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The Applications of Digital Extended Reality in Biomedicine

Jiazi Gao[1]* and Xiaolu Zhang[2]

[1]China State Shipbuilding Corporation Limited (CSSC), China

[2]Department of Physiology and Pathophysiology, School of Basic Medical Sciences, Cheeloo College of Medicine, Shandong University, China

Abstract

Digital Extended Reality (XR) technologies are a group of 3D visualization technologies that have been increasingly adopted in the field of entertainment, education and biomedicine. XR can provide an immersive environment, in which people experience a reality in a virtual background. In the current review, we discuss in detail the applications of modern XR technologies in the field of biomedicine, from classroom biomedical education, medical training to clinical surgical guidance, providing a comprehensive analysis of XR's biomedical impact.

The Concepts of Digital Extended Reality and an Overview

The development of digital Extended Reality (XR), including but not limited to Virtual (VR), Augmented (AR) and Mixed Reality (MR) blooms in the recent ten years, since when they have been wildly used in the field of commerce, education and biomedicine [1]. XR can be considered to include the entire spectrum of the reality-virtuality continuum from absolute reality to utter virtuality. It is a kind of communications between reality and virtuality based on computer graphics, sensory input, computation and network. Those technologies can offer an immersive and interactive Three-Dimensional (3D) environment for visualization. With XR technologies, we could dig ourselves into the reality-mimicking virtual surroundings, like the outer space, dangerous conditions and the micro-world. The features of XR technologies include multi-sensory, immersion, interactivity and imagination. XR technologies were initially widely used in the entertainment sector, such as the Oculus Rift based on VR, created by Palmer Luckey and the famous game Pokémon GO [2] based on AR. The working principles of different XR technologies differ slightly. The experience of VR involves total immersion and visualization a computer-generated environment using software and hardware in an interactive manner [3]. With AR, people experience a superimposition environment of digital elements with the real world in a real-time interaction manner [4]. While for MR, co-existing physical and virtual objects interact in real time [5]. As the accumulating deep investigation and development of XR technologies, the utility of them in the field of life science emerges and expands gradually. In the following sections, we would discuss the use of XR platforms in different aspects of biomedicine.

Use of XR Platforms in Classrooms for Interactive Biomedical Education

The traditional teaching and learning manners in biomedicine absolutely depend on knowledge transmission from experts to freshers, which is less effective and time-consuming. As XR technologies facilitate an environment of engagement that could aid the understanding of new concepts, they serve as ideal approaches in biomedical education [6-8]. First, XR technologies can be used but not limited in the subjects of anatomy, physiology and pathology. Different from the 2D images on textbook, XR could provide a more vivid illustration of human organ structure and physiological process, and an easy way to zoom in to the detail. Second, virtual memory palaces could enhance the effectiveness of memorizing information. Studies showed that compared to standard desktop display, VR could result in a pretty better memory recall as the participants' overall average recall performance was 8.8% higher in VR environment [9]. Third, other studies demonstrated that neuroscience content delivered through a VR platform could lead to greater emotional engagement comparing with flat 2D and 360° experiences [10]. Indeed, by better engaging, motivating and arousing students, VR provides an ideal learning environment, indicating its potential utility in education. In the past and present two years, the COVID-19 pandemic has posed a challenge for

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****Correspondence:***
Jiazi Gao, China State Shipbuilding Corporation Limited (CSSC), No. 1 of Fengxian East Road, Haidian District, Beijing, 100094, China, Tel: (+86) 18911990140;
E-mail: gaojiazi@zhizhenvr.com

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the educations especially of anatomy courses in medical schools as an online format has to be adopted instead of the real classroom [11]. In such circumstances, a VR workspace for anatomy lectures is really helpful.

Use of XR Platforms in Molecular Data Visualization

As XR provides 3D visualization, volumetric data could especially benefit from XR technologies. In such way, VR and AR have dramatically enhanced the micro-world visualization like microscopic images and molecular data. It is reported that a combined research team from Carnegie Mellon University and Benaroya Research Institute at Virginia Mason created a method by pairing a nanoscale imaging technique (expansion microscopy) with VR technology which could allow researchers to 'step inside' the biological data [12,13]. With it, scientists could enlarge, explore and analyze cell structures far beyond the capabilities of traditional microscopy. ExMicro VR was proposed to be used remoted by up to six persons simultaneously in order to improve collaborations. Confocal VR was created by Stefani et al for the purpose of studying the complexity of cell architecture by exploiting consumer-grade VR systems to help the users fully immerse in the 3D cellular images [14]. As well, confocal VR could also allow multiple users to work together simultaneously. Pathology remains the golden diagnostic method in clinic, and digital slides obtained from Whole Slide Imaging (WSI) platforms are typically by pathologists in 2D manner on computers. Oculus Rift and VR technology were reported for examining digital pathology slides in a VR environment. In such way, the diagnosis accuracy remained 90% with much easily viewable confirmation, greater image quality and more diagnostic confidence in a VR environment [15].

Use of XR Platforms in Medical Training

Back to 1995, a program of '3D frog anatomy' was created on the internet, by which the participants could dissect the frogs from the screen, explore anatomy of frogs in great details while going through labeled body systems from every possible angle. This was the first trying of medical training with XR platform. Such training could include anatomy, diagnosis and surgery. Nowadays, the immersive VR (iVR) system for medical surgical training is getting quite popular. It has the advantages of providing accessible, low cost, realistic training adjuncts and financially constrained systems in time. Surgical training with iVR ranged from orthopedic surgery [16-20] to obstetrics and gynecology [21,22]. A wide variety of different software and hardware have been used in iVR surgical training, including Oculus Rift [23], HTC Vive [24,25], Oculus Quest [26,27], and Samsung Odyssey [28]. IVR can improve surgical skills acquisition, lead to significant improvements in time to completion and movement efficiency [29].

Use of XR Platforms in Clinical Surgery Guidance

XR technologies showed great usefulness in clinical surgery guidance especially those demand specific skills and fine manifestations. VR offers medical students an opportunity to practice extensively and easily before the real surgery. Multiple VR- based simulators, for instance RASimsAs, SimSurgery and AnatomyX were created supplying unexpected scenarios during surgery procedures. Teber et al. showed that use of an AR-based soft tissue navigation system in urologic laparoscopic surgery could greatly enhance the surgeon's perception and provide decision-making guidance [30]. In recent years, the FDA (U.S. Food and Drug Administration) approved the first AR applications for elective spinal surgery [31,32]. Microsoft HoloLens is a holographic MR HMD. It can be used by doctors to look at 3D images including anatomical structures with high clarity. In such way it can help surgeons virtually visualize complex organs during surgery.

Challenges and Perspectives of XR Platforms

Although there is great promising of XR platforms used in the field of biomedical, it still has some challenges. First is some hardware and software in the XR platform system for specific medical applications are quite expensive, costing up to tens of thousands of dollars, thus limiting their wide adoption. Second is computational limitation, as lower computational bandwidth could result in latency. Tracking issue is another challenge for XR, for example, for location-based AR systems; the dependency on GPS may provide inaccurate location predictions. Other challenges like privacy, security and ethical concerns also need to be addressed carefully. Besides those challenges, XR platforms brings side effects for the users, such as motion sickness, eye fatigue and headaches, all of which should be paid attention and improved in the future.

Conclusion

XR's widespread use in biomedicine is growing, and indeed facilitates a lot in this field not only for education, but also for the clinical practice. However, it is far from reaching its full potential as multiple challenges still existing. XR technology is expected to be widely used as a daily tool in public in the future through increasing the users' better experience and decreasing its side effects.

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