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The Synergy of Artificial Intelligence and Augmented Reality for Real-time Decision-Making in Emergency Radiology

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Abstract

Recent progress in Artificial Intelligence (AI) and Augmented Reality (AR) has exhibited encouraging uses in emergency radiology. This study delves into their potential applications in this field and how they could enhance patient outcomes. AI's capabilities in analyzing medical images have enabled rapid and accurate detection of critical conditions, such as fractures, hemorrhages, and strokes. By swiftly identifying abnormalities, AI expedites the interpretation process, providing radiologists with timely insights that are crucial in emergency scenarios. Moreover, AI assists in triaging patients effectively, prioritizing urgent cases to ensure immediate medical attention. Augmented Reality, on the other hand, introduces innovative methods for image visualization and interpretation. By displaying medical images in immersive 3D environments, AR enables radiologists to gain a comprehensive understanding of complex cases, facilitating better diagnostic accuracy. The overlaying of diagnostic information directly onto medical images further augments radiologists' abilities, providing valuable context and emphasizing essential findings. In interventional procedures, AR proves to be an invaluable tool by superimposing guidance and navigation information onto patients' bodies. This feature aids radiologists in performing precise and safe interventions, minimizing procedural risks and improving patient outcomes. AR's potential for medical training and education is achieved by creating realistic simulation environments. Medical students and radiologists can practice image interpretation and interventional procedures in a risk-free setting, fostering skill development and enhancing overall competence. The synergistic combination of AI and AR in emergency radiology not only streamlines workflows and improves diagnostic accuracy but also enhances the overall quality of care delivered to patients.

Keywords: Artificial Intelligence (AI), Augmented Reality (AR), Emergency Radiology, Real-time Decision-Making, Medical Imaging, Patient Outcomes, Interventional Procedures

Declarations

Competing interests:

The author declares no competing interests.

Introduction

Artificial intelligence (AI) is a multidisciplinary field that encompasses the development of intelligent systems capable of emulating human cognitive processes. By leveraging advanced algorithms and computational power, AI aims to simulate human intelligence, including abilities such as reasoning, learning, problem-solving, and decision-making. The potential of AI in various industries, including healthcare, is vast and promising. In recent years, AI has been rapidly advancing in the healthcare sector, becoming a transformative force that is revolutionizing the way medical services are delivered and improving patient outcomes.

One of the primary areas where AI is making a significant impact is in medical diagnosis and image analysis. AI-powered algorithms can process vast amounts of medical data, such as medical images, lab reports, and patient records, with unparalleled speed and accuracy. This ability enables AI systems to detect anomalies, identify diseases, and assist medical professionals in making more precise diagnoses. Moreover, AI can continually learn from new data and adapt its algorithms, leading to continuous improvement in diagnostic accuracy over time. By enhancing diagnostic capabilities, AI has the potential to reduce misdiagnoses, optimize treatment plans.

Augmented reality (AR) has evolved from its rudimentary origins in the 1960s into a groundbreaking technology that is now at the forefront of practical application [1]. A convergence of various technological advancements has paved the way for AR to flourish. The recent progress in mobile processing power has been instrumental, enabling devices to handle complex AR computations and render immersive experiences in real-time. Furthermore, the explosion in digital storage capacity has facilitated the storage and retrieval of vast amounts of AR content, allowing for richer and more diverse AR experiences.

Equally crucial has been the widespread availability of wireless broadband connections, which ensures seamless data transfer between AR applications and remote servers, opening up opportunities for cloud-based AR experiences and collaborative interactions. The mass adoption of smart phones has been a driving force in the proliferation of consumer AR applications. With built-in cameras, accelerometers, microphones, and GPS capabilities, smart phones provide a solid foundation for delivering AR content and interactions to users. This widespread usage has also stimulated the development of AR-specific chipsets by major chip companies like Nvidia and Qualcomm. These specialized chips optimize AR processing, enhancing performance while minimizing power consumption, which is vital for prolonged and energy-efficient AR usage. The accessibility of AR technology is poised to undergo a significant transformation, due to the introduction of new AR-specific chipsets. As these chipsets become more prevalent and affordable, the price-point for AR devices will decrease, making AR more accessible to a broader audience [2]. Consequently, the lowered entry barrier for potential AR app developers will spark a surge in innovative AR applications across various industries.

Radiology encompasses a range of essential aspects. Diagnostic imaging is at the forefront, enabling the acquisition of internal body images to swiftly assess and diagnose acute injuries or illnesses. X-rays, CT scans, MRI, ultrasound, and nuclear medicine scans are all commonly used to aid in the diagnosis process [3]–[5]. In cases of trauma, radiology is crucial for evaluating fractures, internal injuries, and dislocations, assisting emergency physicians and surgeons in making critical decisions about treatment. For suspected strokes, CT and MRI scans are employed to assess the brain's blood vessels, guiding appropriate treatment strategies [6], [7]. Additionally, radiology helps evaluate chest and abdominal conditions, diagnose obstetric and gynecological emergencies, and may involve invasive procedures such as central line placement or angiography.

Artificial Intelligence in Emergency Radiology

Artificial Intelligence (AI) represents a paradigm-shifting field in computer science, involving the creation of algorithms and systems capable of emulating human-like intelligence. In the domain of radiology, AI offers immense promise, as it can be harnessed to analyze complex medical images, including X-rays, CT scans, and MRIs, with a level of precision and efficiency that rivals human capabilities.

Image Analysis and Detection

Image analysis and detection have witnessed remarkable advancements due to the application of artificial intelligence (AI) algorithms. These algorithms, meticulously trained on vast datasets of medical images, now demonstrate unprecedented capabilities in the detection of various abnormalities and signs of emergency conditions. One notable example of their efficacy lies in their potential to identify fractures, a critical diagnostic challenge in radiology. The AI models leverage sophisticated image recognition techniques, including convolutional neural networks (CNNs), to discern subtle irregularities in bone structures, enhancing the diagnostic accuracy and efficiency of medical professionals. Moreover, these AI systems exhibit remarkable adaptability, generalizing their learnings across different patient demographics and imaging modalities, thereby paving the way for personalized and precise fracture assessments.

In addition to fractures, AI-driven image analysis and detection also prove instrumental in detecting life-threatening hemorrhages and acute conditions, such as strokes, in medical images. The ability of AI algorithms to accurately pinpoint intracranial hemorrhages, even in complex brain imaging studies like computed tomography (CT) scans, transcends the limitations of conventional methods. Employing machine learning algorithms, and deep learning architectures, these systems can effectively distinguish abnormal bleeding patterns from normal brain anatomy. As a result, medical practitioners can expedite the identification and intervention for patients suffering from hemorrhagic strokes, drastically improving patient outcomes and reducing mortality rates associated with these critical medical emergencies [8].

The integration of AI algorithms in medical image analysis augments the capabilities of radiologists and clinicians, facilitating a symbiotic human-AI diagnostic approach.

Leveraging the vast repository of annotated medical images, these algorithms continuously learn and refine their knowledge [9], surpassing human performance in certain diagnostic tasks.

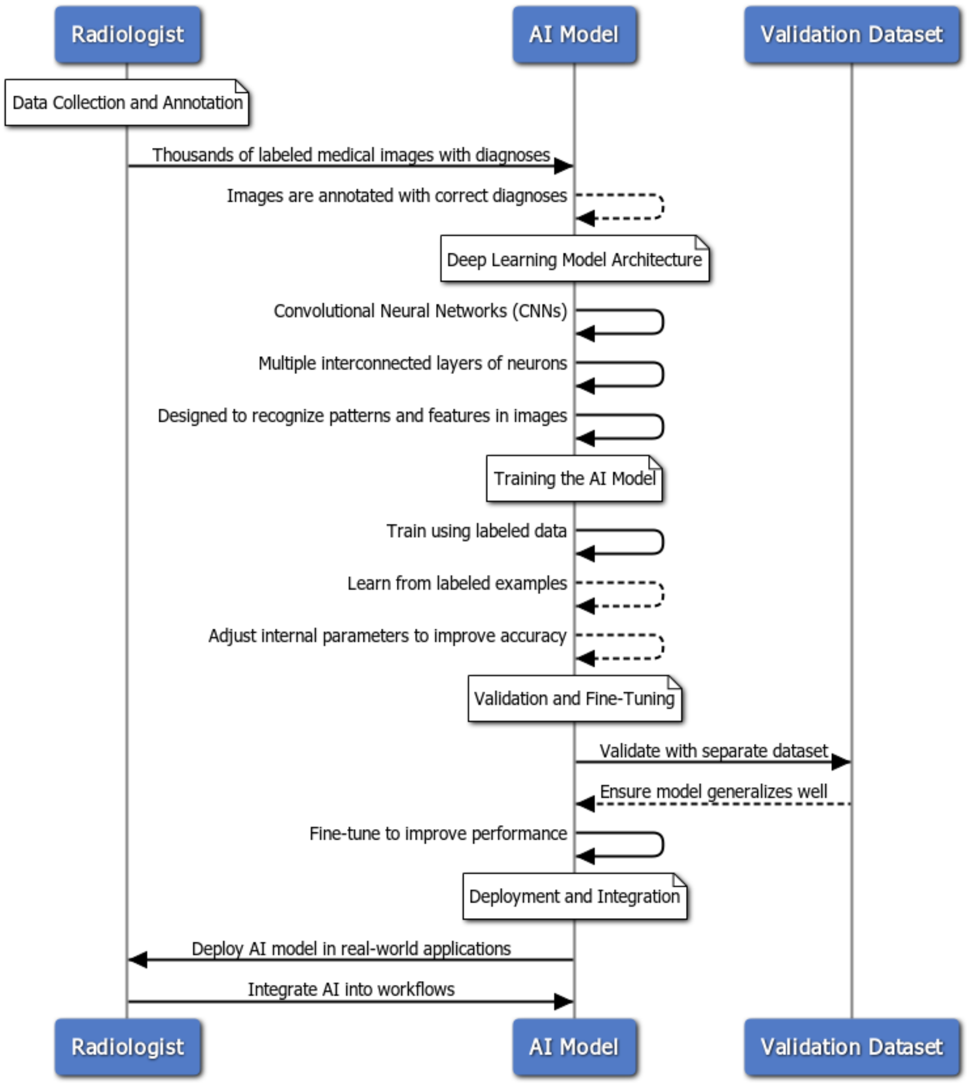

Figure 1 *AI deployment in radiology image analysis and detection for real-time decision making*

Fast and Accurate Interpretation

The rapid and accurate analysis of images by artificial intelligence (AI) represents a transformative advancement in medical diagnostics, particularly in the field of radiology. By harnessing the power of machine learning and deep neural networks, AI algorithms can swiftly process and interpret medical images, thereby significantly reducing the time required for radiologists to make critical diagnoses. This newfound efficiency proves to be of paramount importance in emergency situations, where swift and accurate decisions can mean the difference between life and death. The ability of AI to swiftly analyze medical images enables radiologists to prioritize urgent cases, facilitating timely interventions and improving patient outcomes. Moreover, the accelerated image analysis alleviates the burden on healthcare professionals, allowing them to focus on more complex and nuanced cases, where human expertise remains indispensable.

In emergency medical scenarios, such as trauma or acute neurological events, time plays a pivotal role in determining patient prognosis and treatment efficacy. AI-driven image analysis systems excel in swiftly detecting abnormalities and life-threatening conditions, which is particularly relevant in emergency radiology. These systems utilize sophisticated pattern recognition techniques, such as convolutional neural networks (CNNs), to swiftly identify signs of critical conditions like brain hemorrhages, pulmonary embolisms, or internal bleeding. By promptly flagging such emergent cases, AI enhances the overall efficiency of the diagnostic workflow and streamlines the decision-making process for healthcare providers. Furthermore, the consistent and rapid performance of AI models ensures that no critical cases go unnoticed or experience undue delays, reinforcing the delivery of timely and life-saving interventions to patients in urgent need.

The integration of AI-based image analysis in emergency radiology represents a pioneering step towards augmenting human capabilities and enhancing patient care. Nevertheless, it is imperative to emphasize the importance of rigorous validation and continuous refinement of these AI systems to ensure their accuracy and reliability in time-sensitive situations. Collaborative efforts between AI researchers, radiologists, and medical practitioners are instrumental in validating the algorithms' performance on diverse datasets and real-world scenarios. Additionally, continuous feedback loops and iterative improvements are essential to fine-tune AI models and adapt them to emerging challenges in emergency radiology. As AI technologies continue to evolve, it is vital to maintain a harmonious balance between the speed and accuracy provided by AI algorithms and the nuanced expertise and clinical judgment of radiologists. By forging a symbiotic relationship between human and AI intelligence, the field of emergency image analysis stands poised to revolutionize emergency medical care, saving valuable time, and ultimately, countless lives [10].

Assisted Triage

The integration of artificial intelligence (AI) in patient triage represents a revolutionary advancement in modern healthcare, as it significantly enhances the process of prioritizing urgent cases and expeditiously addressing critical conditions. By leveraging machine learning algorithms and predictive analytics, AI systems can swiftly analyze patient data and medical records to identify individuals requiring immediate attention. This triage assistance is particularly vital in resource-constrained healthcare settings, where timely decision-making is crucial for optimizing patient outcomes. The AI-driven prioritization not only streamlines the workflow of medical professionals but also ensures that critical conditions receive prompt and appropriate interventions, reducing the risk of adverse events and potential complications [11].

AI-assisted patient triage leverages sophisticated data processing and pattern recognition techniques to accurately assess patient conditions and prioritize cases based on the severity of their medical needs. These AI models are trained on vast datasets containing diverse patient profiles and medical histories, enabling them to recognize patterns and indicators of critical conditions efficiently. In emergency departments, for instance, AI can analyze vital signs, laboratory results, and patient symptoms in real-time, swiftly alerting healthcare providers to patients with life-threatening conditions like sepsis, acute myocardial infarction, or respiratory distress. By facilitating a more rapid and informed triage process, AI not only optimizes the utilization of healthcare resources but also empowers medical professionals to allocate their expertise and attention to the most critical cases.

While AI-assisted patient triage holds immense promise in enhancing healthcare efficiency and patient outcomes, its implementation must be approached with careful consideration of ethical and safety implications. The integration of AI technologies in the triage process necessitates stringent validation and continuous monitoring to ensure the accuracy and reliability of the algorithms. Furthermore, healthcare professionals must maintain an active role in the decision-making process, employing their clinical judgment to corroborate AI recommendations and intervene when necessary. Additionally, transparency and interpretability of AI models are essential, as clinicians need to comprehend the rationale behind the triage decisions. As the field of AI continues to evolve, collaborative efforts between AI researchers, healthcare providers, and policymakers are indispensable for developing robust and accountable AI triage systems that seamlessly integrate into clinical workflows. Ultimately, with responsible implementation, AI can serve as an invaluable ally in patient triage, revolutionizing healthcare delivery and contributing to more efficient and effective emergency medical care.

Decision Support:

The incorporation of artificial intelligence (AI) into the domain of radiology marks a momentous leap forward, as it equips radiologists with valuable additional insights and informed recommendations derived from the analysis of medical imaging data. By harnessing the power of machine learning and deep learning algorithms, AI systems can thoroughly scrutinize complex imaging studies and discern subtle patterns or abnormalities that may elude the human eye. This augmentation of radiologists' capabilities offers immense potential for enhancing diagnostic accuracy and overall patient care. AI serves as a trusted collaborator, assisting radiologists in making well-informed decisions based on the amalgamation of their clinical expertise with the comprehensive and data-driven analyses provided by the AI algorithms [12].

AI's ability to extract meaningful insights from medical imaging data is especially beneficial when dealing with large volumes of images and complex cases. The AI models are trained on extensive datasets, enabling them to recognize intricate details and subtle variations indicative of various pathologies. For instance, in the context of oncology, AI can analyze imaging studies to detect minute changes in tumor size or characteristics, assisting radiologists in tracking disease progression and response to treatment. Furthermore, the algorithms can act as intelligent screening tools, flagging potential areas of concern in images for radiologists to further investigate, optimizing their workflow and potentially reducing the likelihood of oversight. The collaborative nature of AI and radiologists thus fosters a synergistic approach to medical diagnostics, leveraging the strengths of both human expertise and

AI's analytical prowess. The successful integration of AI into radiology necessitates a comprehensive validation process to ensure the algorithms' reliability and generalizability across diverse patient populations and imaging modalities. Ethical considerations and patient privacy remain paramount in AI-driven radiology, and robust data governance practices must be upheld to safeguard sensitive medical information [13]. Additionally, transparent and interpretable AI models are vital, enabling radiologists to comprehend the basis for AI-generated recommendations and encouraging a sense of trust in the AI system.

Augmented Reality in Emergency Radiology

AR is a technology that superimposes digital information, such as images, text, or 3D models, onto the user's real-world environment. In emergency radiology, AR can enhance visualization and improve the interpretation of medical images.

Table 1. Augmented Reality (AR) in radiology

3D Image Visualization	AR can be used to display medical images in 3D, allowing radiologists to view the anatomical structures from different angles and better understand complex cases.
Overlaying Diagnostic Information	AR can overlay diagnostic information directly onto the medical images, providing additional context and highlighting important findings.
Guided Procedures	AR can assist during interventional procedures by superimposing guidance and navigation information onto the patient's body, helping the radiologist perform precise and safe interventions.
Training and Education	AR can be used for training purposes, allowing medical students and radiologists to practice interpreting images and performing procedures in a simulated environment.

3D Image Visualization

Augmented reality (AR) has emerged as a transformative technology in the field of medical imaging, offering radiologists a novel approach to visualizing and interpreting complex cases. By harnessing AR's capabilities, medical images can be displayed in three-dimensional (3D) formats, affording radiologists the unique opportunity to view anatomical structures from various angles and perspectives [14]. This newfound spatial understanding not only enhances the radiologists' comprehension of intricate cases but also facilitates more precise and comprehensive diagnoses. AR serves as an invaluable tool, bridging the gap between traditional 2D imaging and the immersive visualization of 3D anatomy, revolutionizing the way medical imaging data is perceived and utilized in clinical practice [15].

Through AR-based visualization, radiologists can interact with medical images in a dynamic and intuitive manner, exploring anatomical structures from every conceivable angle. This level of interactivity empowers them to gain deeper insights into complex pathologies, such as intricate fractures, vascular malformations, or tumors with irregular shapes [16]. By overlaying 3D images onto the patient's actual anatomy in real-time, AR facilitates a seamless integration of imaging data with the physical world, providing a contextualized understanding of the patient's condition. The ability to manipulate the visual representation of medical images aids radiologists in making more informed decisions, planning surgical interventions, and communicating findings with greater clarity to their colleagues and patients.

The successful implementation of AR in medical imaging necessitates robust technological infrastructure and seamless integration with existing radiological workflows. Furthermore, data accuracy and precision are of utmost importance to ensure that the AR-generated 3D representations faithfully represent the underlying anatomy.

Overlaying Diagnostic Information

Through AR, diagnostic information can be seamlessly superimposed directly onto medical images, imparting additional context and accentuating crucial findings. This augmentation of radiological data with AR-generated information facilitates a more comprehensive and intuitive interpretation of imaging studies. By enhancing the radiologists' ability to discern important features and anomalies, AR empowers them to make more informed and accurate diagnostic decisions, ultimately leading to improved patient care and outcomes [17].

AR's ability to overlay diagnostic information directly onto medical images presents a wealth of opportunities in medical diagnostics. Radiologists can leverage AR to annotate and highlight specific regions of interest, aiding in the identification of pathology or abnormalities that might otherwise go unnoticed. This interactive layer of information provides valuable context, enabling radiologists to understand the spatial relationships between different structures and abnormalities. Additionally, AR can be employed to display real-time measurements, quantitative data, and relevant clinical information alongside the imaging study, supporting radiologists in their assessment and expediting the diagnostic process. Furthermore, AR's ability to provide a visual representation of treatment plans and surgical procedures directly on the images assists radiologists and other healthcare professionals in collaborative decision-making and treatment planning [18].

Guided Procedures

AR technology can seamlessly superimpose guidance and navigation information directly onto the patient's body during interventional procedures. This invaluable augmentation equips radiologists with real-time visual cues, enabling them to perform intricate and delicate interventions with heightened accuracy and confidence. By fusing the physical reality with vital navigational data, AR enhances the radiologists' situational awareness, streamlining the execution of complex procedures and ultimately advancing patient care through improved procedural outcomes [19].

During interventional procedures, AR serves as a virtual guide, providing radiologists with a comprehensive and contextual understanding of the anatomical structures and target areas [20]. By overlaying 3D visualizations, such as vessel pathways or tumor margins, onto the patient's body surface, AR assists radiologists in precisely navigating catheters, needles, or instruments to the intended locations [21]. The dynamic nature of AR allows for real-time adjustments and adaptability to patient-specific anatomy, ensuring that procedures remain tailored and optimized for each individual case [22]. Moreover, AR-generated information can include real-time feedback on instrument positioning and trajectory, helping radiologists avoid critical structures or regions of potential risk, thereby minimizing procedural complications and enhancing patient safety [23].

Training and Education

AR technology offers a simulated and immersive learning environment, enabling aspiring medical professionals to practice interpreting medical images and performing complex procedures with unprecedented realism and interactivity. Through AR, learners can access lifelike medical scenarios and virtual patient cases, facilitating hands-on training without the inherent risks associated with real patients. This transformative approach to medical training empowers students and radiologists to develop their expertise in a safe and controlled setting, fostering competence and confidence before they embark on real-world clinical practice [17].

AR-based medical training platforms provide an array of educational opportunities for learners at various stages of their medical careers. Aspiring radiologists can immerse themselves in virtual radiology reading rooms, where they encounter diverse imaging studies and practice diagnosing a wide spectrum of pathologies. The interactive nature of AR allows learners to manipulate and explore medical images from different angles and modalities, emulating the actual conditions encountered in a clinical setting [24]. Moreover, AR enables trainees to participate in simulated interventional procedures, where they can practice using catheters, guidewires, and other instruments, replicating real-world scenarios with high fidelity. The ability to receive real-time feedback and performance evaluations further enhances the learning experience, ensuring continuous improvement and refinement of skills [25].

Conclusion

Our study highlights the transformative impact of Artificial Intelligence (AI) and Augmented Reality (AR) in the realm of emergency radiology. The integration of these technologies has shown promising potential in enhancing patient outcomes and revolutionizing the practice of radiology in emergency scenarios. By expediting the interpretation process and providing timely insights, AI aids radiologists in making swift and informed decisions, crucial for emergency care. Additionally, AI's capability to effectively triage patients ensures that urgent cases receive immediate medical attention, optimizing resource allocation and reducing response times [26].

On the other hand, Augmented Reality offers innovative approaches to image visualization and interpretation. By displaying medical images in immersive 3D environments, AR empowers radiologists to gain a comprehensive understanding of complex cases, leading to improved diagnostic accuracy. The overlaying of diagnostic information onto medical images further enhances radiologists' abilities, providing essential context and emphasizing critical findings.

In interventional procedures, AR proves to be an invaluable tool by superimposing guidance and navigation information onto patients' bodies. This feature enhances precision and safety during interventions, reducing procedural risks and ultimately contributing to better patient outcomes.

Beyond clinical practice, AR's potential for medical training and education is remarkable. Creating realistic simulation environments allows medical students and radiologists to practice image interpretation and interventional procedures in a risk-free setting, fostering skill development and competence.

The principle of limited generalization becomes especially pertinent in emergency radiology. While AI algorithms have demonstrated impressive capabilities in diagnosing medical conditions, their effectiveness heavily hinges on the data they are trained on. Unfortunately, the availability of diverse and representative datasets in emergency radiology can be a significant challenge. The scarcity of comprehensive data may hinder AI models from achieving optimal performance and generalizing their findings across various patient populations and conditions. In a field where timely and accurate diagnoses are crucial, addressing this limitation is of utmost importance. Efforts must be made to curate large, diverse datasets that encompass a wide range of emergency scenarios. By ensuring that AI models have access to comprehensive data, researchers can enhance the technology's ability to assist radiologists and improve patient outcomes, while simultaneously reducing potential biases that may arise from limited training data.

One of the most pressing concerns surrounding AI in emergency radiology is the lack of interpretability and transparency in AI algorithms. Radiologists often face challenges in fully comprehending how AI systems arrive at their diagnostic conclusions. The operation of AI as "black boxes" can lead to a lack of trust and reluctance to fully embrace AI's recommendations, even when they demonstrate high accuracy. Interpretable AI models become pivotal in addressing this issue. Researchers and developers must prioritize the creation of AI algorithms that can provide clear and understandable explanations for their decisions. By employing interpretable AI, radiologists gain valuable insights into the reasoning behind AI-generated diagnoses, allowing them to validate and corroborate the findings. This newfound understanding fosters confidence in the technology's capabilities and ensures that AI becomes a valuable tool rather than an enigmatic entity in the medical diagnostic process.

The integration of AI in medical settings, including emergency radiology, inevitably brings forth regulatory and legal challenges. Safety, efficacy, and compliance with healthcare regulations are paramount in this context. To ensure the responsible deployment of AI, proper validation and certification processes should be established, seeking approval from relevant regulatory bodies. The validation process must be rigorous, encompassing extensive testing on diverse datasets and thorough evaluations of AI algorithms' performance. By adhering to regulatory guidelines, medical professionals can confidently incorporate AI into their decision-making processes, knowing that the technology meets stringent standards for safety and efficacy. Simultaneously, adhering to legal requirements ensures that patient data privacy and security are protected. Regular training and evaluation of AI algorithms are essential to keep them up-to-date and accurate. Additionally, implementing strict quality assurance protocols for image acquisition will enhance AI performance by providing high-quality input data. Healthcare institutions should adopt ethical guidelines specific to AI usage in radiology. These guidelines should address patient privacy, data security, and potential biases in algorithmic decision-making to protect patient rights and ensure fair and equitable care.

For AR to be effective, it requires high-quality medical images as its foundation. In emergency situations, obtaining these images promptly can be challenging, especially if the patient is in critical condition or the hospital lacks the necessary infrastructure. The accuracy of AR-generated information heavily depends on the quality and completeness of the underlying data, which can hinder its real-world application in certain emergency scenarios. In high-pressure emergency situations, any delay or malfunction in the AR system could lead to critical consequences. From minor software glitches to hardware malfunctions, these technological limitations may compromise the efficiency and reliability of AR in emergency radiology. Ensuring robustness and stability is crucial when implementing AR systems in real-time medical settings.

The implementation and maintenance of AR technology can be expensive, particularly for smaller healthcare facilities or those in resource-constrained regions. The costs of hardware, software, training, and ongoing technical support may hinder widespread adoption, limiting access to AR benefits for many patients and healthcare providers.

References

[1] C. Arth, R. Grasset, L. Gruber, and T. Langlotz, "The history of mobile augmented reality," *arXiv preprint arXiv*, 2015.

[2] D. Arioputra and C. H. Lin, "Mobile augmented reality as a Chinese menu translator," in *2015 IEEE International Conference on Consumer Electronics - Taiwan*, 2015, pp. 7–8.

[3] W. E. Brant and C. A. Helms, "Fundamentals of diagnostic radiology," 2012.

[4] H. E. Johns and J. R. Cunningham, "The physics of radiology," 1983.

[5] D. Sutton, "A textbook of radiology and imaging," 1987.

[6] S. Wang and R. M. Summers, "Machine learning and radiology," *Med. Image Anal.*, 2012.

[7] N. R. Dunnick and C. P. Langlotz, "The radiology report of the future: a summary of the 2007 Intersociety Conference," *J. Am. Coll. Radiol.*, vol. 5, no. 5, pp. 626–629, May 2008.

[8] M. A. O'Reilly and K. Hynynen, "Blood-brain barrier: real-time feedback-controlled focused ultrasound disruption by using an acoustic emissions-based controller," *Radiology*, vol. 263, no. 1, pp. 96–106, Apr. 2012.

[9] R. Kitchin, T. P. Lauriault, and G. McArdle, "Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards," *Reg. Stud.*, 2015.

[10] A. Franklin *et al.*, "Dashboard visualizations: Supporting real-time throughput decision-making," *J. Biomed. Inform.*, vol. 71, pp. 211–221, Jul. 2017.

[11] P. V. Pandharipande *et al.*, "CT in the Emergency Department: A Real-Time Study of Changes in Physician Decision Making," *Radiology*, vol. 278, no. 3, pp. 812–821, Mar. 2016.

[12] D. V. Dimitrov, "Medical Internet of Things and Big Data in Healthcare," *Healthc. Inform. Res.*, vol. 22, no. 3, pp. 156–163, Jul. 2016.

[13] C. S. Lee, P. G. Nagy, S. J. Weaver, and D. E. Newman-Toker, "Cognitive and system factors contributing to diagnostic errors in radiology," *AJR Am. J. Roentgenol.*, vol. 201, no. 3, pp. 611–617, Sep. 2013.

[14] M. Mekni and A. Lemieux, "Augmented reality: Applications, challenges and future trends," *Applied computational science*, 2014.

[15] J. R. Petrella *et al.*, "Preoperative functional MR imaging localization of language and motor areas: effect on therapeutic decision making in patients with potentially resectable brain tumors," *Radiology*, vol. 240, no. 3, pp. 793–802, Sep. 2006.
[16] D. W. F. Van Krevelen and R. Poelman, "A survey of augmented reality technologies, applications and limitations," *International journal of virtual reality*, 2010.
[17] N. F. Saidin, N. D. Abd Halim, and N. Yahaya, "A review of research on augmented reality in education: Advantages and applications," *Int. Educ. Stud.*, vol. 8, no. 13, Jun. 2015.
[18] R. Azuma, Y. Baillot, and R. Behringer, "Recent advances in augmented reality," *IEEE computer*, 2001.
[19] S. K. Feiner, "Augmented reality: A new way of seeing," *Sci. Am.*, 2002.
[20] S. Bernhardt, S. A. Nicolau, L. Soler, and C. Doignon, "The status of augmented reality in laparoscopic surgery as of 2016," *Med. Image Anal.*, 2017.
[21] S. Nicolau, L. Soler, D. Mutter, and J. Marescaux, "Augmented reality in laparoscopic surgical oncology," *Surg. Oncol.*, 2011.
[22] R. T. Azuma, "A survey of augmented reality," *Presence: teleoperators & virtual environments*, 1997.
[23] S. Küçük, S. Kapakin, and Y. Göktaş, "Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load," *Anat. Sci. Educ.*, 2016.
[24] J. H. Shuhaiber, "Augmented reality in surgery," *Arch. Surg.*, 2004.
[25] C. Moro, Z. Štromberga, A. Raikos, and A. Stirling, "The effectiveness of virtual and augmented reality in health sciences and medical anatomy," *Anat. Sci. Educ.*, vol. 10, no. 6, pp. 549–559, Nov. 2017.
[26] F. Bektas, C. Eken, S. Soyuncu, L. Kusoglu, and Y. Cete, "Contribution of goal-directed ultrasonography to clinical decision-making for emergency physicians," *Emerg. Med. J.*, vol. 26, no. 3, pp. 169–172, Mar. 2009.