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Augmented and Virtual Reality Environments for Healthcare*

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Abstract

Contemporary life with modern technology has benefited from dramatic advances with electronic devices including the rise in availability and quality of augmented reality (AR) and virtual reality (VR) headsets capable of simulating environments for use in healthcare. By integrating AR/VR headsets into existing educational programs and medical therapies, we can enable new approaches for teaching students and delivering care to patients. This report provides definitions for AR and VR, reviews common device specifications, and discusses a variety of applications described in the biomedical engineering, healthcare, and telehealth literature.

Keywords

Augmented reality, virtual reality, healthcare, telehealth.

Contents

Introduction

In the modern era of continuous advances in technology, new options for providing healthcare, helping patients, and understanding health issues have become available. Healthcare professionals can now meet with their patients remotely via video conferencing software, reducing discomfort or travel requirements for follow up visits or non-emergency questions. Calls for new and better tools for easier access to video conferencing [1] have led to different web-based software applications [2] as well as application models for specific patient demographics such as military veterans [3]. In a 2005 review article, Jarvis-Selinger *et al.* [4] found that telehealth and video conferencing had been used in numerous disciplines of medicine ranging from general practice to neurology, nursing, and physical therapy. Taylor *et al.* [5] showed in a 2015 study that for non-emergency situations in palliative care, the effectiveness of the telehealth care and the experience of conducting the telehealth session were considered equivalent or better than a home visit on 72% and 90% of the care visits, respectively. In general, engineering advances have enabled higher quality medical imaging, which allows physicians to visualize internal body organs with improved clarity and resolution, and thus, to recognize findings related to health issues with greater diagnostic confidence [6], [7]. More recent advances in virtual and augmented reality simulation technology now allow for further improvements in these healthcare areas from consultation to visualization and diagnosis to therapy. This report will define augmented and virtual reality, discuss some considerations for use, and then review a number of emerging use cases in both education and treatment.

Definitions

There are a number of different terms used by different authors and organizations, sometimes with different interpretations, to refer to the various kinds of environments simulated by headset devices with computing hardware and software. Therefore, for the purpose of this report, we define the following terms:

- **Augmented Reality (AR)** An overlay of holographic and often translucent images over the real world. The user can still see the regular world around them and can sense and interact with both the real and augmented world in the same space.
- **Virtual Reality (VR)** An enclosed environment which allows the user to see and interact with a completely simulated world, however, they are still able to physically move in the real world.
- **Mixed Reality (MR)** A blending of virtual space and the real world as accessible in the same environment [8]. AR could be an example of MR, however, other examples include a VR environment

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which detects objects in the real world and then represents them somehow in the simulated world.

- **Cross Reality (XR)** As defined by Paradiso [9], "a mixed reality environment that comes from the fusion of ubiquitous sensor/actuator networks and shared online virtual worlds." A ubiquitous sensor/actuator network (USN) is a connected system of sensors and devices that interact with one another to perform a specific set of tasks. In the case of XR, the USN helps transport a person to a virtual world.

Available Devices

Although AR/VR has gained a lot of attention recently due to significant advances in performance, designs for MR devices are nothing new. A mirror-based binocular display was first designed by Sir Charles Wheatstone in 1838 by creating an array of mirrors which would eventually become the stereoscope [10]. Stereoscopes relied on separated images to cause the effect of looking at a 3D object based on our stereoscopic vision. Over a century later, a cinematographer named Morton Heilig built the Sensorama Simulator [11]. The Sensorama was a stereoscopic device which allowed people to see, hear, smell and feel a virtual environment, which could only be experienced within the device. Since the Sensorama, numerous head mounted displays (HMDs) have been created, but many were very expensive, restricted to visualizing certain material, or not available to consumers. Although numerous attempts at VR, AR, motion tracking devices and more were built by companies such as SEGA and government agencies like NASA, there was no real commercial success. Finally, in 2010, Palmer Luckey, an 18 year old entrepreneur, presented the first prototype of the Oculus Rift to the general public. Soon after the Oculus Rift prototype, the modern AR/VR craze began.

Within the past decade after that first prototype of the Oculus Rift, the AR/VR industry has become revitalized with major electronics companies throwing their own devices into the ring. Beyond the original Oculus Rift now owned by Facebook, the electronics companies HTC, Google, and Microsoft have all created different devices. HTC initially worked with the game distributor Valve to create the HTC Vive, a VR headset focused on gaming, which later split into the Valve Index and the Vive Cosmos. While Oculus and HTC focused on VR, Microsoft and Google focused on AR, putting the famous Microsoft Hololens and Google Glasses onto the market. Microsoft also built a mixed reality Windows platform which functioned as a VR system that tracked nearby objects for movement and danger alerts. See Table 1 for a list of headsets available on the market with their recent costs and technical specifications.

Current headsets have a number of specifications to consider outside of their designation as AR, VR, or MR, including connection to a computer, image resolution, refresh rate, field of view (FOV), and weight. Traits such as image resolution, refresh rate, and FOV all relate to the quality and performance of the device. Higher image resolution improve the quality of the image, refresh rate will increase the speed at which the image updates, while FOV relates to how wide of an angle you can see from within the headset. Dating back to military studies in the 1990s, HMDs are well known for causing a phenomena called "simulator sickness" which is a form of motion sickness caused by the visual sensation of movement when the inner ear detects no motion or change in position or balance [12]. While multiple factors such as the experience and content of the simulation play a role in contributing to simulator sickness, visual quality and refresh rate are also incredibly important to consider. One of the more important characteristics to consider is whether or not the device is tethered, meaning if it is connected to a computer or not. Some devices are self-contained, such as the Microsoft Hololens which sports a built in processor for rendering of images, similar to having a powerful cell phone connected to the device, while others require a computer to even run and are only highly specialized input/output devices such as the Oculus Rift. Recently, some advances in wireless technology have also enabled traditionally tethered devices such as the HTC Vive Cosmos and Valve Index to connect to a nearby computer via a wireless pack and battery power. In all cases, the quality of the rendered virtual environment depends directly on the power of the device rendering the scene.

Other devices besides headsets can also be connected to an overall MR system to improve the fidelity of the experience. Many headsets such as the Oculus Rift and HTC Vive come equipped with motion tracking controllers, while other devices such as Leap Motion and Microsoft Kinect allow for ranged hand or body tracking based on infrared and color cameras combined with real-time image processing. Haptic gloves and controllers, including HaptX gloves and VRGluv, are able to track hand movement via a glove on the hand while also using various techniques to apply pressure or vibration to the hand, stimulating the sense of touch. A larger scale application of haptics can be seen in the TeslaSuit which not only has electrical stimulation but also adds sensors for biometric monitoring and electrical monitoring of muscles to track movement.

Visualization of Anatomy

Dating back more than two millenia ago to Herophilus of Chalcedon and Erasistratus of Ceos [13], scientists have been trying to understand human life by dissecting and investigating the organs that make up our bodies. Medical students are often trained in anatomy or surgical procedures by dissecting cadavers or practicing on dummies, letting them gain a better appreciation for the three dimensional nature of the human body. Similarly, clinical physicians need to have a better understanding of a specific patient's anatomy, ideally without performing any invasive procedures prior to interventions, especially because biopsies are not always an available option. Usually to visualize anatomy or internal functions, physicians would then call for some form of diagnostic medical imaging study to be done. However, medical imaging scans are often seen on a 2D monitor or screen, rather then a 3D display. By using virtual environments, we can better visualize organs in a more realistic 3D environment, rather than simulating a 3D object in a 2D monitor. A few other professional fields have already begun to use AR/VR technologies to train students and to understand better the inner workings of a certain object or device. A non-medical example beyond healthcare is the use of AR in aerospace engineering by Airbus to visualize airplane turbines and other components [14].

This concept of using AR or VR to view and understand anatomy has been applied in both educational and clinical settings. For training knowledge which needs to be practically applied, AR has been frequently used as it allows the user to both interact with the rendered hologram model of an organ or body while still being able to reference the real world externally. McJunkin *et al.* [15] used the Microsoft Hololens to visualize the structure of the skull for image guidance to

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Table 1: A Comparison of headset devices sorted by cost (Headset Only*)

Name	Cost	Type	Tethered (Y/N)	Resolution Per Eye	Refresh Rate	FOV	Weight*
Samsung Gear VR	$100	Virtual	N	1280x1440	60Hz	101°	345g
PlayStation VR	$270	Virtual	Y	960x1080	90-120Hz	100 °	600g
Oculus Rift S	$399	Virtual	Y	1280x1440	80Hz	115 °	500g
Asus Windows MR	$399	Mixed	Y	1440x1440	90Hz	95 °	<400g
Acer Windows MR	$399	Mixed	Y	1440x1440	90Hz	100 °	171g
Samsung Odyssey	$500	Mixed	Y	1440x1600	90Hz	110 °	644g
HTC Vive Cosmos (Elite)	$699-899	Virtual	Optional	1440x1700	90Hz	110 °	—
Meta AR 2	$949	Augmented	Y	1280x1440	75Hz	90°	500g
Steam Valve Index	$999	Virtual	Optional	1440x1600	120Hz	130°	800g
Google Glass Enterprise Edition 2	$999	Augmented	N	—	—	83°	46g
Magic Leap 1	$2,295	Augmented	N	1280x960	60Hz	50°	—
Microsoft Hololens 2	$3,500	Augmented	N	2048x1080	240Hz	52°	566g

then be overlaid on physical models, finding that it was a valuable tool for lateral skull base surgery and anatomical dissection. Elmi-Terander [16] used interoperative imaging and augmented reality to help improve accuracy of screw placement in thoracic spine surgery from 64% accuracy to 85% in 94 screws placed by two neurosurgeons. In a similar study, Peden *et al.* [17] trained 14 medical students with no prior experience in suturing by utilizing HMD-assisted instruction or HMD aided self-training and found that HMD-assisted instruction was equally as successful as conventional instruction but significantly more enjoyable. Two different studies focused on augmented reality aided insertion of central venous catheters. Both studies found that AR was a useful tool in training and active use, but further investigation and training with the device may be needed to fully assess use of AR [18], [19]. One study looked at the use of AR/MR in the acute care setting to rapidly look at a model based on a patient's CT for aid in inserting a central venous catheter or tube thoracostomy [20]. Although the proof-of-concept design needs further testing, Kobayashi *et al.* [20] was able to successfully create a working pipeline for medical imaging, image registration and viewing for rapid treatment of patients. More recently, Boyd *et al.* [21] have built a system for looking at a patient's medical records in the Microsoft Hololens, making it easier for medical professionals to rapidly pull up and view their current status.

In addition to guiding specific procedures, AR and VR can be used to help facilitate the learning of anatomy and medicine. Some systems such as Gunner Goggles have built on existing physical textbooks by enabling the use of AR goggles to add holographic models and improve overall student engagement [22]. Numerous studies have looked into teaching neuroanatomy with VR. One of the earlier neuroanatomy education studies looked into how to present information in a VR environment [23]. In this study, Levinson *et al.* [23] found that allowing users to see multiple views simultaneously may be confusing and instead VR education should focus on showing a singular key important view at a time in instruction. A decade later, Stepan *et al.* [24] compared the efficacy of VR aided learning in comparison to traditional textbook learning of neuroanatomy. Similar to the study by Peden *et al.* on suturing training, Stepan *et al.* found that while there was no significant difference in understanding the content, subjects reported that VR learning was more engaging and motivating to use, resulting in a more positive experience overall. To support a future of VR use in medical imaging, Taswell *et al.* [25] built an image processing pipeline and application called BrainWatch for the purposes of volumetrically rendering any medical image stored in the Digital Imaging and Communications in Medicine (DICOM) format on the Oculus Rift. The BrainWatch application enables a number of different viewing modalities, letting the user move within the rendered brain volume freely or move outside and around the brain volume looking in. Future plans for this application include improved rendering and the automated following of brain matter tracts as calculated from a specific brain volume.

One important concept to consider when designing any application with identified health information is the need for secure login for user identification and authorization. Health information when it includes any form of personal identifiers such as name, contact information, or address is protected by law from being shared in many countries including the United States (See USA HIPAA Laws). Similar to any secure login system, users must be verified as having the authorization to access the data prior to viewing any information. While AR/MR/VR tools for authorization are still in the works for many systems, developers at Microsoft collaborated with Aveva to build 3DToolkit [26]. This system allows for secure login based on the industry standard OAuth 2.0, assuring users better privacy and confidentiality of their data. Another application that should require the use of identity verification and authorization would be any form of remote telehealth consultation. Zhang *et al.* built a system for remote consultation by using AR technologies with the Microsoft Kinect to make it easier for patients to access an AR system[27]. Alternatively, if a clinical research application uses health information without requiring identified and authorized access, then the data must be properly de-identified and marked anonymous for use in the research study.

Therapies and Treatments

For many years, VR and AR technologies have been used as a part of exposure therapy for psychological disorders. Commonly dubbed VRET, this type of exposure therapy relies on the ability to create a virtual scene to desensitize a patient to their triggers associated with a specific phobia or trauma related to PTSD. Early studies in this field looked at treating PTSD in combat veterans [28]. With increased availability of HMDs, use of VRET has become much more widespread, now also being applied to specific phobias and other anxiety disorders. Out of many studies published on the topic of PTSD, two studies looked at the modern use of VRET. Beck *et al.* [29] found that post-trauma behaviors such as avoidance and emotional numbing significantly reduced after VRET driving simulations. More recently, Beidel *et al.* [30] compared the use of VRET to other therapy modalities commonly used for PTSD in combat veterans. Beidel's findings showed that VRET was an effective tool, but needed to be used in conjunction with other methods for comprehensive patient management. Specific phobias and anxiety disorders have also been investigated as possible use cases for VRET. One set of studies looked at VRET for arachnophobia by exposing patients with the severe fear of spiders to a 3D moving model of in a virtual environment [31]–[33]. In these studies, Lindner, Miloff, and their colleagues utilized both traditional VRET desensitization techniques and gamification to improve overall user outcome. Gamification is a commonly used technique which makes a treatment or therapy more fun with a game-like structure and design [34]. While developing these applications, Lindner *et al.* created a set of design considerations for the creation of future VRET applications [35].

According to the Centers for Disease Control Autism and Developmental Disabilities Monitoring Network, since the year 2000, the incidence of autism has increased from 1 in 150 children to approximately 1 in 54 children. Commonly, children with autism have difficulty interacting with others in social situations and require assistance to navigate social interactions more comfortably [36]. Voss *et al.* began a project called Superpower Glass which developed an AR application on Google Glass which automatically recognizes facial expressions and prompts children on appropriate reactions [37], [38]. Another major medical issue which appears in both psychology and other realms of medicine is pain management [39]. VR therapy has been shown to be a potential tool for managing and reducing pain in a number of different situations. Mosso-Vázquez *et al.* looked at the use of VR in post-operative pain management for cardiac surgery by having patients go through a 30 minute VR simulation designed to help calm and reduce pain[40]. As a result of undergoing this treatment, patients displayed various signs such as slower breathing rate and lower blood pressure which typically indicates lower pain and stress levels. In a similar study, patients were distracted from pain via an immersive VR experience while undergoing a change in the dressing of a hand injury[41]. With this study, Guo *et al.* found that the level of interaction and immersiveness of the simulated experience was positively correlated with the level of pain reduction. VR Therapy has also been found to be a useful tool for patients with chronic pain associated with amputation. In a series of studies by Osumi *et al.* , researcher found that by having patients undergo VR modified therapy, patients not only experienced lessened pain levels but movement and body representations as patients are better able to mentally visualize their missing limb[42], [43]. This was accomplished by showing patients a virtual model of their arm which matched the movements of their opposite healthy arm when asked to perform certain symmetrical rehabilitation tasks.

VR has been used for other forms of physical therapy in training to regain or improve muscular function. Bahat *et al.* looked at the use of VR integration into therapy related to impairments and pain in the cervical spine and neck, finding that VR integrated therapy outperformed traditional methods [44]. For patients who have survived a stroke, physical therapy is a crucial method to regain the ability to move normally. Shin *et al.* investigated the use of VR therapy for quality of life in upper extremity rehabilitation and found that VR rehabilitation could be more effective in comparison to conventional therapy methods when combined with occupational therapy[45]. A similar study focused on gait and walking in stroke patients and reported that the patients with VR therapy outperformed those who did not use VR technology [46], however, it was a very small (n=3) pilot study which requires more investigation for validity.

Some congenital disorders such as cerebral palsy benefit from physical therapy by helping the patient maintain some level of movement. One approach implemented the Microsoft Kinect for motion tracking of the patient as they completed the rehab exercises [47]. In this study, Jung *et al.* found that the few patients (n=4) who underwent this therapy all had noticeable improvement in their movement, but further investigation is needed to determine effectiveness in children with Cerebral Palsy. Another study utilized the techniques of gamification and VR games to help improve mood and occupational performance in three school children [48]. Two out of three children showed great improvement in their overall performance and the three patients all displayed an increased level of motivation to play, which was not in their normal behavior.

Sometimes, there is not a very clear method by which therapy can physically help a patient, and what is most needed assistance in improving quality of life. This is especially true in the case of a neurodegenerative disorders with progressing dementia and memory loss, where little will allow a patient to regain in lost mental faculties. Wolf *et al.* built a system called cARe which utilizes augmented reality to provide visual and auditory reminders about a patient's daily activities within the home [49]. With the cARe system, patients are able to engage in normal household tasks such as cooking a meal with the added assistance of reading a meal recipe on a holographic display without needing to use a printed out copy. The cARe project is still an ongoing study, but may prove helpful in improving daily quality of life for patients with dementia.

AR and VR during COVID-19

During the current COVID-19 viral pandemic, AR and VR have experienced significant growth in use as people turn to virtual environments to simulate a large number of experiences in which they would have normally participated in person, but can no longer do so because of the pandemic. The tourism industry decided to use XR solutions to enable users to visit foreign countries and monuments virtually [50], [51]. The medical world had to handle three issues which are now being addressed with AR/VR technology: 1) managing healthy individuals experiencing stress, distress and upset from being quarantined. 2) helping with lingering symptoms of COVID-19. 3) treating patients with active COVID-19 that may or may not be hospitalized.

A meta-analysis by Bueno-Notivol *et al.* [52] found that the pooled prevalence for depression has increased to a rate almost 7 times as much as an estimate from 2017. For many, this observation is not very surprising when daily life cooped up at home is not a very pleasant experience. However, worsening rates of depression present a large challenge for the mental health community. One study [53] looked at the psychological impact of COVID-19 restrictions on subjects who played GPS location based AR video games. In this study, Ellis *et al.* [53] found that many players had a hard time initially but as the game developers adjusted to the changing situation of COVID-19, it became easier for them to play and their overall stress level was able to be more easily managed with the game as a way of coping with these hard times. Other coping strategies which were used by many included VR based

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exercises and active video games. Gao *et al.* [54] found that the application of VR to general exercise for wellness proved to be helpful in adults older than the age of 65 years old. Other researchers studied and compiled recommendations for how to utilize technologies such as VR to help the population cope with the realities of COVID [55]. Due to the need for social distancing, elderly patients who would normally be able to receive physical, cognitive or neurological rehabilitation have found it hard to go in person to undergo their treatment. Mantovani *et al.* [56] prepared a guideline on the use of VR and telemedicine with recommendations for how to proceed when treating these patients. Among the host of symptoms related to COVID-19, one debilitating symptom has been described as "Brain Fog" where the patient experiences cognitive dysfunction [57], [58]. While many other symptoms can be managed through telemedicine visits and recommendations, issues such as brain fog and depression remain as lingering problems leading to reduced occupational performance and quality of life. However, perhaps, AR and VR could prove to be useful tools in aiding daily life during COVID-19.

Conclusion

Augmented and virtual reality simulation technology has greatly advanced, enabling new methods for practical and theoretical medical education, communication with patients, and treatment or therapy for patients. AR and VR have both proven to be useful tools even in the immediate short term for mental health management and coping with the harsh reality of COVID-19. With social distancing becoming a necessity, video conferencing has been used more often to lessen the unnecessary exposure to a deadly virus, further emphasizing the need for use of already existing but rarely used methods for communication with AR or VR. Prior to COVID-19, AR and VR had already begun to change the possible futures for medicine by allowing the human body to be better visualized and understood in real 3D space, a huge change from the past limitations of 2D imaging modalities. These visualization tools can be applied to education settings as well as to training and planning for surgical procedures. Since HMDs are now more available than ever, patients and physicians have access to AR or VR devices for therapies and treatments which could be utilized within the comfort of a patient's own home. As this field continues to grow with the progressive technological advancements in headsets, more medical applications of AR and VR should be evaluated for possible use in comparison to traditional methods. Based on current results, AR and VR both seem very promising for healthcare and telehealth in general. However, the use of AR and VR should always be investigated for clinical safety and efficacy independently for each medical problem.

Citation

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