Ceruti A, Marzocca P, Liverani A, Bil C. Maintenance in aeronautics in an Industry 4.0 context: The role of augmented reality and additive manufacturing. Journal of Computational Design and Engineering. 1 Oct 2019;**6**(4):516-526

[29] Eschen H, Kötter T, Rodeck R, Harnisch M, Schüppstuhl T. Augmented

and virtual reality for inspection and maintenance processes in the aviation industry. Procedia Manufacturing. 1 Jan 2018;**19**:156-163

[30] Mourtzis D, Siatras V, Angelopoulos J. Real-time remote maintenance support based on augmented reality (AR). Applied Sciences. 8 Mar 2020;**10**(5):1855

[31] Verde S, Marcon M, Milani S, Tubaro S. Advanced assistive maintenance based on augmented reality and 5G networking. Sensors. 14 Dec 2020;**20**(24):7157

[32] Liu C, Zhu H, Tang D, Nie Q, Zhou T, Wang L, et al. Probing an intelligent predictive maintenance approach with deep learning and augmented reality for machine tools in IoT-enabled manufacturing. Robotics and Computer-Integrated Manufacturing. 1 Oct 2022;**77**:102357

[33] Runji JM, Lee YJ, Chu CH. User requirements analysis on augmented reality-based maintenance in manufacturing. Journal of Computing and Information Science in Engineering. 1 Oct 2022;**22**(5):050901

[34] Schaffernak H, Moesl B, Vorraber W, Koglbauer IV. Potential augmented reality application areas for pilot education: An exploratory study. Education Sciences. 2020 Mar 25;**10**(4):86

[35] Zollmann S, Hoppe C, Langlotz T, Reitmayr G. Flyar: Augmented reality supported micro aerial vehicle navigation. IEEE Transactions on Visualization and Computer Graphics. 24 Mar 2014;**20**(4):560-568

[36] Wu H, Cai Z, Wang Y. Vison-based auxiliary navigation method using augmented reality for unmanned aerial vehicles. In IEEE 10th International Conference on Industrial Informatics IEEE; 25 July 2012. pp. 520-525

[37] Macchiarella ND, Liu D, Vincenzi DA. 18 Augmented reality as a means of job task training in aviation. In: Hancock PA, Vincenzi DA, Wise JA, Mouloua M, editors. Human Factors in Simulation and Training (1st ed.). Boca Raton: CRC Press; 17 Dec 2008. p. 333

[38] Kaplan AD, Cruit J, Endsley M, Beers SM, Sawyer BD, Hancock PA. The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. Human Factors. Jun 2021;**63**(4):706-726

[39] Utzig S, Kaps R, Azeem SM, Gerndt A. Augmented reality for remote collaboration in aircraft maintenance tasks. In 2019 IEEE Aerospace Conference. IEEE; 2 March 2019. pp. 1-10

[40] Schneider M, Rambach J, Stricker D. Augmented reality based on edge computing using the example of remote live support. In 2017 IEEE International Conference on Industrial Technology. IEEE; 22 March 2017. pp. 1277- 1282

[41] Han X, Chen Y, Feng Q, Luo H. Augmented reality in professional training: A review of the literature from 2001 to 2020. Applied Sciences. 19 Jan 2022;**12**(3):1024

[42] Moesl B, Schaffernak H, Vorraber W, Holy M, Herrele T, Braunstingl R, et al. Towards a more socially sustainable advanced pilot training by integrating wearable augmented reality devices. Sustainability. 15 Feb 2022;**14**(4):2220

[43] Füchter SK, Schlichting MS, Salazar G. Aeronautic pilot training and augmented reality. Acta Imeko. 30 Sep 2021;**10**(3):66-71

[44] Huang H, Gartner G. A survey of mobile indoor navigation systems. In: Gartner G, Ortag F, editors. Cartography

in Central and Eastern Europe (1st ed.). Lecture Notes in Geoinformation and Cartography. Berlin, Heidelberg: Springer; 2009. pp. 305-319

[45] Kim J, Jun H. Vision-based location positioning using augmented reality for indoor navigation. IEEE Transactions on Consumer Electronics. 7 Oct 2008;**54**(3):954-962

[46] Huang BC, Hsu J, Chu ET, Wu HM. Arbin: Augmented reality based indoor navigation system. Sensors. 17 Oct 2020;**20**(20):5890

[47] Yoon C, Louie R, Ryan J, Vu M, Bang H, Derksen W, Ruvolo P. Leveraging augmented reality to create apps for people with visual disabilities: A case study in indoor navigation. In The 21st International ACM SIGACCESS Conference on Computers and Accessibility. 24 October pp. 210-221

[48] Ayyanchira A, Mahfoud E, Wang W, Lu A. Toward cross-platform immersive visualization for indoor navigation and collaboration with augmented reality. Journal of Visualization. Jun 2022;**25**:1249-1266

[49] Gladston A, Duraisamy A. Augmented reality indoor navigation using handheld devices. International Journal of Virtual and Augmented Reality (IJVAR). 1 Jan 2019;**3**(1):1-7

[50] Bonetti F, Warnaby G, Quinn L. Augmented reality and virtual reality in physical and online retailing: A review, synthesis and research agenda. Augmented Reality and Virtual Reality. 2018;**1**:119-132

[51] Riar M, Korbel JJ, Xi N, Zarnekow R, Hamari J. The use of augmented reality in retail: A review of literature. In Proceedings of the 54th Hawaii International Conference on System Sciences 5 January 2021 p. 638

[52] Tan YC, Chandukala SR, Reddy SK. Augmented reality in retail and its impact on sales. Journal of Marketing. Jan 2022;**86**(1):48-66

[53] Janssen C. Consumer Acceptance of Mobile Augmented Reality Shopping Applications in Stationary Retail Trade. Mid Sweden University, Faculty of Human Sciences, Department of Business, Economics and Law, Sundsvall and Östersund, Sweden; 2018

[54] Zhang T, Ouyang Y, He Y. Traceable air baggage handling system based on RFID tags in the airport. Journal of Theoretical and Applied Electronic Commerce Research. Apr 2008;**3**(1):106-115

[55] Singh A, Meshram S, Gujar T, Wankhede PR. Baggage tracing and handling system using RFID and IoT for airports. In 2016 International Conference on Computing, Analytics and Security Trends. IEEE; 19 December 2016. pp. 466-470

[56] Serrano F, Kazda A. The future of airports post COVID-19. Journal of Air Transport Management. 1 Oct 2020;**89**:101900

[57] Albers S, Rundshagen V. European airlines' strategic responses to the COVID-19 pandemic. Journal of Air Transport Management. 2020 Aug 1;**87**:101863

[58] Gössling S. Risks, resilience, and pathways to sustainable aviation: A COVID-19 perspective. Journal of Air Transport Management. 1 Oct 2020;**89**:101933

[59] Gold L, Balal E, Horak T, Cheu RL, Mehmetoglu T, Gurbuz O. Health screening strategies for international air travelers during an epidemic or

pandemic. Journal of Air Transport Management. 1 Mar 2019;**75**:27-38

[60] Adrienne N, Budd L, Ison S. Grounded aircraft: An airfield operations perspective of the challenges of resuming flights post COVID. Journal of Air Transport Management. 1 Oct 2020;**89**:101921

[61] Chaouk M, Pagliari R, Moxon R. The impact of national macro-environment exogenous variables on airport efficiency. Journal of Air Transport Management. 1 Jan 2020;**82**:101740

[62] Rolnick D, Donti PL, Kaack LH, Kochanski K, Lacoste A, Sankaran K, et al. Tackling climate change with machine learning. ACM Computing Surveys (CSUR). 8 Feb 2022;**55**(2):1-96

[63] Schultz M, Evler J, Asadi E, Preis H, Fricke H, Wu CL. Future aircraft turnaround operations considering post-pandemic requirements. Journal of Air Transport Management. 1 Oct 2020;**89**:101886

[64] Mandle PB, Mansel DM, Coogan MA. Use of public transportation by airport passengers. Transportation Research Record. 2000;**1703**(1):83-89

[65] Vuchic VR. Urban public transportation systems. Philadelphia, PA, USA: University of Pennsylvania; 5 Jan 2002;**5**(5):2532-2558

[66] Mohanty P, Hassan A, Ekis E. Augmented reality for relaunching tourism post-COVID-19: Socially distant, virtually connected. Worldwide Hospitality and Tourism Themes. 2 Dec 2020;**12**(2):753-760

[67] Kerdvibulvech C, Chen LL. The power of augmented reality and artificial intelligence during the COVID-19 outbreak. In International Conference on Human-Computer Interaction. Cham: Springer; 19 July 2020. pp. 467-476

[68] Priyan L, Johar MG, Alkawaz MH, Helmi RA. Augmented reality-based COVID-19 SOP compliance: Social distancing monitoring and reporting system based on IOT. In 2021 IEEE 12th Control and System Graduate Research Colloquium. IEEE; 7 August 2021. pp. 183- 188