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A Multidimensional Biomedical Engineering (Bme) Study of Ai and Xr Applications in Healthcare

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Abstract

The convergence of Artificial Intelligence (AI) and Extended Reality (XR) has ushered in a transformative era in Biomedical Engineering, offering significant advancements in diagnostics, treatment, and education. This review aims to explore the integration of AI and XR technologies, highlighting their collective potential to revolutionize healthcare practices while addressing associated challenges. AI, with its adaptive algorithms, has become indispensable in medical imaging, disease prediction, and optimizing treatment protocols. XR technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), provide immersive and interactive environments that enhance medical training, rehabilitation, and surgical precision. This study critically evaluates the applications of AI and XR in real-world biomedical scenarios, comparing outcomes with traditional healthcare practices and presenting case studies that demonstrate their effectiveness. Additionally, the review discusses the limitations of these technologies, including algorithmic biases, privacy concerns, and the need for robust regulatory frameworks. The ethical considerations surrounding patient safety and data security are examined to ensure a balanced perspective. By analyzing recent advancements and identifying research gaps, this paper provides actionable insights and suggests future directions for the integration of AI and XR in Biomedical Engineering. With the potential to refine diagnostics, enhance therapeutic interventions, and bridge the gap between theoretical knowledge and clinical practice, the fusion of AI and XR technologies represents a paradigm shift in healthcare delivery.

Keywords: Eye Drop Packaging, Drug Product Leakage, Discoloration in Ophthalmic Formulations, Printed Label Contamination, Cap and Nozzle Design, Printed Label Contamination.

Introduction

In the ever-evolving landscape of healthcare, the integration of Artificial Intelligence (AI) and Extended Reality (XR) has emerged as a transformative force, signaling a paradigm shift in Biomedical Engineering (BME). This interdisciplinary convergence promises to revolutionize medical diagnostics, treatment protocols, and education, fostering a new era of innovation with far-reaching implications for patient care and healthcare delivery. AI, with its capacity for adaptive learning and intelligent decision-making, has transformed medical imaging, predictive analytics, and personalized treatment strategies. Meanwhile, XR technologies, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), provide immersive and interactive environments that enhance surgical precision, rehabilitation, and experiential learning.

This investigative exploration aims to critically explore the intersection of AI and XR in Biomedical Engineering, providing a structured analysis of their potential, applications, and associated challenges. By investigating real-world implementations and comparing outcomes with traditional healthcare practices, this study seeks to evaluate the practical impact of these technologies. The review includes an analysis of current advancements in AI-driven medical imaging, XR-enhanced surgical procedures, and the use of immersive technologies in medical education and rehabilitation. Furthermore, it identifies gaps in existing research and highlights the need for comprehensive studies to validate these innovations.

Key challenges, including algorithmic biases, privacy concerns, and ethical implications, are addressed to ensure a balanced perspective on the adoption of AI and XR in healthcare. Additionally, this work emphasizes the importance of establishing regulatory frameworks and standardizing best practices to ensure patient safety and data security. By critically examining these factors, this review not only underscores the transformative potential of AI and XR in Biomedical Engineering but also provides a roadmap for future research and development in this field.

As AI evolves into a diagnostic powerhouse and XR becomes an indispensable tool for immersive learning, their synergy offers unprecedented opportunities to enhance healthcare delivery. This review explores how this fusion of intelligent algorithms and immersive environments can redefine the boundaries of possibility, paving the way for innovative solutions that bridge the gap between theoretical advancements and practical implementation in Biomedical Engineering.

Methods and Experimental Analysis

This research adopts a mixed-methods approach to investigate the integration of Artificial Intelligence (AI) and Extended Reality (XR) within Biomedical Engineering, combining quantitative and qualitative methodologies to ensure a comprehensive analysis.

Quantitative Analysis

The quantitative component focuses on leveraging state-of-the-art AI algorithms to analyze medical imaging datasets, evaluating their performance in diagnostic accuracy and treatment optimization. Key steps include:

Dataset Selection and Preprocessing: Publicly available and de-identified medical imaging datasets (e.g., MRI, CT scans) were curated and preprocessed to ensure uniformity and eliminate noise.

Algorithm Development and Training: Advanced machine learning techniques, including convolutional neural networks (CNNs) and deep reinforcement learning, were employed to develop AI models tailored for specific diagnostic tasks.

Performance Metrics: The models were evaluated based on standard metrics such as accuracy, sensitivity, specificity, precision, and F1-score to ensure reliability in clinical applications.

Comparative Analysis: Results from the developed AI models were compared against existing traditional diagnostic methods to assess their efficacy and identify areas for improvement.

Qualitative Investigation

The qualitative component aims to explore the practical implications, challenges, and perceptions surrounding the integration of AI and XR in healthcare. Key steps include:

Data Collection

Semi-structured interviews with healthcare professionals, including radiologists, surgeons, and rehabilitation therapists, were conducted to gather insights into real-world applications and potential barriers.

Surveys targeting a broader audience, including patients and medical educators, were distributed to understand public and professional perceptions of AI and XR technologies in healthcare.

Thematic Analysis: A systematic thematic analysis was performed to identify recurring themes, such as ethical concerns, usability, accessibility, and the impact of these technologies on patient outcomes. NVivo software was utilized for coding and data organization.

Implementation Process

The implementation involved the simultaneous development of AI algorithms and XR applications:

AI Development: Machine learning frameworks like TensorFlow and PyTorch were utilized for training and testing AI models, while addressing challenges such as algorithm biases and computational efficiency.

XR Application Development: XR applications were designed using tools such as Unity and Unreal Engine to simulate immersive environments for surgical training, rehabilitation, and patient education. These applications were tested for usability and integration into existing healthcare workflows.

Data Analysis

Quantitative Data: Statistical methods, including regression analysis and ROC curves, were employed to validate the performance of AI algorithms.

Qualitative Data: Insights from interviews and surveys were categorized and interpreted through thematic analysis, providing a holistic understanding of user experiences and concerns.

Ethical Considerations

This study adhered to strict ethical guidelines to ensure the integrity and privacy of all participants and data:

Informed Consent: All participants provided written consent after being informed about the study’s objectives and procedures.

Data Anonymization: Personal and sensitive information was anonymized to maintain confidentiality.

Compliance: The study complied with ethical standards set by institutional review boards and applicable regulations, including GDPR and HIPAA, for handling medical data.

Limitations

Acknowledging the limitations of this research, potential challenges include:

Dataset Availability: The reliance on publicly available datasets may limit the scope of the findings.

Algorithm Biases: The performance of AI models may be influenced by biases in the training data, necessitating further refinement and validation.

Scalability of XR Applications: The development and deployment of XR applications in diverse clinical settings may face technical and logistical barriers.

Through this methodological framework, the research aims to contribute to a deeper understanding of the transformative potential of AI and XR in reshaping Biomedical Engineering practices, while identifying pathways to overcome existing challenges.

Background Research and Investigative Exploration for Available Knowledge

Artificial Intelligence (AI)

Artificial intelligence (AI) refers to the capacity of machines and software systems to simulate human intelligence and execute tasks that typically require cognitive functions. AI applications have expanded into diverse fields, including web search engines (e.g., Google Search), recommendation systems (e.g., YouTube, Amazon, Netflix), virtual assistants (e.g., Siri, Alexa), autonomous vehicles (e.g., Waymo), generative AI tools (e.g., ChatGPT, AI-based art), and strategic gameplay (e.g., chess, Go) [1,2,3]. These practical implementations highlight AI's transformative potential in automating processes, enhancing user experiences, and driving innovations across industries [4,5,6].

The inception of AI as an academic discipline occurred in 1956. Since then, its trajectory has been characterized by periods of heightened optimism, followed by phases of stagnation due to limited computational resources, technical challenges, and unrealistic expectations [7,8,9].

However, since 2012, AI has witnessed exponential growth, primarily fueled by advancements in machine learning (ML) and deep learning (DL) technologies. These techniques have outperformed traditional AI methodologies, ushering in a new era of innovation backed by increased funding and global research interest [3-13].

AI research encompasses various subfields, each addressing unique objectives through specialized methodologies. Key goals include reasoning, knowledge representation, planning, learning, natural language processing (NLP), perception, and robotics. A prominent aspiration in the field is achieving general intelligence—an AI capable of solving a wide range of complex problems with human-like adaptability [11-22]. Progress toward these objectives relies on diverse problem-solving techniques, such as search algorithms, mathematical optimization, artificial neural networks, probabilistic methods, and logic-based approaches. Moreover, AI draws insights from disciplines like psychology, linguistics, philosophy, neuroscience, and economics, emphasizing its multidisciplinary nature [13-33]. This interplay of fields highlights AI's complexity and its role as a cornerstone of modern technological advancements.

Biomedical Engineering (BME)

Biomedical Engineering (BME), often referred to as medical engineering, is a dynamic and interdisciplinary field that integrates engineering principles and design concepts with medicine and biology. Its primary objective is to advance healthcare by improving diagnostics, therapies, and patient care. BME bridges the gap between engineering and healthcare, providing innovative solutions that address medical challenges and enhance patient outcomes.

The responsibilities of biomedical engineers are diverse, ranging from designing and managing medical devices to ensuring compliance with healthcare standards [22-44]. Key tasks include equipment procurement, routine testing, preventive maintenance, and optimization of medical tools. These roles are critical in hospital settings, often undertaken by Biomedical Equipment Technicians (BMETs) or clinical engineers. Beyond maintenance, biomedical engineers contribute significantly to research and development in areas such as biocompatible prosthetics, diagnostic devices, therapeutic equipment, and regenerative medicine [2-22].

Historically, BME has evolved from being an interdisciplinary specialization to an established field with a unique identity. Its research spans a broad spectrum, including the development of micro-implants, imaging technologies (e.g., MRI, ECG), and regenerative tissue engineering. Moreover, BME plays a pivotal role in the advancement of pharmaceutical drugs and therapeutic biologicals. This field exemplifies the synergy between engineering and biology, driving innovations that enhance medical treatments and redefine healthcare practices.

Extended Reality (XR)

Extended reality (XR) encompasses augmented reality (AR), virtual reality (VR), and mixed reality (MR), offering transformative ways to interact with digital and physical environments. XR technologies enable users to merge the real and virtual worlds, fostering immersive experiences that are reshaping sectors such as education, entertainment, and healthcare [18-38]. Although the concept of VR dates back to the 19th century, significant progress began in the 1990s with advancements in hardware and computer graphics. However, challenges like bulky headsets, limited computing power, and motion sickness delayed widespread adoption. Since 2010, XR technologies have gained renewed attention due to innovations in VR, AR, and MR devices. Modern VR headsets, such as the Oculus Rift, HTC Vive, and devices by Valve and Samsung, offer improved resolution, frame rates, and reduced motion sickness. Similarly, AR and MR technologies have made strides, with devices like Microsoft HoloLens enabling untethered mixed-reality experiences and applications like Pokémon GO popularizing AR. Despite these advancements, XR's integration into biomedicine, surgery, and medical education remains underexplored [16-28]. This research aims to address this gap by analyzing the potential of XR in biomedical applications. Current trends highlight XR's role in visualization, clinical care, and interactive education [33-44]. Case studies demonstrate XR's ability to enhance medical training through immersive platforms, enabling healthcare professionals to practice complex procedures in simulated environments. However, challenges persist, including the high cost, complexity, and limited scalability of XR platforms. This study explores these limitations while emphasizing the opportunities XR offers for fostering innovation in healthcare and education. By providing a comprehensive overview of XR technologies and their biomedical applications, this research seeks to inform professionals about XR's transformative potential, paving the way for future discoveries and implementations.

This exploration of AI, BME, and XR highlights their individual strengths and intersections, providing a foundation for integrating these technologies to revolutionize biomedical engineering. By addressing the challenges and leveraging their combined potential, this research aims to contribute to advancements that enhance patient care, medical training, and healthcare innovation.

The Potentials for AR-VR-XR in Medical Informatics

The integration of Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) into medical informatics is revolutionizing healthcare practices, offering unprecedented opportunities to enhance medical training, diagnosis, treatment, and patient care. These immersive technologies are transforming traditional approaches to medicine by enabling healthcare professionals to interact with data, patients, and complex medical scenarios in novel and impactful ways.

Enhanced Patient Understanding and Pain Management

AR, VR, and XR technologies contribute significantly to improving patient understanding of their medical conditions and treatments. By offering immersive visualizations of complex medical procedures or anatomical structures, these technologies bridge communication gaps between doctors and patients. For instance, VR programs have been developed to distract patients during painful treatments, such as chemotherapy, reducing their discomfort and anxiety. Immersive XR applications also allow medical professionals to experience scenarios from the patient's perspective, fostering empathy and strengthening the doctor-patient relationship. This empathetic approach improves trust and encourages better patient outcomes.

Revolutionizing Surgical Training and Preoperative Planning

XR technologies have become indispensable tools for surgical training and preparation. AR and VR enable medical practitioners to practice surgical techniques using realistic simulators, eliminating the need for live patients, cadavers, or animals. These simulators provide an immersive, risk-free environment for honing technical skills and learning complex procedures. Furthermore, XR-based platforms allow surgeons to interact with detailed 3D models of patient-specific anatomy, derived from imaging data. This aids in preoperative planning, enabling surgeons to visualize and rehearse procedures in advance. The tactile feedback integrated into XR applications enhances precision, equipping surgeons with the confidence and competence needed for real-life operations. Additionally, collaborative XR environments allow teams of surgeons to discuss and strategize procedures, further optimizing surgical outcomes.

Advancements in Medical Education and Training

The incorporation of XR technologies into medical education has transformed the way medical students and professionals acquire knowledge. Interactive AR and VR applications provide an immersive learning environment where learners can explore anatomically accurate 3D models of the human body. These tools enhance the comprehension of intricate anatomical structures, improve spatial understanding, and facilitate hands-on practice of medical procedures. XR simulations also enable the replication of rare or complex medical scenarios, offering learners the opportunity to gain experience in situations they may not encounter during traditional training.

Innovations in Diagnosis and Health Assessment

The ability of AR, VR, and XR to create real-time, interactive 3D models has opened new avenues in diagnostic medicine. XR technologies allow clinicians to visualize internal organs, tissues, and bones in unprecedented detail, aiding in the detection of fractures, tumors, and other medical conditions. These immersive tools enable doctors to scan patient bodies and identify abnormalities with greater accuracy. Additionally, XR facilitates patient education by visually explaining diagnoses and surgical steps, improving patient comprehension and decision-making.

Transforming Collaborative Care and Multidisciplinary Interaction

XR platforms foster collaboration among healthcare professionals, allowing specialists from different disciplines to work together in shared virtual environments. This integration enhances communication and coordination, leading to more effective treatment plans and improved patient outcomes. XR applications enable real-time sharing and manipulation of 3D medical data, facilitating cross-disciplinary discussions and fostering innovation in medical research and treatment.

Challenges and Future Potential

While the benefits of AR, VR, and XR in medical informatics are immense, challenges such as cost, accessibility, and the complexity of developing and deploying these technologies remain. However, continued advancements in hardware, software, and user interfaces are expected to mitigate these barriers. As XR technologies become more affordable and accessible, their adoption is likely to accelerate, expanding their impact across a broader range of healthcare settings.

AR, VR, and XR hold transformative potential for medical informatics, reshaping the landscape of healthcare education, diagnosis, treatment, and patient engagement. These technologies offer immersive, interactive, and precise solutions to longstanding challenges in medicine, paving the way for a more informed, empathetic, and effective healthcare ecosystem. As research and innovation in this field progress, the integration of XR technologies will undoubtedly redefine medical practices, elevate the standards of care and improve patient outcomes. To better visualize the concepts Figures 1 and 2 provide illustrations towards

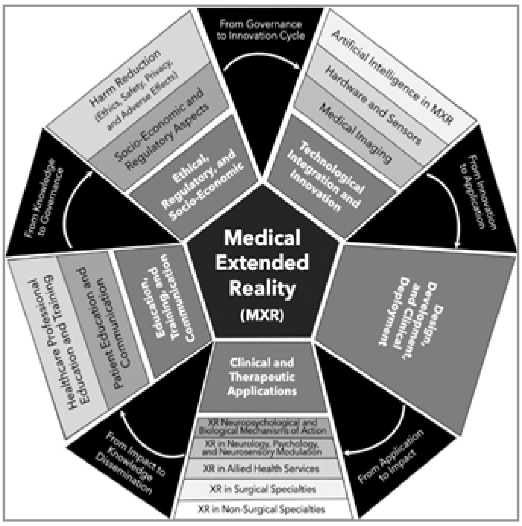

Figure 1: The Medical Extended Reality (MXR) overviews

Figure 2: An Experimental Outlook for Ar-Vr-Xr in Terms of Medical Informatics

Applications with Advancements and Innovations towards AR-VR-XR

The convergence of Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) with Artificial Intelligence (AI) has unlocked transformative opportunities across various sectors. This integration addresses complex challenges, enhances user experiences, and drives innovation in industries such as healthcare, defense, gaming, robotics, autonomous systems, and advanced visualization. The global applicability of AI-AR/VR/XR technologies and their impact are illustrated within Figures 3, 4, 5 showcasing a comprehensive visual representation of their advancements.

Medical Training and Healthcare Advancements

The integration of AI with AR, VR, and XR has revolutionized medical training by creating immersive, risk-free environments for healthcare professionals. These technologies enable trainees to practice surgical procedures and diagnostic tasks with high precision. AI-driven algorithms enhance this process by analyzing XR-generated data, objectively assessing trainees' skills, and offering tailored feedback.

Key advancements include:

Virtual Patients: AI-powered virtual patients simulate real-world interactions, allowing medical students to develop diagnostic and communication skills.

Skill Assessment: AI extracts feature from XR data to provide quantitative performance evaluations, enhancing the effectiveness of medical training programs.

Advanced Visualization: AI-powered XR platforms aid in visualizing intricate anatomical structures, improving surgical planning and training while fostering better patient outcomes.

Armed Forces Training

AI-XR combinations have transformed training for armed forces, offering dynamic and adaptive virtual environments to simulate real-world scenarios. AI agents act as intelligent adversaries, challenging participants based on their skill levels and enhancing overall preparedness.

Notable Advancements Include

Adaptive AI Agents: Using techniques like Gaussian process Bayesian optimization, AI agents dynamically improve their strategies through interaction, creating realistic and effective training scenarios.

AI-AI Interactions: The integration of multiple AI entities in XR environments allows participants to experience diverse challenges, simulating unpredictable real-world combat situations.

Cost-Effective Training: These technologies eliminate the need for extensive physical resources, reducing training costs while maintaining effectiveness.

Gaming Innovations

The synergy between AI and XR has elevated the gaming industry by offering highly interactive, immersive, and challenging experiences. AI agents serve as both integral components of gameplay and tools for developing and testing advanced algorithms.

Key innovations include

AI-Driven Non-Player Characters (NPCs): These NPCs adapt to players' behaviors, enhancing game dynamics and engagement.

Complex Environment Simulation: Games like Starcraft II and Dota 2 serve as platforms for AI development, pushing the boundaries of algorithmic innovation.

Immersive Gaming Experiences: AR and VR environments combined with AI create unparalleled user experiences by blending realism with adaptability.

Robotics and Autonomous Systems

AI-AR/VR/XR technologies play a crucial role in designing and training robots and autonomous vehicles. Virtual environments provide a cost-effective solution for training and testing these systems in realistic yet controlled conditions.

Advancements Include

Feature Extraction and Interaction Modeling: AI algorithms process sensor data within XR environments, enabling robots and autonomous systems to navigate complex tasks.

Reinforcement Learning (RL): AI uses RL within virtual simulations to train robots and autonomous vehicles, preparing them for real-world deployment.

Scalability: Virtual training environments offer scalable solutions for developing AI-driven systems, significantly reducing the cost and time required for physical testing.

Advanced Visualization for Complex Systems

AI and XR integration have redefined advanced visualization, offering intuitive and accessible platforms for understanding complex structures and systems. These technologies enhance visualization capabilities in industries ranging from medicine to engineering.

Key Features Include

AI-Powered Imaging: AI algorithms optimize XR displays to focus on target structures, improving clarity and accuracy in medical and scientific applications.

Deep Learning Visualization: Advanced AI models integrated with XR platforms support the visualization of deep learning structures, aiding researchers and developers in understanding intricate networks.

User-Centric Interfaces: Intuitive interfaces make advanced visualization tools more accessible to a wider audience, fostering collaboration and innovation.

Challenges and Future Potential

Despite their transformative potential, challenges such as cost, accessibility, and technological complexity remain. Continued advancements in hardware, software, and AI algorithms will help overcome these barriers, accelerating the adoption of AR, VR, and XR technologies across sectors.

The fusion of AR, VR, and XR with AI continues to redefine

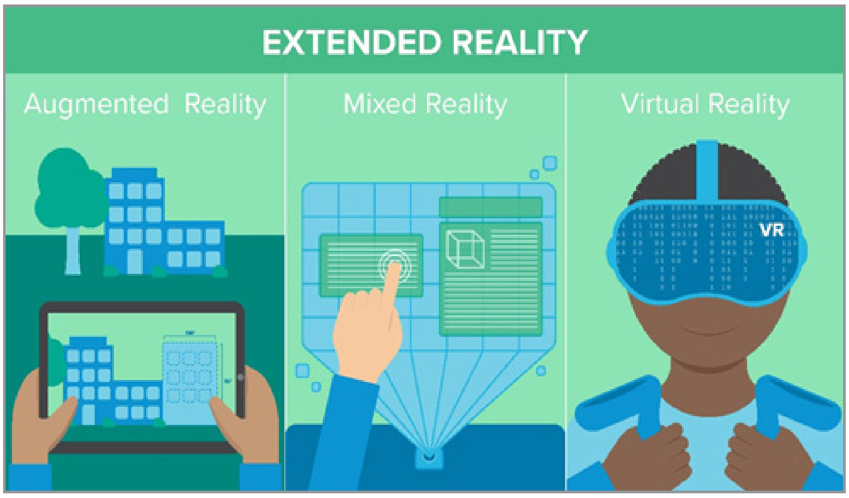

Figure 3: The Global Applicability of Ai-Ar/Vr/Xr Technologies and Their Impacts 1

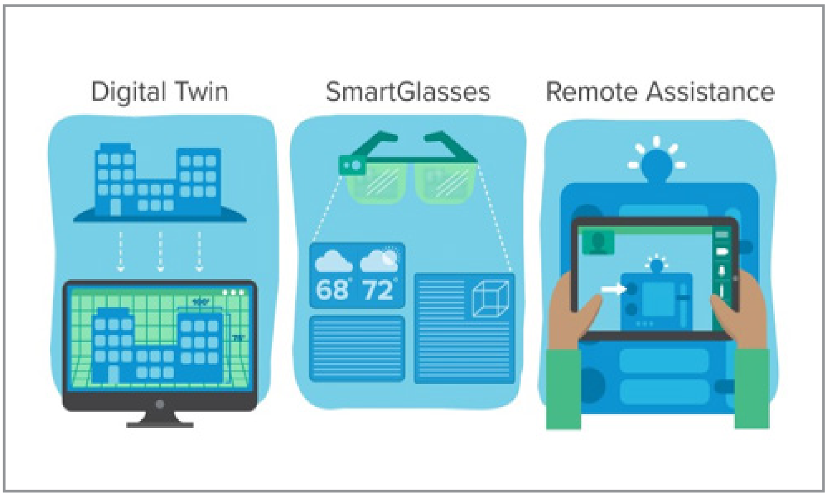

Figure 4: The Global Applicability of Ai-Ar/Vr/Xr Technologies and Their Impacts 2

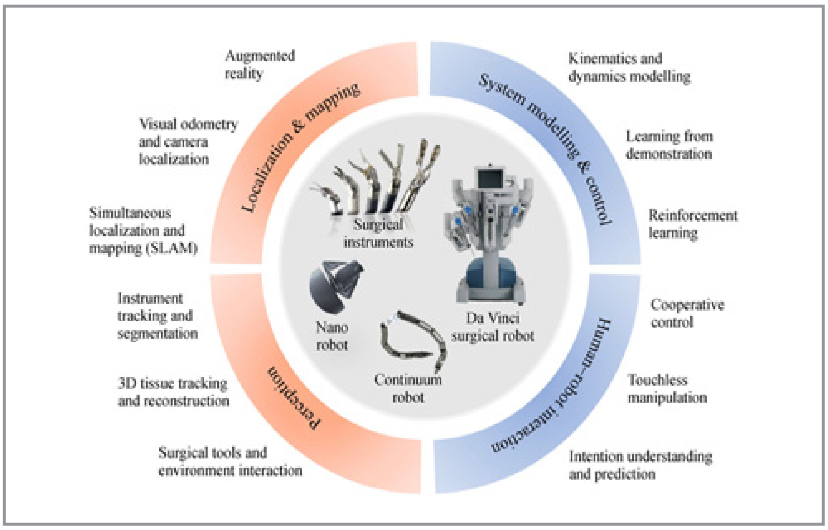

Figure 5: The Global Applicability of Ai-Ar/Vr/Xr Technologies and Their Impacts 3

Ai-Ar-Vr-Xr Overviews: Perspectives from Various Types of Healthcare Professionals

The integration of Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) is revolutionizing healthcare by providing transformative tools and applications. Insights derived from various professionals highlight the potential of XR technologies in healthcare, offering a comprehensive understanding of their impact, opportunities, and challenges. This overview caters to healthcare professionals, extended reality technologists, biomedical engineers, instrumentation experts, and computer scientists interested in exploring the intersection of XR and healthcare.

Immersive Training and Education

XR, powered by AI, has redefined medical training and education by creating immersive, risk-free environments for healthcare professionals. These tools simulate realistic scenarios, allowing trainees to practice procedures, hone skills, and gain confidence without risking patient safety.

Virtual Patients: AI-driven virtual patients simulate human interactions, enabling medical students to practice diagnostic and communication skills effectively.

Surgical Simulations: XR environments provide high-fidelity simulations for complex surgical procedures, enhancing the learning experience and minimizing errors in real-life surgeries.

Personalized Learning: AI algorithms tailor training modules to individual learners, adapting content to their pace and performance for improved outcomes.

Diagnosis and Treatment Support

AI-AR/VR/XR integration enhances diagnostic accuracy and supports treatment planning by visualizing complex data in accessible formats.

Enhanced Imaging: AI-powered XR platforms transform traditional imaging techniques, offering 3D visualizations of anatomy and pathology for better diagnosis and surgical planning.

Precision Medicine: XR applications aid in customizing treatment plans by visualizing patient-specific data and predicting outcomes using AI models.

Therapeutic Applications: Virtual environments are used for cognitive rehabilitation, pain management, and mental health treatments, providing patients with immersive therapeutic experiences.

Remote Healthcare and Telemedicine

XR technologies are playing a pivotal role in advancing remote healthcare and telemedicine services.

Virtual Consultations: XR facilitates interactive, immersive telemedicine sessions, bridging the gap between patients and healthcare providers.

AI-Assisted Diagnostics: Remote diagnostic tools enhanced by AI and XR enable accurate assessments, even in geographically isolated areas.

Training for Remote Providers: XR simulations offer tailored training programs for healthcare professionals working in underserved regions.

Surgical Assistance and Augmented Reality

AR-assisted surgeries, combined with AI algorithms, are transforming operating rooms by providing surgeons with real-time, actionable insights.

Augmented Surgical Guidance: AR overlays critical information, such as anatomy and surgical tools, onto the surgeon's field of view, enhancing precision.

AI-Powered Analytics: Real-time data analysis by AI ensures improved decision-making and reduces surgical risks.

Collaboration in Surgery: XR platforms allow surgeons and experts to collaborate remotely during complex procedures, enhancing outcomes through shared expertise.

Healthcare Infrastructure and Patient Engagement

The fusion of AI and XR is redefining patient engagement and healthcare infrastructure.

Interactive Patient Education: XR applications help patients understand their medical conditions and treatment plans through immersive, interactive experiences.

AI-Driven Resource Optimization: AI models analyze XR-generated data to optimize healthcare workflows, resource allocation, and hospital management.

Enhanced Accessibility: XR technologies make healthcare more inclusive by offering innovative solutions for patients with disabilities or language barriers.

While AI-AR-VR-XR technologies offer immense potential in healthcare, challenges such as high implementation costs, ethical considerations, and data security must be addressed. Future advancements should focus on improving accessibility, integrating cross-disciplinary expertise, and addressing regulatory frameworks to ensure safe and effective adoption. The intersection of AI, AR, VR, and XR with healthcare provides transformative opportunities for education, diagnosis, treatment, and patient engagement. By leveraging these technologies, healthcare professionals can enhance outcomes, improve accessibility, and redefine patient care. This integration continues to shape the future of healthcare, offering innovative solutions for challenges faced by the medical community.

Case Studies Analysis: Biomedical Engineering (BME) for AI-VR-XR Perspectives

The following case studies comprehensively explore the integration of Artificial Intelligence (AI), Virtual Reality (VR), and Extended Reality (XR) in biomedical engineering (BME), showcasing their versatility and transformative potential in healthcare.

These case studies provide critical insights into how XR technologies enhance biomedical applications, ranging from cellular visualization to surgical planning and medical education.

Case Study 1: XR for Cellular Visualization

This case highlights the use of XR to visualize complex protein images within single cells, providing an immersive platform for analyzing cellular architecture and protein distribution.

Technology Overview: The investigation utilizes Head-Mounted Displays (HMDs) and VR software, such as ConfocalVR by Immersive Science, to render 3D visualizations of high-resolution CODEX (CO-detection by indexing) images. These datasets are derived from multiplex imaging of cellular markers.

Application in Research: By leveraging ConfocalVR, researchers gain a deeper understanding of subcellular structures and spatial protein distribution, significantly enhancing their ability to analyze cellular mechanisms.

Impact: This approach bridges the gap between static imaging and dynamic, interactive data interpretation, providing an advanced tool for biomedical research and education.

Case Study 2: AR in Neurosurgical Planning and Execution

This study focuses on the application of Augmented Reality (AR) for improving neurosurgical procedures.

Implementation: AR technology was employed to visualize presurgical neurovascular anatomy, particularly for interventions in the head, neck, and spine. AR surgical navigation (ARSN) techniques were utilized for precise screw placements in spine fixation procedures.

Findings: The use of AR significantly enhanced the accuracy of screw placements, reducing cortical breaches and improving procedural outcomes.

Clinical Relevance: AR's ability to overlay critical anatomical information in real time facilitates better decision-making and surgical precision, setting a benchmark for integrating AR into surgical workflows.

Case Study 3: VR for Cardiac Surgical Planning

This case demonstrates the use of VR in planning complex cardiac surgeries for patients with congenital anomalies and heart failure.

Methodology: VR technology enabled the creation and manipulation of computational models of cardiac anatomy. These models provided an interactive environment for surgeons to visualize both typical and altered anatomy.

Benefits: Enhanced spatial comprehension allowed surgeons to plan and simulate surgical interventions, improving accuracy and confidence during actual procedures.

Significance: This case highlights how VR serves as a valuable planning tool for intricate and high-risk surgical scenarios, offering a new dimension to preoperative preparation.

Case Study 4: Cost-Effective VR in Medical Education

This study explores the use of Google Cardboard, a low-cost VR viewer, for educational purposes in biomedical sciences.

Implementation: Google Cardboard was paired with smartphones to deliver immersive 360-degree video experiences, such as visualizing plant cell organelles.

Outcomes: The experiment provided learners with an engaging, interactive educational experience, demonstrating the potential of affordable VR solutions in academic settings.

Broader Impact: This case emphasizes the democratization of VR technology, making immersive learning accessible to institutions with limited budgets.

Analysis of XR Implementation Strategies

The implementation of XR in biomedical applications varies significantly in terms of complexity and cost, offering a wide spectrum of solutions to cater to diverse needs and resources.

Entry-Level Solutions: At the lower end of the cost spectrum, tools like Google Cardboard paired with open-source software (e.g., Blender) enable affordable VR experiences. These solutions require minimal investment and basic programming or 3D modeling skills.

Advanced Platforms: High-end XR solutions designed for specialized medical applications often involve significant costs, sometimes reaching tens of thousands of dollars. These platforms offer integrated hardware and software for precise and tailored applications.

Classification Overview: Table 1 categorizes XR solutions into three cost tiers—no/low cost, prosumer, and professional/commercial. Each tier is further divided into software-only, hardware-only, and complete platform solutions. This classification enables users to align their choices with available resources and technical capabilities.

These case studies and implementation strategies underscore the transformative potential of XR technologies in biomedical engineering and healthcare. From affordable educational tools to sophisticated surgical planning platforms, XR provides a versatile and impactful suite of solutions tailored to diverse biomedical applications.

By addressing varying levels of technical expertise and resource availability, XR demonstrates its potential to democratize healthcare innovations, paving the way for widespread adoption and significant advancements in the field. To provide more context concerning the case studies Figure 6 sheds some lights on the matter of retrospect.

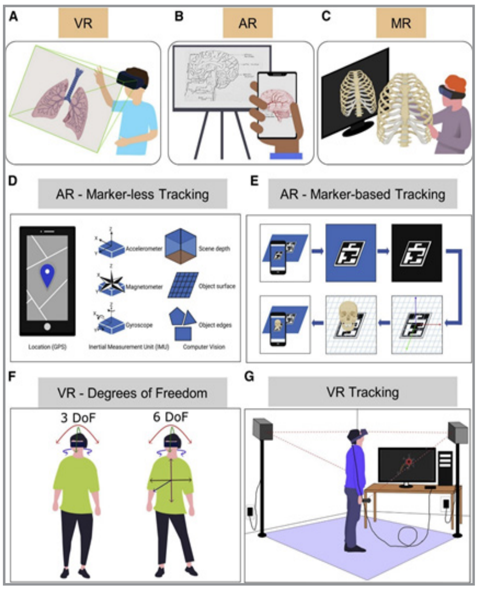

Figure 6: An overview of the Case Studies Analysis

Challenges, Concerns within AR-VR-XR Systems: Addressing Technical, Ethical, Practical Limitations

The integration of Extended Reality (XR), including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), in biomedical applications presents immense opportunities but also comes with significant challenges and concerns. These challenges span technical limitations, ethical dilemmas, and practical implementation hurdles, all of which must be addressed to harness the full potential of these technologies in healthcare and education. Technical challenges inclusive to the followings.

Computational Constraints and Latency XR experiences often require high computational bandwidth to achieve seamless interaction. Limited computational power can lead to latency issues, which not only degrade user experience but also pose risks, particularly in applications requiring high precision. For instance, in Head-Mounted Displays (HMDs), latency can cause spatial disorientation, potentially leading to collisions with physical objects. In AR systems, inaccuracies in localization can result in the misalignment of virtual elements with the real world, undermining the reliability of the technology.

Proposed Solution: Developing more efficient algorithms, leveraging edge computing, and integrating optimized graphics processing units (GPUs) to minimize latency and enhance real-time performance.

Tracking and Interaction Challenges: Location-based AR systems face difficulties in achieving precise tracking due to inconsistencies in environmental mapping and hardware limitations. These challenges hinder the seamless overlay of virtual objects onto real-world environments. Mixed Reality systems, in particular, require real-time synchronization between image capture, computer vision, tracking, and display components. The Field of View (FOV) in MR glasses also remains a limiting factor, reducing the usability of such types of computing peripheral device systems within medicalapplications.

Proposed Solution: Improving sensor fusion techniques and employing advanced tracking technologies, such as simultaneous localization and mapping (SLAM), to enhance alignment and usability.

Device Constraints and Compatibility Issues: VR and AR hardware undergo frequent updates and modifications, often resulting in content compatibility issues. High-quality VR content development is resource-intensive, demanding expertise in 3D modeling, programming, and design. Moreover, mobile XR devices face bottlenecks in memory storage, energy consumption, and the most significant feedback delays for the real-time computations for the 3D rendering.

Proposed Solution: Establishing standardized frameworks for XR content development and optimizing hardware-software compatibility to ensure a more cohesive user experience.

User Experience and Health Concerns

Negative Physiological Effects: The immersive nature of VR devices can induce motion sickness, eye fatigue, and nausea, which are significant deterrents to prolonged use. Additionally, concerns about VR addiction, particularly among younger users, have been raised, with implications for mental health and physical well-being also spending the highest amount of time in terms of usage.

Proposed Solution: Designing user-centered interfaces, incorporating adjustable comfort settings, and conducting further research into mitigating the physiological effects of prolonged XR use.

Educational Adoption Barriers: Despite their potential, AR and VR technologies face obstacles in educational contexts. Lack of time for educators to master the technology, high implementation costs, limited access to stable internet connectivity, and the need for spatial navigation skills can hinder adoption.

Proposed Solution: Providing affordable XR solutions and offering teacher training programs to foster technological literacy and confidence in integrating these tools into curricula.

Privacy, Security, and Ethical Concerns

Privacy Breaches: XR systems often rely on input from sensors like microphones, cameras, and GPS, raising significant privacy concerns. Unauthorized access to these components can result in data breaches, compromising user safety. For example, mobile AR applications could be exploited to track users' locations or access sensitive information.

Proposed Solution: Implementing robust encryption protocols, adopting stringent access controls, and promoting user awareness about privacy settings.

Security Vulnerabilities Collaborative XR environments, such as virtual meeting spaces or shared AR platforms, are susceptible to intellectual property theft, identity manipulation, and hacking attempts. These vulnerabilities could have far-reaching consequences, especially in sensitive fields like healthcare.

Proposed Solution: Enhancing cybersecurity measures, incorporating two-factor authentication, and developing tamper-proof frameworks for XR systems.

Ethical Challenges: Ethical dilemmas arise from the potential misuse of XR technologies, including the manipulation of virtual identities and the creation of deepfakes. Moreover, the inclusivity of these systems remains a concern, as individuals with limited technological literacy or physical disabilities might face barriers to adoption as there is also the complexity of integrations and usage.

Proposed Solution: Establishing ethical guidelines for XR development and promoting inclusive design practices to ensure equitable access.

Future Considerations

Overcoming these challenges requires a multidisciplinary approach, involving researchers, developers, policymakers, and end-users. A concerted effort to address technical limitations, coupled with robust ethical and security frameworks, will pave the way for XR technologies to realize their potential across diverse biomedical applications. From enhancing surgical precision to transforming medical education, AR, VR, and MR hold the promise of revolutionizing healthcare—provided these concerns are effectively addressed.

AI Integrations in Medical and Healthcare Systems: Transforming Processes and Patient Outcomes

Artificial Intelligence (AI) has emerged as a transformative technology in the healthcare sector, driving advancements across clinical, operational, and administrative domains. Through its diverse applications, AI facilitates precision, efficiency, and personalization, thereby addressing critical challenges in modern healthcare systems.

Key AI Technologies in Healthcare

Machine Learning (ML) and Deep Learning (DL) Machine Learning (ML), including advanced forms like neural networks and deep learning, has become one of the most prevalent AI technologies in healthcare. ML algorithms analyze extensive datasets to identify patterns and make predictions. Applications in healthcare include:

Precision Medicine: Predicting treatment outcomes based on patient attributes and contextual data.

Radiology and Imaging: Deep learning models are widely used for disease detection, classification, and anomaly detection in medical imaging, including X-rays, CT scans, and MRIs.

Disease Prediction: Neural networks are particularly effective in identifying early signs of diseases such as cancer, diabetes, and cardiovascular conditions.

Natural Language Processing (NLP): NLP focuses on enabling computers to understand and process human language. In healthcare, it supports:
Clinical Documentation Analysis: Automating the extraction of critical information from patient records.

Transcription Services: Converting spoken clinical interactions into the formations towards various types of structured digital records.

NLP employs both statistical and semantic approaches, ensuring accuracy and efficiency in handling unstructured data like physician notes and lab reports.

Rule-Based Expert Systems and Data-Driven Approaches: Traditional rule-based systems, once popular for clinical decision support, are being replaced by data-driven approaches powered by machine learning. These modern systems offer probabilistic and evidence-based insights, improving the accuracy of diagnosis and treatment recommendations.

Robotics and Automation
Physical Robots: Intelligent and collaborative robots are increasingly utilized in surgical procedures, rehabilitation, and elderly care. Robotic surgery systems, such as those used in minimally invasive procedures, enhance precision and reduce recovery times.

Robotic Process Automation (RPA): Applied to repetitive digital tasks such as claims processing, billing, and appointment scheduling, RPA improves administrative efficiency and reduces human errors.

AI in Diagnosis and Treatment: AI's implications for diagnosis and treatment are profound, transitioning from rule-based systems to machine learning and big data-driven solutions. These innovations enable:

Evidence-Based Diagnoses: Leveraging ML and DL algorithms to predict diseases and recommend treatments based on large datasets.

Genomics and Precision Medicine: AI facilitates the analysis of genomic data, paving the way for personalized medicine tailored to individual genetic profiles.

Tech giants like Google and numerous startups are developing AI-driven platforms that integrate with clinical workflows to support diagnosis and treatment planning.
However, challenges persist in harmonizing these tools with existing systems such as Electronic Health Records (EHRs).

Enhancing Patient Engagement and Adherence
AI plays a pivotal role in personalizing and contextualizing patient care, which improves engagement and adherence:
Personalized Interventions: Machine learning models analyze patient behavior and preferences to deliver tailored health interventions.

Improved Participation: Business rule engines provide context-aware reminders and recommendations, encouraging active patient involvement in their healthcare journeys.

AI for Administrative Efficiency
The integration of AI extends beyond clinical settings to streamline administrative workflows:
Claims Processing and Billing: RPA automates routine processes, reducing turnaround times and improving accuracy.

Chatbots and Virtual Assistants: AI-powered chatbots handle patient inquiries, appointment scheduling, and symptom triage, easing the administrative burden on healthcare staff.
Payment Administration: Machine learning algorithms optimize claims management and fraud detection.

Integration Challenges
Despite its potential, the adoption of AI in healthcare faces several challenges:

Integration with Clinical Workflows: Aligning AI solutions with EHR systems and existing clinical workflows remains a significant obstacle.

Ethical and Privacy Concerns: The use of patient data for AI development raises concerns about data security and compliance with regulations like HIPAA and GDPR.

Visual Overview
To better understand the transformative impact of AI in healthcare, Figures 7 and 8 illustrates a comprehensive visual overview of AI's applications across various domains, highlighting its contributions to clinical precision, operational efficiency, and patient engagement. The integration of AI into healthcare systems represents a paradigm shift in how medical services are delivered. By addressing technical, ethical, and operational challenges, AI has the potential to revolutionize healthcare, improving outcomes for patients while enhancing the efficiency of healthcare providers.

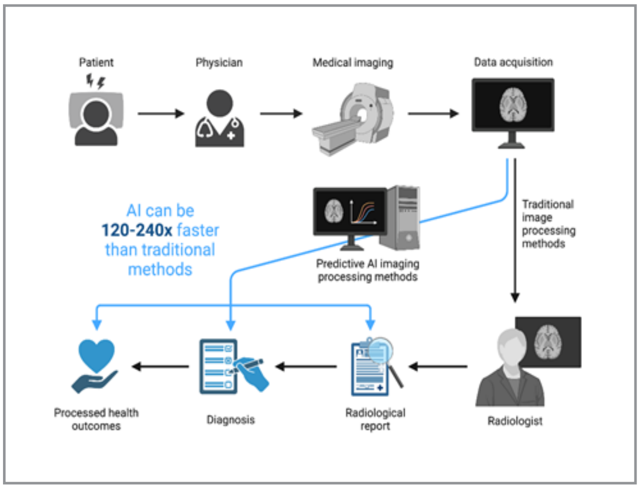

Figure 7: The Transformative impacts of AI in Healthcare 1

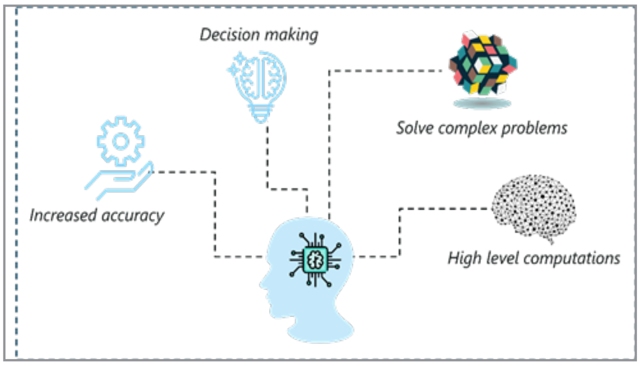

Figure 8: The Transformative impacts of AI in Healthcare 2

Results and Findings

AI Governance and Ethical Frameworks

The rapid expansion of Artificial Intelligence (AI) applications has emphasized the need for robust guidelines and ethical frameworks to govern its multifaceted uses in research, clinical practice, and public health. Current regulatory mechanisms, while valuable, often fall short of addressing the complexity of AI applications, necessitating innovative governance models to foster public trust and accountability.

One proposed governance approach is the AFIRRM framework-Assessment, Foresight, Innovation, Regulation, Responsibility, and Monitoring—which provides a systemic oversight blueprint for managing AI's societal impact. This research highlights the following key findings:

AI in Research Governance:

- Ethical review committees should conduct reflexive assessments, evaluating both scientific advancements and societal implications of AI-driven research.
- Multidisciplinary committees, including professionals like social scientists, are crucial for providing diverse perspectives.
- Research funders are encouraged to implement monitoring mechanisms as part of research plans, ensuring accountability throughout the lifecycle of AI-driven projects.
- Large-scale AI initiatives involving community data should prioritize inclusive practices to foster broad social learning across varied epistemic communities.

AI in Clinical Practice:

- Clinical validation remains critical, with tailored evidence standards enabling responsible clinical innovation.
- Ethical concerns in patient care require the establishment of clinical AI oversight bodies within hospitals. These bodies can guide technology adoption, monitor its impact on patient outcomes, and ensure patient engagement throughout care processes.
- In AI-driven diagnostics, consent processes must adapt to automated data processing, addressing transparency and patient autonomy.

AI in Public Health:

- AI's granular capabilities in disease surveillance and health promotion necessitate community-wide deliberations to define acceptable boundaries for data collection and algorithmic analysis.
- Collaborative, inclusive negotiations with communities are essential to maintain public trust and prevent disempowerment in public health interventions.
- These findings suggest that AI governance should evolve as a socially robust system, engaging stakeholders—including scientific and clinical institutions—in experiments with governance frameworks to harness AI's benefits while addressing ethical challenges.

XR Applications in Medicine and Biology

Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has seen accelerated adoption in medicine and biology, offering transformative potential in visualization, education, and treatment. This research identifies the following trends and findings:

Visualization and Analysis: XR, particularly VR, facilitates the interactive visualization and analysis of 3D models at varying scales, from molecular structures to detailed anatomical representations.

These tools are instrumental in enhancing diagnostic accuracy, surgical planning, and the understanding of complex biological systems.

Educational Applications

- Integrating XR in education significantly enhances learning experiences, as demonstrated in teaching cell structures and human anatomy.
- XR provides immersive simulations that improve student engagement and comprehension across different educational levels.

Telehealth and Therapy

- XR applications in telehealth enable remote consultations and therapy, bridging geographical barriers and improving access to care.
- Rehabilitation and psychological therapies benefit from XR's immersive environments, offering innovative solutions for patient recovery.

Surgical Planning and Training

- • XR aids in surgical planning by providing realistic, interactive simulations of anatomical structures, improving precision and outcomes.
- Surgeons can use XR for hands-on training, refining their skills in a risk-free virtual environment.

Challenges in XR Adoption

Despite its promise, XR technology faces significant challenges that must be addressed for widespread adoption:

Technical Limitations: Issues with software and hardware reliability hinder seamless integration into medical workflows.
Affordability and Accessibility: The high cost of XR systems limits accessibility, particularly in resource-constrained healthcare settings.

User Experience: Improving the usability and comfort of XR devices is essential to ensure long-term adoption and minimize user fatigue.
Mitigation of Side Effects: Potential side effects, such as motion sickness and visual discomfort, require further research and technological innovation.

Final Thoughts on XR's Potential

This research underscores the ongoing progress of XR technologies in medicine and biology while acknowledging the hurdles that remain. Addressing these challenges will unlock XR's full potential, allowing it to revolutionize biomedical engineering, education, and patient care. By overcoming these barriers, XR can become a mainstream technology, enhance healthcare outcomes and broaden its impact across diverse medical disciplines. To better understand the perspectives on the matters Figures 9-12 provides visualizations for an overview illustration of the exploration findings.

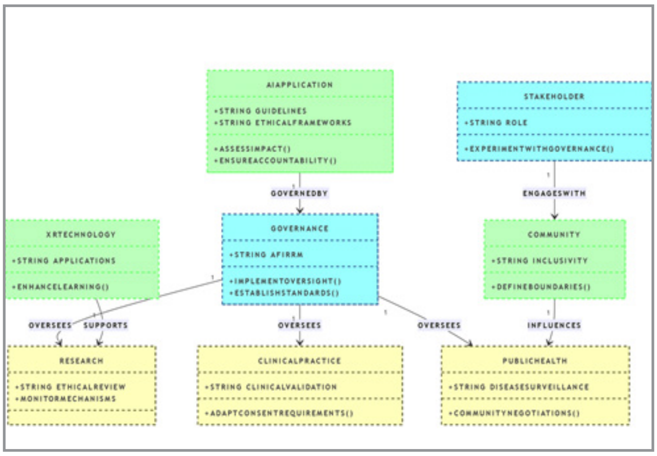

Figure 9: An Overview of the Research Findings 1

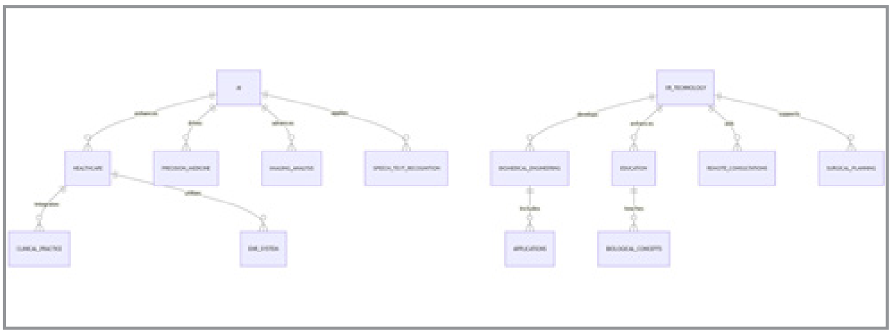

Figure 10: An Overview of the Research Findings 2

Figure 11: An Overview of the Research Findings 3

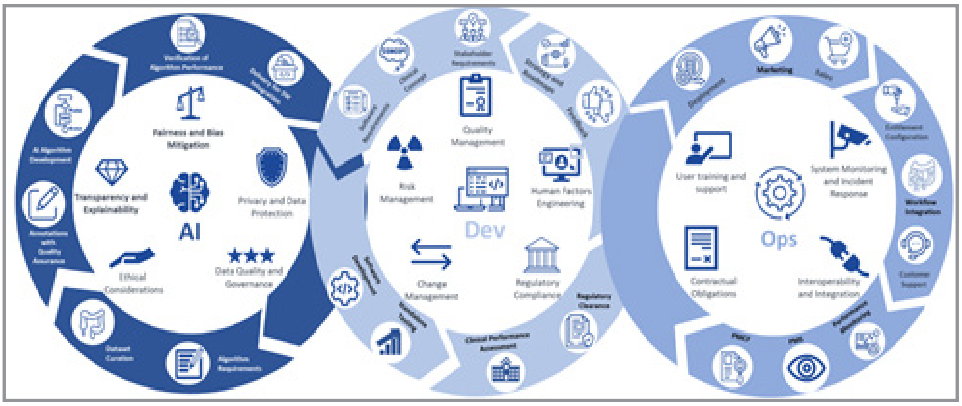

Figure 12: An Overview of the Research Findings 4

Table 1: An Overview of Xr Technology Solutions and Their Associated Costings

XR Type	Type	Product Name	Company	Information	No-Cost to Low-Cost Solutions	Production/ Commercial Solutions
	Software	**VE DICOM2P**	**30Systems**	**Utilizes a VR set or Microsoft Hololens**	**Software: MIL**	**Software: SyngoVia (Siemens)**
	Hardware	VIE	Vive	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	Hardware: VIE	
	Software	AR/VR/MR Unity	Unity Technologies	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions		

	Software	AR/VR/MR	Unreal	EPIC Games	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Hardware	VR	Oculus hardware	Facebook	Hardware at time of publication includes Oculus Quest, Quest 2, and Rift S	
	Hardware	VR	HP			
	Hardware	VR	Valve Index	Valve	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Hardware	VIE	Reverb	HP	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Software	AR/VR/MR	WHXR Device	Immersive Web Working Group at the WIC	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Software	AR	Google Glass	Google	Requires programming knowledge to develop/implement biomedical solutions	
	Software	AR/VR	Sketchfab	Sketchfab	No programming experience needed	
	Software	AR/VR/MR	Blender	Blender Foundation	Benefits from programming and 3D modeling experience	

	Hardware	AR	Apple Glasses	Apple	Requires programming knowledge to develop/implement biomedical solutions	
	Software	MR	HoloAnatomy	Case Western Reserve University	No cost for software but requires Microsoft Hololens	
	Hardware	VR	Google Cardboard	Google/DIY or Do It Yourself [DIY] Viewer	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Hardware	VR	Gear VR	Samsung	Requires programming knowledge or additional software packages to develop/ implement biomedical solutions	
	Platform	VR	Enduvo	Enduvo	Platform is compatible with SteamVR tracking-based VR systems, Windows MR VR systems, and Oculus VR systems	
	Platform	VR	Realize Medical	Realize Medical	Platform is compatible with SteamVR tracking-based VR systems, Windows MR VR systems, and PC-Based Oculus VR systems	
	Platform	N/A	None readily identifiable	N/A	N/A	
	Software	VR	True 3D	EchoPixel	Utilizes zSpace monitor	
	VR	PrecisionVR	Surgical Theater	Platform service includes on-site VR specialist		
	VR	SimX	SimX	Platform is intended for simulation/ training		

Discussions

Artificial Intelligence (AI) is poised to revolutionize the healthcare industry, with transformative potential in areas such as diagnosis, treatment recommendations, and precision medicine. This discussion delves into key aspects of AI's integration into healthcare, its current challenges, and the potential for future advancements based on the review feedback.

AI in Precision Medicine

AI, particularly machine learning and deep learning, is driving significant advancements in precision medicine. These technologies enable personalized care by analyzing vast datasets to predict treatment outcomes tailored to individual patients' attributes and contexts. While initial challenges have been observed in developing reliable AI systems for diagnosis and treatment, the technology is evolving rapidly. Over time, AI's ability to process complex datasets and provide evidence-based predictions is expected to significantly enhance healthcare outcomes, further establishing precision medicine as a cornerstone of modern healthcare.

AI in Imaging Analysis

The rapid progress in AI for imaging analysis highlights its transformative potential in radiology and pathology. Machine learning algorithms are increasingly being trained to identify patterns in medical images with accuracy comparable to, or even surpassing, human experts. This capability is expected to make machine-based examination of radiology and pathology images a standard practice in healthcare. As AI systems become more robust and reliable, their adoption will streamline diagnostic workflows, reduce human error, and enhance early disease detection.

Expansion of Speech and Text Recognition

Existing AI applications in speech and text recognition are already proving valuable in healthcare, particularly for patient communication and clinical note capture. These systems enhance efficiency by automating routine tasks, freeing up clinicians to focus on patient care. The future will see these applications expand to cover a broader range of tasks, including real-time transcription of clinical interactions, automated documentation, and more nuanced patient engagement.

Challenges in AI Integration

Despite its potential, the integration of AI into daily clinical practice faces significant challenges that need to be addressed:

Regulatory Approval: Ensuring compliance with stringent regulatory frameworks remains a critical barrier. AI systems must meet rigorous safety and efficacy standards before they can be widely adopted.

EHR System Compatibility: The lack of standardization in electronic health record (EHR) systems poses a major hurdle. Seamless integration of AI tools with existing EHR platforms requires interoperability and data harmonization.

Standardization: Establishing uniform standards for data collection, processing, and AI implementation is essential for widespread adoption.

Clinician Training: Healthcare professionals need specialized training to effectively utilize AI tools. Bridging the knowledge gap between clinicians and AI technologies is vital for successful implementation.

Funding: The high cost of developing, implementing, and maintaining AI systems can be prohibitive for many healthcare institutions, particularly those in resource-constrained settings.

Ongoing Updates: AI systems require continuous updates to stay aligned with the latest medical knowledge, regulatory changes, and technological advancements.

Future Outlook

As AI technologies mature, their integration into healthcare systems is expected to overcome these challenges. Stakeholders, including healthcare institutions, policymakers, and technology developers, must collaborate to create an ecosystem that supports AI adoption. This includes streamlining regulatory processes, enhancing EHR compatibility, and providing funding and training opportunities.

Ultimately, AI's role in healthcare will expand beyond current applications, offering transformative solutions for diagnosis, treatment, and patient care. By addressing these challenges proactively, the healthcare industry can harness the full potential of AI to improve outcomes, reduce costs, and deliver more personalized care.

Conclusions

Artificial Intelligence (AI) and Extended Reality (XR) technologies are transforming the landscape of healthcare and biomedical engineering. Rather than replacing human clinicians, AI serves as a powerful augmentation tool, enabling healthcare professionals to focus on human-centric skills while leveraging AI-driven insights for improved decision-making and patient outcomes. In the short term, AI adoption in clinical practice will remain limited due to integration and regulatory challenges, but broader implementation is anticipated within the next decade.

XR technology, despite its longstanding history, has gained significant traction in recent years, particularly in medicine and biology. Its ability to visualize and analyze 3D models across molecular to anatomical scales has revolutionized education, research, and clinical applications. XR tools, such as Virtual Reality (VR) and Augmented Reality (AR), are enhancing learning experiences by replacing traditional methods, like cadaver-based training, with interactive simulations. In addition, XR is proving instrumental in telehealth and therapy, facilitating remote consultations and treatments, and aiding in surgical planning. The case studies highlighted in this research—ranging from Google Cardboard applications in education to advanced surgical simulations—demonstrate XR's growing relevance in healthcare. However, widespread adoption of XR in daily medical practice still faces obstacles, including limitations in software and hardware, challenges in user experience, and affordability concerns. Addressing these barriers will be critical for the full realization of XR's potential.

As both AI and XR technologies continue to evolve, their integration into healthcare and biomedical engineering will drive innovative solutions, improve patient care, and expand educational possibilities.

The ongoing collaboration between technology developers, healthcare professionals, and policymakers is essential to overcoming current challenges and ensuring these technologies are accessible, reliable, and ethically applied. Together, AI and XR promise to redefine the future of healthcare and biomedical research.

Supplementary Information

The various original data sources some of which are not all publicly available, because they contain various types of private information. The available platform provided data sources that support the exploration findings and information of the research investigations are referenced where appropriate.

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Declarations

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Conflict of interest/Competing interests

There are no Conflict of Interest or any type of Competing Interests for this research.

Ethics approval

The authors declare no competing interests for this research.

Consent to Participate

The authors have read, approved the manuscript and have agreed to its publication.

Consent for Publication

The authors have read, approved the manuscript and have agreed to its publication.

Availability of Data and Materials

The various original data sources some of which are not all publicly available, because they contain various types of private information. The available platform provided data sources that support the exploration findings and information of the research investigations are referenced where appropriate.

Code Availability

Mentioned in details within the Acknowledgements section.

Authors' Contributions

Described in details within the Acknowledgements section.

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