

THE FUTURE OF AUGMENTED REALITY APPLICATION DEVELOPMENT TRENDS AND OPPORTUNITIES

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ABSTRACT

The future of augmented reality (AR) application development is being shaped by emerging trends and expanding opportunities across various industries. In this study, key advancements in AR technology, including artificial intelligence integration, cloud computing, and 5G connectivity, are examined. The increasing adoption of AR in sectors such as healthcare, education, retail, and manufacturing are highlighted, emphasizing its role in enhancing user experiences and operational efficiency. The challenges related to hardware limitations, data security, and user privacy are also discussed. A review of current development frameworks and platforms is conducted, showcasing the evolution of AR tools and their impact on accessibility for developers. The shift toward web-based and cross-platform AR solutions is explored, demonstrating the growing demand for seamless and scalable applications. Additionally, opportunities for innovation in AR content creation, user interaction, and enterprise applications are identified. Through an analysis of these trends, it is concluded that AR development will continue to evolve, driven by advancements in computing power, sensor technology, and user demand. It is suggested that collaboration between researchers, developers, and businesses will play a crucial role in overcoming existing barriers and unlocking the full potential of AR applications in the future.

Keywords: Augmented Reality, Artificial Intelligence, Internet of Things, Extended Reality.

1. INTRODUCTION

AR is being increasingly recognized as a transformative technology with the potential to reshape various industries. By overlaying digital information onto the physical world, AR applications are being utilized in sectors such as healthcare, education, retail, entertainment, and manufacturing. The growing demand for interactive and immersive experiences has driven significant advancements in AR development, allowing more sophisticated and accessible applications to be created [1]. Recent technological innovations, including artificial intelligence (AI), cloud computing, and 5G networks, are being integrated into AR systems, enabling enhanced performance, real-time data processing, and improved user experiences. The evolution of AR application development has been influenced by multiple factors, including the advancement of hardware, software, and user expectations. The development of AR headsets, smart glasses, and mobile devices has contributed to the widespread adoption of AR technologies. However, challenges related to hardware limitations, high development costs, and data security concerns are still being encountered. To address these challenges, improvements in AR development frameworks, programming tools, and cross-platform compatibility are being continuously explored. In recent years, the shift toward web-based AR applications has been observed, enabling greater accessibility and reducing the dependency on dedicated AR devices. Cloud-based solutions are being increasingly implemented, allowing seamless storage, processing, and sharing of AR content [2]. These advancements are facilitating the creation of AR applications that are not only interactive but also scalable and adaptable to various industries. Furthermore, the role of AI in AR applications is being expanded, with machine learning algorithms being used to enhance object recognition, scene understanding, and user interaction. Despite these advancements, several challenges must still be addressed to unlock the full potential of AR. Privacy concerns related to data collection and user tracking are being raised, necessitating the implementation of robust security measures. Additionally, user adoption is being influenced by factors such as ease of use, affordability, and application relevance. Research is being

conducted to improve the usability and effectiveness of AR applications, ensuring that they can be seamlessly integrated into everyday activities. As AR continues to evolve, new opportunities for innovation are being identified. The integration of AR with the Internet of Things (IoT), blockchain technology, and extended reality (XR) environments is being explored to create more advanced and interconnected digital experiences [3,4]. The use of AR in remote collaboration, virtual training, and e-commerce is being expanded, demonstrating its potential to enhance productivity and customer engagement. With the continuous development of AR technologies, industries are being presented with new possibilities for enhancing operations and creating immersive digital experiences. In this study, the latest trends and opportunities in AR application development will be examined. The challenges and potential solutions for improving AR technologies will be discussed, along with an analysis of emerging technologies that are expected to shape the future of AR. Through this exploration, insights into the evolving landscape of AR development will be provided, highlighting the key factors that will drive its growth in the coming years.

2. MATERIALS AND METHODS

A literature overview is being employed as the primary research method for this study to analyse the future trends and opportunities in AR application development. This approach allows existing research, technological advancements, and industry insights to be systematically reviewed and synthesized. By examining academic publications, industry reports, white papers, and case studies, a comprehensive understanding of AR development is being obtained [5]. Relevant sources are being selected based on their contribution to the field of AR, focusing on studies published within the last decade to ensure that the most recent advancements and emerging trends are included. Peer-reviewed journal articles, conference proceedings, and books are being analysed to explore theoretical and practical perspectives on AR technologies. Additionally, industry reports from leading technology firms and market research agencies are being examined to assess current market trends and potential future developments. The literature is being categorized into key themes, including AR hardware advancements, software development frameworks, AI integration, web-based AR applications, and security concerns [6,7]. Comparative analysis is being conducted to identify common patterns, challenges, and opportunities within the AR landscape. By synthesizing findings from multiple sources, an informed discussion on the future direction of AR application development is being presented.

2.1 Related work

AR is revolutionizing education by making learning more interactive and engaging. It enables students to visualize complex concepts through 3D simulations, enhancing their understanding and retention of information [1]. AR tools provide immersive learning environments that benefit students across various disciplines, including science, mathematics, and history [2]. Additionally, AR-based educational applications help bridge the gap between theoretical knowledge and practical implementation by offering real-time interactive learning experiences [3]. In healthcare, AR plays a crucial role in medical training, patient education, and clinical procedures. Medical students and professionals use AR for surgical simulations, allowing them to practice complex procedures in a risk-free environment [4]. AR applications assist doctors by overlaying critical patient information and real-time data during surgeries, improving precision and reducing errors [5]. Additionally, AR enhances patient education by providing visual demonstrations of medical conditions and treatment procedures, helping patients make informed decisions [6]. The integration of AR in industrial settings is improving productivity, safety, and operational efficiency. AR-powered smart manufacturing systems assist workers in assembly, maintenance, and quality control tasks by providing real-time guidance and visual instructions [7]. In Industry 4.0, AR is used for remote collaboration, allowing technicians to troubleshoot machinery issues without being physically present [8]. Moreover, AR-driven data visualization tools help industries monitor real-time analytics, optimizing workflow efficiency and minimizing downtime [9]. AR is transforming the retail sector by enhancing customer engagement and

personalizing shopping experiences. Many retailers now offer AR-powered virtual fitting rooms, enabling customers to try on clothes, accessories, and cosmetics before making a purchase [10]. AR applications allow consumers to visualize products, such as furniture and home appliances, in their real-world environment, increasing purchase confidence [11]. Brands are leveraging AR in marketing campaigns to create interactive advertisements and improve customer interactions, driving higher conversion rates and sales [12]. The automotive industry is utilizing AR for vehicle design, navigation, and driver assistance. AR-powered heads-up displays (HUDs) provide drivers with real-time navigation guidance, speed limits, and hazard warnings, enhancing road safety [13]. In motorsports, AR is being used for real-time performance analytics, helping drivers improve their racing strategies [14]. Similarly, AR is revolutionizing sports education and training by enabling athletes to analyse their movements, receive instant feedback, and improve their skills through immersive simulations [15]. Additionally, AR is enhancing fan experiences at sporting events by providing interactive stadium features, real-time player stats, and augmented live broadcasts [16].

3. DISCUSSION

Augmented reality is an enhanced version of the real physical world that is achieved through the use of digital visual elements, sound, or other sensory stimulus. There are many augmented reality use cases we'll see in the future like in the education field, marketing and sales, virtual assistance, automotive industry and the metaverse integration.

3.1. Education

Augmented reality offers numerous applications that enhance the learning experience, particularly for students who benefit from visual learning. One of its primary advantages is the ability to interact with 3D holograms, allowing students to examine virtual objects from multiple angles [8]. This capability significantly improves the understanding of complex subjects such as biology, anatomy, cosmology, and geometry. By visualizing 3D models, students can explore intricate details that would otherwise be difficult to grasp using traditional learning methods. AR has the potential to revolutionize history education as well, enabling students to visualize historical events through interactive holograms and simulations. Instead of merely reading about past events, learners can engage with them in a dynamic way, fostering deeper comprehension and retention.



Figure 1. The future of learning new skills [3]

By applying this technology, repetitive practice of musical instrument playing techniques is possible, as shown in Figure 1. Additionally, AR supports at-home experiential learning by providing opportunities for students to conduct scientific and mathematical simulations in a virtual environment. Through AR, students can observe how medications affect different organs in the human body or manipulate planetary conditions

to study their impact on sustaining life. These interactive experiences enhance learning by making abstract concepts more tangible and memorable [9]. Compared to traditional learning methods, AR fosters deeper engagement, improves comprehension, and enhances knowledge retention, ultimately transforming the educational landscape.

3.2. Appliances, Furniture, and Other Tangible Products

Augmented reality is transforming the shopping experience by allowing customers to visualize products in real-world settings using their smartphones. Currently, numerous AR-powered apps enable users to overlay digital representations of products, such as furniture and appliances, into their homes. By simply pointing their mobile devices at a space, customers can instantly see how different items fit within their environment. This technology provides flexibility, as users can easily switch between different models, colours, and sizes to find the perfect match [10]. One of the key benefits of AR in retail is its ability to offer an interactive 360-degree product viewing experience as depicted on Figure 2. Customers can examine products from multiple angles, gaining a more comprehensive understanding of their features and overall value.



Figure 2. AR Digital shopping assistant [4]

This level of engagement enhances confidence in purchasing decisions, reducing the likelihood of returns or dissatisfaction. Shopify AR is one example of an existing tool that enables consumers to view products in their intended environment before finalizing a purchase. Although AR shopping applications are already available, the technology is expected to become even more seamless and user-friendly in the future. As advancements continue, AR will play an increasingly significant role in e-commerce, enhancing customer experiences and streamlining the decision-making process.

3.3. Clothing & Fashion

Augmented reality is revolutionizing online shopping by simulating in-person experiences, allowing customers to visualize how products look on them before making a purchase. This technology enables users to try on virtual versions of clothing, footwear, jewellery, makeup, and accessories like sunglasses. Often referred to as virtual fitting room technology, this innovation enhances the shopping experience by providing a realistic preview of products. As a result, customers can make more informed purchasing decisions, reducing uncertainty and the likelihood of returns [11]. The market for virtual fitting room technology is projected to reach \$10 billion by 2027, highlighting its growing adoption across the retail industry. AR experiences are primarily delivered through smartphones, smart glasses, and other wearable or handheld devices, making them accessible to a broad audience.



Figure 3. Augmented reality shopping [5]

Another key advancement in this field is the use of smart mirrors, which integrate AR technology to provide interactive fitting experiences within physical retail stores. Major brands have already implemented smart mirrors to enhance their in-store shopping experience as can be seen on Figure 3. As AR technology continues to evolve, virtual fitting rooms and smart mirrors are expected to become more seamless and widely adopted, transforming the retail landscape by merging digital convenience with immersive, personalized shopping.

3.4. J.A.R.V.I.S.-Like Virtual Assistance

JARVIS, or Just a Rather Very Intelligent System, is a cutting-edge AI-powered personal assistant designed to make our life easier by automating daily tasks on various systems. Mojo, a company specializing in augmented reality technology, is developing AR lenses equipped with micro-LED displays that project information directly into the wearer's eyes. Initially, these lenses are designed to assist individuals with poor vision by enhancing contrast and providing zoom capabilities. However, future versions will be available to the general public and offer a wide range of features, including health tracking, text message notifications, weather updates, and more [12]. Beyond basic functionalities, AR lenses have the potential to enhance vision in low-light conditions and act as a teleprompter for public speaking. As AR technology advances, these lenses, along with AR glasses, could significantly augment the way users interact with the world. Through integration with artificial intelligence, virtual assistance capabilities could be enhanced, providing real-time support in various aspects of daily life. By granting permissions to AI-powered virtual assistants, users could enable features such as real-time conversation monitoring, email reading, and health tracking through blood chemistry analysis. With access to vast amounts of personal data, AI could learn individual preferences, anticipate needs, and automate tasks such as shopping and health monitoring. Ultimately, AR lenses and AI integration could help users navigate their mid- and long-term goals more efficiently, reshaping human-computer interaction.

3.5. The Creation of the Metaverse

The combination of augmented reality, virtual reality, AI, 5G networks, and other technologies will make an open metaverse possible. The metaverse refers to a convergence of physical, augmented, and virtual reality in a shared online space. The metaverse is the next step in the internet's evolution. We can think of the metaverse as a 3D or 4D version of the current 2D internet [13]. The metaverse can be thought of as an internet that we are inside of rather than one that we are merely looking at. It will impact every industry in existence. Other names given to the metaverse are Web 3.0 and SpatialWeb.

3.6. Outdoor & Indoor Navigation

AR could make it easier to navigate in outdoor and indoor environments. For indoors, a line could overlay the ground and guide us toward a destination in a large airport, an airport parking lot, a large mall, an office building, a college campus, and so on. For outdoors, instead of typing in an address into our map software, we will be able to point to a location and the directions will pop up automatically. And we can follow an AR-created trail on the ground perhaps with consideration to physical obstacles that might be in the way. Additionally, we could point to an object such as a building and receive information about it without even knowing what it's for.

3.7. Healthcare

Augmented reality is set to play a crucial role in the future of healthcare, particularly in three key areas: consumer education, assisting doctors, and medication sales. Through visual demonstrations and simulations, AR can help patients better understand the benefits and risks of medications and medical procedures. By providing an interactive way to learn about treatments, AR enhances patient education, leading to more informed decision-making and increased adherence to medical advice. For medical professionals, AR offers significant advantages by creating realistic simulations of surgical procedures and treatments. Doctors can use AR to practice complex surgeries, improving precision and reducing risks. Medical students also benefit from AR by exploring highly detailed, interactive 3D representations of the human body [14,15]. This hands-on learning approach enhances their understanding of anatomy and medical procedures in a way that traditional textbooks and lectures cannot provide. In the pharmaceutical industry, AR is becoming an essential tool in medication sales. Given the intense competition among drug manufacturers, gaining the attention of doctors is crucial [16]. Sales representatives can use AR-driven virtual simulations to showcase the effectiveness of new medications, making their presentations more engaging and persuasive. Overall, AR is revolutionizing healthcare by improving patient education, enhancing medical training, and transforming pharmaceutical marketing strategies.

3.8. Automotive Industry

AR heads-up displays can help drivers process information that enhances their view of roads. This type of display can make drivers aware of potential hazards occurring ahead of them on their commutes. They can also make it easier to navigate than traditional map software could due to customized visuals that are tailored to the terrain. Car manufacturers already use this type of technology. Additionally, AR can be used for automotive marketing [17]. This technology can superimpose information from a connected device like a smartphone directly into our field of view imagine seeing speed limits navigation arrows and other important information without looking away from the road or our surroundings that's AR at its finest as depicted on Figure 4.



Figure 4. Augmented reality-based navigation [6]

Developers had already designed an AR application that enables customers to experience a new car in their driveway without having to go to the dealership. Customers can also see what the virtual car looks like in different colours.

3.9. Sporting Events

Augmented reality is transforming the experience of sporting events by enhancing fan engagement, improving athlete training, and optimizing game analysis. With AR, sports spectators can access real-time data, interactive visualizations, and immersive experiences that make events more engaging and informative. At the same time, athletes and coaches are using AR to refine skills, analyse performances, and develop better strategies. For fans, AR enhances live and televised sporting events by overlaying real-time statistics, player information, and game analysis onto their screens. Mobile apps and smart glasses allow spectators to access instant replays, heat maps, and player tracking data while watching a game. AR-powered apps also enable fans in stadiums to view additional content, such as alternate camera angles or historical player statistics, simply by pointing their devices at the field or scoreboard. Some stadiums are integrating AR into their venues to guide visitors, provide interactive experiences, and even offer AR-based advertisements tailored to individual users [18]. Athletes and coaches are also leveraging AR for training and performance improvement. By using AR headsets and smart glasses, players can simulate real-game scenarios and receive real-time feedback on their techniques. AR-driven virtual coaching tools allow athletes to visualize plays, track their movements, and identify areas for improvement. This technology is particularly beneficial in sports like football, basketball, and golf, where precision and strategy play a crucial role in performance. Broadcasters and sports analysts are also utilizing AR to enhance game coverage. AR graphics, such as virtual lines, player tracking, and real-time statistical overlays, make it easier for audiences to follow the action and understand key moments in a match. This technology is commonly seen in football broadcasts, where virtual first-down lines and goal-line technology improve the viewing experience. Additionally, AR replays help referees and officials make more accurate calls by providing a clearer view of controversial moments. Beyond professional sports, AR is also being used to enhance fan engagement through gamification. Many teams and leagues have introduced AR-powered apps that allow fans to interact with virtual mascots, participate in live trivia, and even engage in AR-powered fantasy sports experiences. Social media platforms also integrate AR filters and effects that let fans show support for their favourite teams in creative ways. As AR technology continues to evolve, its impact on sports will only grow. Future applications may include fully immersive AR experiences that allow fans to view live games from a player's perspective or interactive AR training systems that provide real-time biomechanics analysis. With advancements in AR headsets, mobile applications, and AI integration, the sporting experience will become more personalized, interactive, and data-driven. AR is revolutionizing the way sporting events are experienced by fans, athletes, and analysts alike. By providing real-time data, immersive training tools, and interactive broadcasting features, AR is enhancing engagement and performance in sports. As the technology continues to improve, AR is expected to play an even bigger role in making sports more accessible, dynamic, and enjoyable for everyone.

3.10. Virtual User Instructions & Assembly instructions

AR-based virtual user manuals can display 3D holograms, overlays, and visual instructions in the form of 3D animations for products such as vehicles, refrigerators, cameras, and more [19]. And when it comes to assembly instructions, we'll be able to see the construction of items such as desks, cabinets, and more in many phases in the form of 3D holograms and 3D animations.

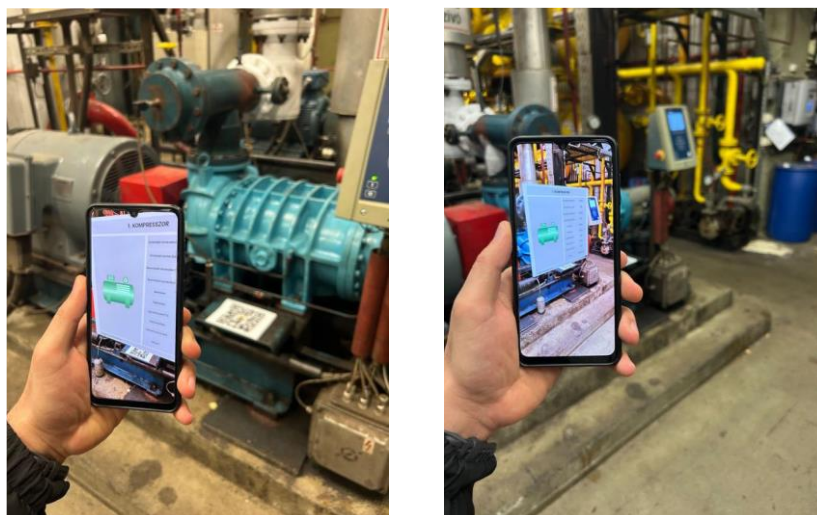


Figure 5. Augmented reality-based SCADA system [7]

Key implementation methods involve AR-powered smart interfaces that overlay real-time data on physical equipment, allowing operators to access system parameters, alerts, and maintenance instructions through smart glasses or mobile devices. These systems leverage IoT sensors to collect and transmit data, providing an interactive and immersive monitoring experience. AI-driven analytics further enhance predictive maintenance by visualizing potential failures and recommending corrective actions before breakdowns occur. Another significant feature is remote assistance, where AR enables experts to guide on-site personnel through complex troubleshooting via virtual annotations and live video feeds. Additionally, digital twin technology integrates with AR-SCADA systems to simulate industrial processes in real-time, optimizing performance and minimizing risks [20]. These implementations reduce downtime, enhance safety, and improve workforce training, making AR-based SCADA systems a critical component of smart manufacturing and Industry 4.0 transformation as can be seen on Figure 5. As AR technology evolves, its integration with SCADA will continue to drive automation, efficiency, and innovation in industrial settings.

4. CONCLUSIONS

AR is rapidly evolving and is expected to play a significant role in shaping the future of various industries. As technological advancements continue to enhance AR applications, numerous opportunities for innovation and integration are being identified. In particular, AR is anticipated to have a profound impact on education, marketing and sales, virtual assistance, the automotive industry, and metaverse integration. These applications highlight the versatility and potential of AR in transforming traditional practices into immersive and interactive experiences. In the education sector, AR is being increasingly utilized to enhance learning experiences by providing interactive content, virtual simulations, and real-time collaboration. Traditional teaching methods are being supplemented with AR-based applications that enable students to visualize complex concepts, conduct virtual experiments, and engage with digital content in a more interactive manner. The accessibility of AR in education is expected to grow as mobile devices and AR-enabled platforms become more widely available. In marketing and sales, AR is being adopted to improve customer engagement and drive purchasing decisions. Brands are leveraging AR to provide virtual try-on experiences, interactive product demonstrations, and location-based advertisements. Consumers are being given the ability to visualize products in real-world environments before making a purchase, reducing uncertainty and increasing confidence in their buying decisions. As AR technology advances, personalized and immersive

marketing strategies are expected to become more prevalent. Virtual assistance is another area where AR is being increasingly integrated to enhance productivity and efficiency. AR-powered virtual assistants are being designed to provide real-time guidance, hands-free instructions, and interactive support in various industries, including healthcare, manufacturing, and customer service. Through AR-enabled devices, users can access contextual information, receive step-by-step instructions, and interact with digital overlays in real time. The combination of AR with artificial intelligence is expected to further enhance the capabilities of virtual assistants, making them more intuitive and responsive. The automotive industry is also witnessing significant advancements with AR technology. AR-powered heads-up displays are being integrated into vehicles to provide real-time navigation, safety alerts, and driver assistance features. By overlaying crucial information onto the windshield, drivers can access navigation directions, hazard warnings, and vehicle diagnostics without diverting their attention from the road. Additionally, AR is being utilized in vehicle design and manufacturing processes to improve efficiency and precision. As automotive technology progresses, AR is expected to play a crucial role in the development of smart and autonomous vehicles. One of the most transformative applications of AR is its integration with the metaverse. The concept of a fully immersive digital environment is being actively explored, with AR serving as a bridge between the physical and virtual worlds. AR-powered experiences in the metaverse are expected to revolutionize social interactions, gaming, remote work, and digital commerce. As advancements in AR hardware, 5G connectivity, and AI continue, seamless and immersive metaverse experiences are likely to become more accessible to users worldwide. The future of AR application development is filled with promising opportunities across various industries. As technological advancements drive the adoption of AR, its impact on education, marketing, virtual assistance, the automotive industry, and the metaverse will continue to expand. With continuous research and development, AR is poised to revolutionize the way people interact with digital content, enhancing efficiency, engagement, and overall user experience in the years to come.

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