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Articles

Contribution of artificial intelligence in improving the user experience of augmented reality learning applications

Contributo dell'intelligenza artificiale nel miglioramento dell'esperienza utente delle applicazioni di apprendimento in realtà aumentata

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Abstract

Integrating Artificial Intelligence (AI) with Augmented Reality (AR) presents transformative opportunities for improving user experiences by addressing challenges such as accessibility, usability, and adaptive learning. While AR enhances engagement through tracking, rendering, and visualization, but challenges such as motion sickness, limited field of view, cognitive load, and content creation complexity persist. This paper explores how AI techniques, such as real-time object recognition, scene understanding, personalized feedback, and virtual instructors, can mitigate these issues. Using MirageXR tool, we demonstrate AI-AR integration in improving user experience and accessibility. Demonstrating features for users with visual and hearing impairments such as voice-command navigation and real-time captioning and AI-controlled avatars, context-aware training sessions for diverse learning needs. This study highlights the potential of AI-enhanced to improve usability and accessibility to meet the evolving diverse needs of modern workplaces

Keywords: artificial intelligence techniques; augmented reality learning; user experience

Sintesi

L'integrazione dell'Intelligenza Artificiale (IA) con la Realtà Aumentata (RA) offre opportunità trasformative per migliorare l'esperienza utente, affrontando sfide come l'accessibilità, l'usabilità e l'apprendimento adattivo. Sebbene la RA migliori il coinvolgimento attraverso il tracciamento, il rendering e la visualizzazione, persistono sfide come la cinetosi, il campo visivo limitato, il carico cognitivo e la complessità della creazione di contenuti. Questo articolo esplora come le tecniche di IA, come il riconoscimento degli oggetti in tempo reale, la comprensione delle scene, il feedback personalizzato e gli istruttori virtuali, possano mitigare questi problemi. Utilizzando lo strumento MirageXR, dimostriamo l'integrazione IA-RA nel miglioramento dell'esperienza utente e dell'accessibilità. Dimostriamo funzionalità per utenti con disabilità visive e uditive come la navigazione a comando vocale, i sottotitoli in tempo reale, gli avatar controllati dall'IA e le sessioni di formazione contestuali per diverse esigenze di apprendimento. Lo studio evidenzia il potenziale dell'IA potenziata per migliorare l'usabilità e l'accessibilità e soddisfare le mutevoli esigenze dei moderni luoghi di lavoro.

Parole chiave: tecniche di intelligenza artificiale; apprendimento in realtà aumentata; esperienza utente

1. Introduction

Artificial intelligence (AI) is the technology designed to enable machines to think and perform tasks that were traditionally carried out by humans (Zhang & Lu, 2021). It enhances Augmented Reality (AR) systems by enabling advanced functionalities such as object detection and location binding. This relationship allows AR technologies to interact more intelligently with the real world, improving both performance and user experience (Makhataeva et al., 2023). It is important to note that these are two different technologies. AR's definition revolves around its derivation from mixed reality technology as it combines the real world and the virtual world by superimposing digital content on top of the real-world environment view in which the user is located (Devagiri et al., 2022).

Despite their differences, AR and AI can be integrated to enhance AR applications by improving user experience through smarter interactions. Additionally, user interfaces significantly impact user experience, as noted by (Derby & Chaparro, 2021) . The interaction of users with AR applications is largely dependent on the design of the application and the hardware which it runs from (Patkar et al., 2020). However, the AR application interface design variations can lead to inconsistencies that affect 'user's experience. For example, some applications may overload the user with text, while others might focus predominantly on the aesthetics of holograms, providing minimal contextual information (Vertucci et al., 2023). Such discrepancies can confuse users, complicate the learning process of the AR system, cause a bad user experience, and ultimately decrease the application's usage.

According to ISO 9241-210:2019, 3.15, UX is defined as “user's perceptions and responses that result from the use and/or anticipated use of a system, product or service”. Usability primarily concentrates on the learnability and ease of use of a product, whereas user experience (UX) encompasses the entire process of product creation, from conception to interaction with users. Problems in user experience often stem from design flaws, which can lead to poor usability and negatively impact the overall UX. The creation process of the AR experience includes core functions such as Tracking, Rendering, and Visualization. Tracking involves real-time user mapping within a scene, tracking the user's position to establish a reference point for viewing digital content relative to the user's location. Rendering is the process of aligning virtual content with the real world from the user's viewpoint. The final function, Visualization, is the real-time generation of virtual content to be overlaid in the real world. These functions depend on how the application is designed as well as the hardware it runs from, as previously mentioned. Historically, AR systems utilized computer vision techniques known as Simultaneous Localization and Mapping (SLAM) to analyze visual features across camera frames, mapping, and tracking environments effectively (Liu et al., 2019). SLAM performs optimally in static environments but faces challenges in dynamic settings, particularly with moving objects and in unstructured or uncertain environments (Bahraini et al., 2019). Different UX challenges on AR applications have been reported by scholars. For instance, (Dirin & Laine, 2018) conducted UX evaluation on mobile AR and identified several technical challenges affecting user experience, including screen size limitations, tracking issues and battery drain from power consumption during rendering (Hari Chandana et al., 2023) reported UX challenges in AR applications, such as motion sickness, field of view limitations, cognitive load, and physical constraints, need to be addressed (Bialkova, 2022) mentioned attention, sensation, perception, and action as daily drivers of UX on consumer-based applications, however these key drivers are still challenge in AR application. The integration of AR with AI offers an opportunity to leverage AI techniques to enhance the user experience, mitigating these issues effectively (Devagiri et al., 2022). AR applications indeed face user experience challenges, and the recent advancement of AI techniques can impact them. This paper wants to explore the contributions of these techniques to improving the user experience of AR applications. Moreover, to show the impact of AI in AR, this paper presents how AI was utilized to improve the accessibility and user experience of an AR authoring tool, MirageXR. The rest of the paper is organized as follows: first, the PRISMA methodology is presented, then UX challenges in AR learning applications followed by the contribution of AI in addressing these challenges, and lastly, the integration of AI in improving UX of MirageXR.

2. Methods

Figure 1 summarizes the search strategy and the selection of articles. A systematic search was performed using the PRISMA technique (Page et al., 2021) to summarize the challenges of AR user experience and how AI techniques are incorporated into AR to address these challenges. The main research question was: How to utilize AI to improve the user experience in AR applications? The secondary questions were as follows: (1) What are the challenges of AR learning applications? (2) How could AI address the User Experience challenges of AR learning applications?

Four phases of the PRISMA methodology were conducted: identification, screening, eligibility, and inclusion. Figure 1 illustrates the phases, activities, and number of records obtained in each activity. In the first phase, identification, we identified the required articles according to the defined search strategy against the publication databases. The databases were IEEExplore, ACM Digital Library, and Scopus. This included journal articles and conference proceedings. The search string was as follows: In the title (T), the search string was ("Augmented Reality" OR "Mixed Reality" OR "AR" OR "MR") and in all metadata (M) was [("Augmented Reality" OR "Mixed Reality") AND ("Artificial Intelligence" OR "Machine Learning") AND ("User Experience" OR "usability")]. The overall search query was T AND M.

The identification phase returned 1.769 articles, and they were all imported into RAYYAN to check for duplicates. This process located and eliminated 106 duplicates, leaving 1.663 papers.

In the second phase, screening, the publications were screened based on inclusion and exclusion criteria found in the abstract and title of each publication. The main inclusion criteria are that the mainstream technology is AR, discussing user experience challenges and how artificial intelligence can help to address these challenges. The main exclusion criteria were when an article did not discuss either user experience challenges or artificial intelligence and an article written in a language other than English. We forwarded the article to the next phase, eligibility, if, after screening the abstract and title, the decision to include or exclude it was unclear. In the screening stage, 1459 articles were removed because they did not pass the criteria provided. Therefore, the eligibility criteria had only 204 articles.

The third phase, eligibility, assessed the full-text articles according to the inclusion and exclusion criteria presented in the screening phase. This stage confirmed the exclusion or inclusion of an article based on the full-text of the paper. The articles behind the paywall that either of the authors was not subscribed to were also removed. After this stage, 189 articles were removed, and 15 were included in the inclusion phase for analysis and reporting. Appendix I presents the articles that are included for SLR.

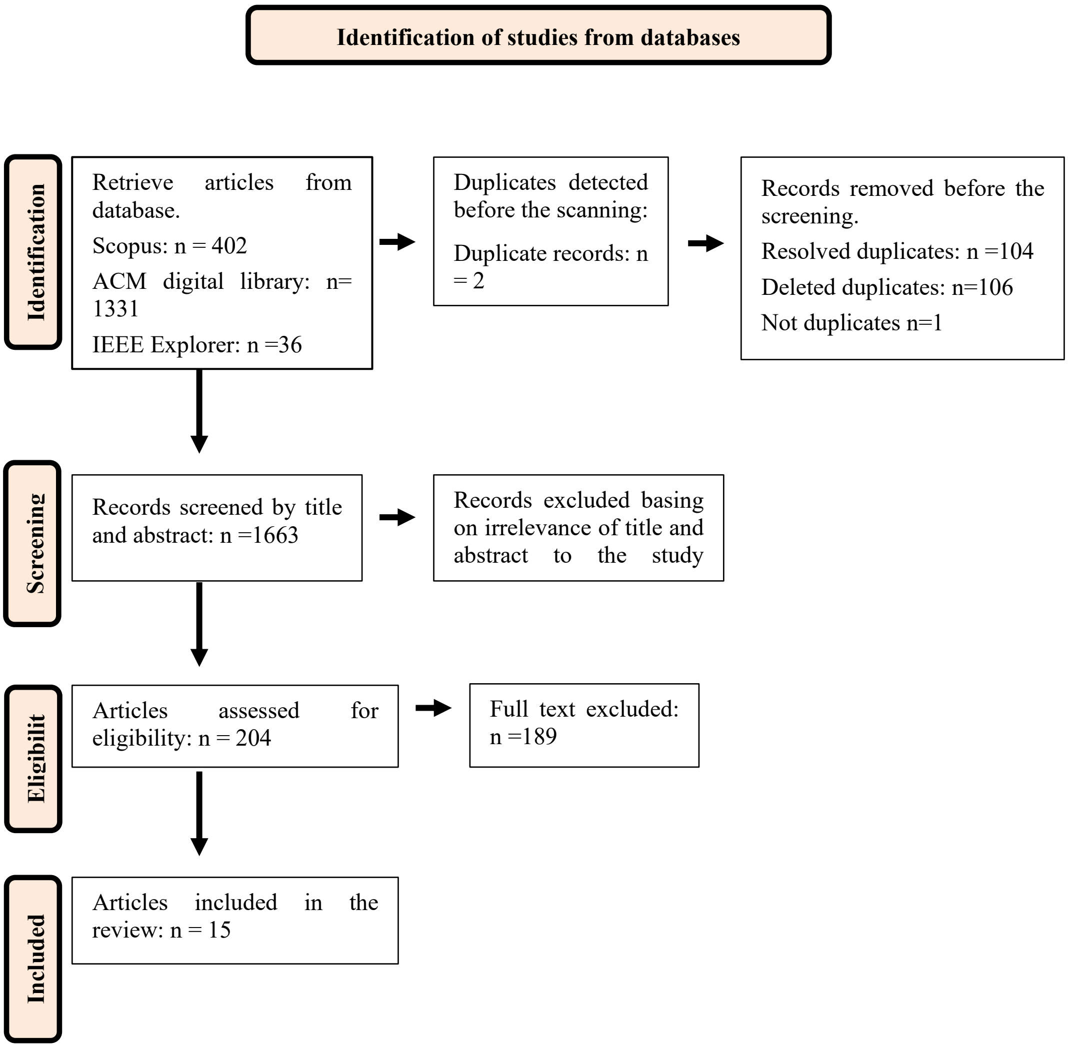

Figure 1. Prisma flow diagram.

3. Results and Discussion

3.1 User Experience Challenges in Augmented Reality Learning Applications

AR devices are essential resources that enable the use of AR applications (Al-Ansi et al., 2023). They are designed to capture real-world images, project virtual images, process sensor information, and display content in augmented reality in real-time. Various hardware components, including peripheral tracking and orientation devices, waveguide and Diffraction Optical Elements (DOE) glass wafers and the hand gesture recognition system for natural interaction and user experiences (Battegazzorre et al., 2020; S et al., 2024) . However, the adoption levels of AR hardware remain far lower than other types of software systems as AR hardware (Khamaisi et al., 2021). AR devices are expensive, which results in only a small subset of users having such devices; hence, AR applications are rarely used. In contrast, the lower the popularity of a user, the higher the difficulty of achieving it with a comprehensive evaluation of the user experience because slightly users can provide feedback on this technology (Sebiraj et al., 2024). Traditional marker-based AR-based applications have been consistently more common than marker-less applications due to the GPS-reliant characteristics of the wireless experiences' marker-less experiences, such as the applications described in this paper are reported for stability and performance challenges, when outdoor (Law & Heintz, 2021; Orlandi et al., 2024). As a result, markerless AR applications are highly likely to frustrate or disappoint users when they see virtual objects drifting or getting lost. Bad user experiences contribute to more unfavorable beliefs of AR technology overall and result in lower penetration rates in both the consumer and enterprise markets (Lukava et al., 2022) , (Y. F. Wu & Kim, 2022). Gestures and hand movements are common interactions for AR systems. However, detecting and interpreting these gestures correctly is difficult (Law & Heintz, 2021), especially in a mobile setting, where lighting conditions change quickly and where clutter in the background could confuse the gestures. A study by (Sinlapanuntakul et al., 2023) found that users had trouble with specific interactions performed, such as propagation, scrolling, and resizing. Some virtual objects require complex manipulation, such as rotation, scaling, and translation. While the feeling of control is important for delightful user experiences since users feel like they are directly "manipulating" the digital content on the display (C. Wu et al., 2023), but challenges with occlusion and gorilla arm problems mean that these may not always be reliable solutions (C. Wu et al., 2023).

Limited content in AR applications can also reduce the richness of user interactions. The complexity of Creating AR content ranges between high and medium complexity, and creating high-quality content is time-consuming and technically complex (Shaleh Md Asari et al., 2024; Whitehand et al., 2021). Content like 3D models and animations with interactive elements requires specific skills and tools. This is mostly due to rendering delays, as an AR application is executed, the user sees movement differently than his own movement and this difference between actual and expected motion using AR applications is referred to as Motion sickness (Duan et al., 2024) . This leads to the user's disorientation or dizziness and nausea, which work and fall in a similar (Y. C. Chen et al., 2022). Furthermore, too much information has been reported to induce slow rendering times and overwhelming or cluttered delivery, thus potentially under or misinforming (Cao et al., 2023). Nowhere do these UX implications appear to be as problematic as in areas with more immediate aspirations like on-demand education and training (Mendoza-Ramírez et al., 2023).

3.2 Artificial Intelligence Contribution to Addressing the UX Challenges in Augmented Reality Learning Applications

AI enhances AR experiences through predictive analysis and personalized content delivery, bringing about an AI-powered AR concept that involves leveraging AI techniques to enhance various aspects of AR, including object recognition, scene understanding, and interaction (Nurhadi et al., 2022). By integrating AI capabilities into AR systems, developers can create more intelligent and adaptive experiences that better cater to user needs and preferences (Mendoza-Ramírez et al., 2023).

Advanced algorithms and computer vision techniques have markedly improved the precision and reliability of marker-based and marker-less AR (Amparore et al., 2024). Sophisticated image processing, machine learning, and deep learning algorithms enable more robust object recognition and tracking, even under challenging conditions, significantly enhancing applications in domains like healthcare and manufacturing

(Sadeghi-Niaraki & Choi, 2020). Deep learning techniques have started to revolutionize the field of AR by introducing higher levels of automation and efficiency in object recognition and scene understanding. Convolutional Neural Networks (CNN) have proven particularly effective in image classification tasks, making it easier for AR systems to identify and superimpose digital information over real-world objects with greater accuracy. Generative Adversarial Networks (GAN) facilitate more realistic virtual object generation, contributing to a more immersive AR experience (Lu et al., 2022). Reinforcement learning algorithms have also been adapted to optimize tracking algorithms in AR, making them more resilient to environmental noise and variable lighting conditions. (Tiple et al., 2024) had an Object Detection Module with OpenCV intending to develop an efficient object detection system capable of swiftly identifying and tracking objects within the augmented reality (AR) environment. Also, the integration of cutting-edge deep learning models like Faster R-CNN and YOLO to enable real-time object recognition and localization, ultimately contributing to immersive AR experiences.

The concept of AI-powered AR suggests that AI can enhance AR-based applications by utilizing smart user feedback, predictive analytics, and classification techniques. It involves (1) online learning (training) of the AI model based on systematic data collection, (2) generating predictions for similar users and use cases, and (3) focusing on content generation for the AR creation process using modern technologies such as natural language processing (NLP) to enhance scene understanding (Sulema et al., 2023). This could add detailed descriptions to scenes and improve user experience through techniques like text/speech-to-image conversion, image-to-image diffusion, and photogrammetry. These techniques could enable the creation of AR services with a high level of generalization (Pucihar et al., 2023).

Furthermore, the integration of AI in content generation processes has significantly enhanced customer relationships for numerous businesses. This is achieved through text-based generative AI tools, such as NLP-powered chatbots (Lalwani et al., 2018) AI content generation tools are categorized based on the type of content they produce, ranging from tools specialized in generating images and enhancing photo quality (Z. Wu et al., 2023), to those focused on generating text, which rely on NLP algorithms (Dang et al., 2022). The use of AI-generated content in AR display has provided easy implementation of subtitle captions for videos and audio using NLP-powered speech recognition tools such as IBM Watson, Google, Vosk toolkit, and VisualGPT (Li, 2023) (Kumar et al., 2022) (J. Chen et al., 2022). By creating digital twins of real-world objects, this approach not only enhances the practicality of augmented reality content but also streamlines the content creation process by offering reusable digital objects. Furthermore, implementing AI-driven AR digital assistants facilitates seamless assistance for people across diverse linguistic backgrounds, making the technology universally accessible (Castelo et al., 2024; Lin et al., 2022). Making the AR experience more intelligent to reduce redundant operations is one solution to enhance the user experience. Semantic segmentation (Attention U-Net deep neural network) was used to assist automatic information placement in AR, utilizing a case study within precision agriculture as an example. The precise location of the crop area in the user view is determined by semantic segmentation, which helps to place information in the AR environment automatically (Nurhadi et al., 2022), thereby prompting the combination of deep learning-based object detection and instance segmentation with wearable AR technology to improve the performance of complex tasks. This challenge was addressed in this work using convolutional neural networks in the detection and segmentation of objects in actual environments. Experimental results showed satisfactory segmentation and accurate detection.

4. Integrating AI in MirageXR to Improve Learning UX in Workplaces

MirageXR is an open-source tool for authoring augmented reality (AR) learning based on XR lesson authoring tool kits (WEKIT-ECS, 2025). It facilitates quick curation and instruction of *how-to* processes in various environments (WEKIT ECS, 2021). Integrating AI into AR expands the potential of tools like MirageXR to create flexible, inclusive, and sustainable workplaces by addressing accessibility barriers and training inefficiencies. This AR-AI synergy enhances learning environments and ensures equitable access to resources for diverse users (Shidende et al., 2023).

MirageXR exemplifies this innovation by incorporating AI to improve accessibility for individuals with visual and hearing impairments (Shidende et al., 2023). The addition of AI-driven features, such as voice-command navigation, enables visually impaired users to explore AR environments independently (Bakshi et al., 2019). Additionally, real-time captioning of audio-centric augmentations, such as audio and video augmentations, ensures seamless comprehension for those with hearing impairments (Shidende et al., 2024). By integrating AI, MirageXR broadens its usability and underscores its role in fostering inclusivity.

AI also powers MirageXR's virtual instructor, a generative AI-driven avatar capable of delivering context-aware and personalized training sessions. This feature addresses diverse learning needs, such as language acquisition, by providing tailored lessons to accommodate various proficiency levels (Kißmehl, 2024). In dual-learning universities, the virtual instructor could simulate real-world scenarios and deliver practical feedback in real-time, enhancing learner engagement and retention. With its marker-less spatial mapping, real-time content creation capabilities, and cross-platform compatibility (Karampatzakis et al., 2024), MirageXR integrates AI seamlessly into workplace learning environments, making it an ideal tool for dual students and professionals.

The integration of AI into AR applications like MirageXR bridges critical gaps in accessibility and training, creating inclusive and adaptive learning environments. These advancements represent a transformative step toward workplaces that foster continuous skill development, inclusivity, and equitable opportunities for a diverse workforce to excel.

5.Conclusion

This study highlights the potential of integrating AI into AR to address user experience challenges in AR applications. Through a systematic literature review, the research identifies key barriers to effective AR adoption, such as accessibility limitations, motion sickness, cognitive load, and complex content creation processes. AI techniques, including advanced computer vision algorithms, predictive analytics, and generative AI tools, were found to significantly enhance AR functionalities, including object recognition, scene understanding, and personalized user interactions.

Integration of AI in AR applications can prove to be an answer to some of the common usability issues pestering other AR applications that have uses in areas such as health, manufacturing and education. Additionally, there is the need for a design framework for AR and AI applications to mitigate the constraints imposed by AR hardware and software interfaces to ensure more consistent AR interactions.

The case of MirageXR illustrates the practical application of AI-driven AR, showcasing its ability to foster inclusivity and adaptability in workplace learning environments. Features such as voice-command navigation for users with visual impairments, real-time captioning for users with hearing impairments, and generative AI-powered virtual instructors underscore the potential of AI-enhanced AR to provide equitable learning opportunities and tailored training experiences. These advancements demonstrate how AI can bridge accessibility gaps and create adaptive, efficient, and sustainable solutions for diverse user groups.

Therefore, integrating AI into AR not only addresses the technological and user experience challenges of AR applications but also paves the way for an inclusive, user-centered design that fosters engagement and continuous skill development. Future research and development should continue exploring AI-AR synergies to expand their potential in diverse domains, ensuring that these technologies remain accessible, adaptable, and impactful in meeting the evolving needs of users.

Appendix

ID	Authors	Yeear	Type	Publisher
1	Al-Ansi, A. M., Jaboob, M., Garad, A., & Al-Ansi, A.	2023	Peer reviewed	ScienceDirect
2	Battegazzorre, E., Calandra, D., Strada, F., Bottino, A., & Lamberti, F.	2020	Comference	Springer nature
3	Cao, J., Lam, K. Y., Lee, L. H., Liu, X., Hui, P., & Su, X.	2023	Peer reviewed	ACM
4	Castelo, S., Rulff, J., McGowan, E., Steers, B., Wu, G., Chen, S., Roman, I., Lopez, R., Brewer, E., Zhao, C., Qian, J., Cho, K., He, H., Sun, Q., Vo, H., Bello, J., Krone, M., & Silva, C.	2024	Peer reviewed	IEEE Explore
5	Khamaisi, R. K., Prati, E., Peruzzini, M., Raffaeli, R., & Pellicciari, M.	2021	Peer reviewed	MDPI
6	Law, E. L. C., & Heintz, M.	2021	Peer reviewed	Science Direct
7	Lin, H., Wan, S., Gan, W., Chen, J., & Chao, H. C.	2022	Conference	IEEE Explore
8	Mendoza-Ramírez, C. E., Tudon-Martinez, J. C., Félix-Herrán, L. C., Lozoya-Santos, J. de J., & Vargas-Martínez, A.	2023	Peer reviewed	MDPI
9	Nurhadi, Stiawan, D., Idris, M. Y., & Saparudin.	2023	Peer reviewed	IJEEI
10	Orlandi, L. O., Depedri, K., & Conci, N.	2024	Peer reviewed	IEEE Explore
11	Pucihar, K. Č., Geroimenko, V., & Kljun, M.	2023	Conference	Spinger nature
12	S, K., P, V., M, R. K., & R, R.	2024	Peer reviewed	IEEE Explore
13	Sebiraj, N., Advaith, K., & Priyadharshini, P. S.	2024	Peer reviewed	IEEE Explore
14	Wu, C., Huang, M., Sun, W., & Yang, R.	2023	Peer reviewed	IEEE Explore
15	Wu, Z., Fan, M., Tang, R., Ji, D.	2023	Conference	Spinger nature

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