A survey on Virtual Reality for Medical Applications

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Abstract

The evolution of low-cost Virtual Reality (VR) technology is captivating the attention of researchers and users around the globe implying that it may be the next remarkable feat in technological innovation. Healthcare is among the top 3 industries that are the leading adapters of VR technology. Extreme demand for the high quality healthcare services, increased use of connected devices in the medical field and the need to make healthcare cost-effective are the key drivers of the adoption of VR in medicine. Both medical professionals and patients benefit from the VR as it allows them to work in the computer-simulated environment explicitly devised for practices and various medical procedures. This paper intends to provide comprehensive information about the application of VR in diverse disciplines of the medical field. This review aims at investigating the past studies on VR to improvise the traditional method of treating various medical conditions.

Keywords: Virtual reality, virtual therapy, virtual training, virtual rehabilitation

1.   Introduction

Virtual reality can be best defined as a virtual, three dimensional environment generated by a computer that mimics a real or an imaginary world [1]. An user is able to perceive the virtual environment using computers, Head Mounted Displays (HMDs) or big projection screens and can interact with that environment using several input peripherals like mouse, motion trackers, haptic feedback systems, sensing gloves, joysticks, track pads, device control buttons or full body suits [2].

The highlights of virtual reality have been its immersive and interactive aspects which have been the bases for rapid increase in the use of VR in many domains including defence, education, real estate, automotive industry, architecture, sports, healthcare, etc. Figure 1

shows the gradual rise in the number of consumers of VR headset between 2018 to 2025. Virtual reality usually comes with another technology termed as Augmented Reality (AR), and the increase in the revenue of AR and VR jointly over the past 5 years is depicted in figure 2.
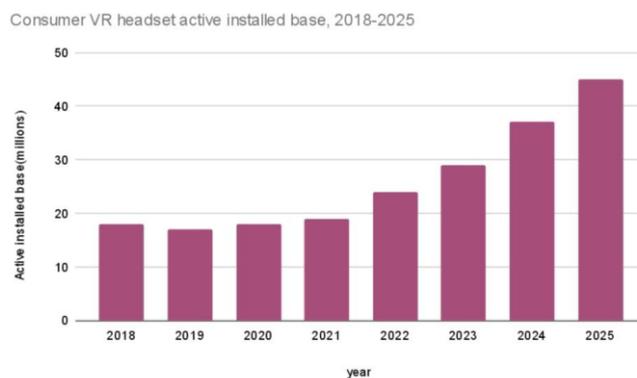

Figure 1. Graphical representation of increase in the number of active VR users worldwide from 2018 to 2025 [20]
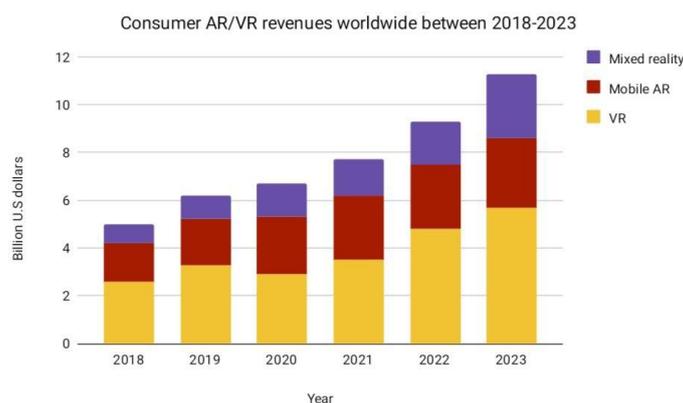

Figure 2. Graphical representation of increase in consumer AR/VR revenues worldwide between 2018 and 2023 [21]

1.1 General architecture of a VR system

A general VR system as shown in figure 3 consists of the below mentioned elements

- 3D content is a graphic model which is an object oriented database where every object represents an object in the virtual environment.

- Modeling program is a program that creates the virtual objects in the graphic model.

- Translators provide information about the real world objects that are replicated in the virtual environment through VRML input, CAD database input or web-med data input. These inputs provide data in the form of mathematical equations or descriptions which are modelled into 3D objects.

- Dynamics generator is used to manipulate the dataset. It also tracks the orientation and position of the user's hand and head through input peripherals.

- Application specific programs describe movement of the virtual objects for each particular experience according to the natural laws like inertia and gravity or variables like flexibility or spring rate.

- Renderers generate the 3D visuals from the graphic model and present it to the user in real time along with appropriate audio (if necessary).

- Output peripherals are the devices which display the virtual world to the user and the input peripherals are the devices which the user uses to interact with the environment they view [3].
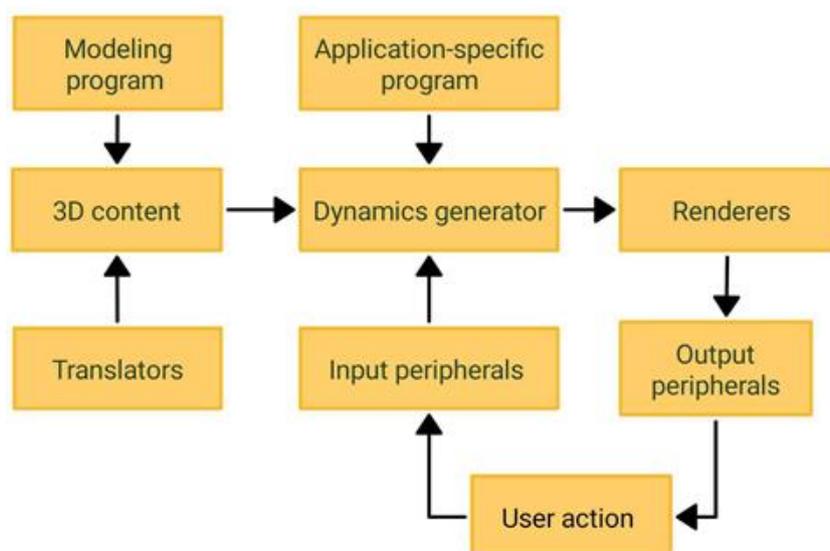
Figure 3. Architecture of a VR system [3]

2. Virtual reality in medical field

Although being majorly known for its application in gaming, VR has shown the potential to revolutionize the healthcare industry. With certain modifications to the existing VR models, practitioners are exploring efficient ways in which the virtual reality can aid the doctors and patients to customize treatments and achieve outcomes, including in cognitive and physical rehabilitation, pain management, surgery, mental health, and more.

2.1 Customisations made in VR modules for medical applications

Some of the novel customisations made in virtual reality modules for specific applications in medical field are:

1. **Customized VR environments**: VR environments are designed for specific medical procedures or conditions, like surgeries or phobias, to provide realistic simulations for training or treatment.

2. **Haptics**: VR systems incorporate haptic technology, which allows users to touch and feel virtual objects, providing a more realistic and tactile experience.

3. **Biometric monitoring**: Some VR systems are equipped with sensors that can monitor an user's biometric data like breathing and heart rate, to provide a more personalized experience and track progress.

4. **Augmented reality overlays:** AR technology are used to overlay information or images onto the VR environment, allowing for a more interactive and immersive experience.

5. **Telemedicine capabilities**: VR is used to connect doctors and patients remotely for virtual consultations.

3.   Medical applications of virtual reality

3.1 Pain management

Virtual reality has been in use as a means of distraction from pain during medical situations and treatments like,

- Burn injury care
- Chemotherapy
- Labor pain during childbirth
- Physiotherapy for rehabilitation after stroke, fractures and surgeries etc.

In the cases of both chronic and acute pain circumstances, virtual reality can effectively reduce the perception of pain by engaging the patient's attention, emotions, senses and concentration. VR intervention for pain relief has also proven to alleviate any distress or anxiety of the patient during the treatment procedures [4-6].

3.2 Surgical training

Effective surgeries will depend on the skills and efficient performance of the surgeons for many years in the near future. Hence it is important that the training of new surgeons is

done meticulously. Virtual reality has intervened to improve the efficiency of these training sessions. The objectives of VR in surgical training have been to provide the surgeons with a realistic environment to learn in, and to enable them to rehearse the actual surgery to become confident without putting any patient's life in danger.

VR provides a medium of performing any surgery using machines like a surgery simulator which takes in the CT scan the patient has undergone and creates a 3D model out of it. Surgeons use this model to practice for the surgery. VR also provides high quality radiation therapy and has organised planning in every stage. Technologies built in the domain of imaging, merging, projecting or visualising increases the understanding of a surgeon [7].

3.3 Treatment for cerebral palsy

Cerebral palsy is an incurable disorder caused due to improper development of the brain. It affects the person's mobility, posture and balance. Traditional treatment methods focus only on improving the functions in lower extremities but virtual therapy has given hope to enhance functions in both upper and lower extremities.

VR has children with cerebral palsy experience 3D scenarios where they get to exercise and play that can possibly improve their motor skills along with posture and balance when practiced for a long time consistently. Virtual therapy can also be delivered remotely through virtual reality games at home when patients cannot afford to attend therapy sessions with a professional due to financial reasons or mobility issues [8-9].

3.4 Educating young adults with Autism

Autism Spectrum Disorder (ASD) is a developmental dysfunction caused by differences in the brain due to which the individuals find it hard to understand other's thinking or feelings and tend to get anxious about social situations. However various studies have demonstrated that individuals with ASD can learn to improve their social skills by participating in specific scenarios regularly.

VR intervention for educating young adults with Autism is proven efficient due to its low cost, vast access and engaging contents when compared to traditional interventions. Young adults can be educated with life skills with the help of VR. It is observed that such individuals are capable of comprehending, using and reacting appropriately to virtual environments and can possibly transfer these skills into real life [10-11].

3.5 Dentistry

Virtual reality and augmented reality stand out among many great technological advancements in the field of dentistry in recent times. Using Virtual reality, laser scans of an individual's oral structures are taken as required and a 3D model of the same is created using a computer. This 3D model helps the dentists to gain accurate knowledge about the mouth and teeth anatomy of the patient. The model is then uploaded to a simulator which is used by the dental surgeons and students to assess and practice before performing the actual procedure on the patient. These virtual practice sessions make the trainee dentists efficient and the outcomes predictable. Virtual reality has been a great help to dental students during Covid-19 pandemic when practical learning opportunities at universities were limited due to lockdown. VR allows dental students to observe an oral treatment as a direct participant and practice under the guidance of professionals. Also virtual reality enables the patient to know about the result after the treatment beforehand as it provides a visual representation of the implants, orthodontics, bridge and crown [12-13].

3.6 Phobia treatment

Phobia is an anxiety disorder that causes a person to feel an inordinate and irrational fear of objects, feelings, places, situations or animals. It develops when a person has an excessively inflated sense of danger about an object or a situation. Exposure therapy is a popular and effectual way to treat phobias. It involves exposing the sufferer to their anxiety source without causing any danger. This kind of exposure therapy aims at gradually decrease the patient's phobia by exposing them to their feared stimuli frequently. Virtual reality is now being used to enhance exposure therapy.

The VR system creates 3D visual and auditory content related to the patient's phobia using computer graphics. This may include images with 360° view or videos about the feared situation. Exposure therapy using virtual reality can take place in the therapist's office which proves to be less expensive and restrictive to both the patient and the therapist when compared to the traditional exposure therapy which involves having the patient subjected to real world stimulus. This also makes it easy for the therapist to analyse the psychological changes in the patient's body including heart rate, skin conductance, etc. during the therapy [14-16].

All the observations made while implementing virtual reality technology in various medical applications are summarised in the below table.

Table 1. Attainments of VR techniques in various medical applications

Medical applications	Observations
Pain management (During wound care, childbirth, physiotherapy)	• Reduction in perception of pain. • Alleviation of distress and anxiety during treatment procedures.
Surgical training	• Increase in the efficiency of the surgeons. • Increased rate of success in complex surgeries. • Faster completion of surgeries.
Treatment of cerebral palsy	• Faster results in improving mobility and functions in cerebral palsy patients undergoing VR therapy when compared to traditional therapy. • Improved functions in both upper and lower extremities of the patients using virtual therapy.
Educating children with Autism	• Teaching social skills to young adults with Autism has been made easier and efficient. • ASD patients are able to apply the life skills learnt through VR in real life.
Dentistry	• Improved confidence in the dental surgeons before performing the actual procedure. • VR models could predict the outcomes of the procedures beforehand. • VR also helps in distraction from pain or discomfort and reduces distress in children.
Phobia treatment	• Exposure therapy for nature phobia could take place in the therapist's office. • Virtual exposure therapy is cost effective and less restrictive on both therapists and patients.

4. Case study: Surgery performed with the help of VR to separate conjoined twins

A London-based charity, Gemini Untwined, facilitated a VR-supported procedure to separate conjoined twins in Rio de Janeiro, under the direction of London's Great Ormond Street Hospital. The three-year-olds Brazilian twins Arthur and Bernardo were born craniopagus, an extremely rare condition in which twins are born with their skulls and, often, some brain tissue and blood vessels fused together. Surgeons in London and Rio de Janeiro, in two different continents, used virtual reality to develop 3D models of the twins based on

MRI and CT scans to practice for the 27-hours long operation which was one of the most complex separation procedures on record. It took a team of nearly 100 clinicians and seven separate surgeries. It was also at the risk of additional complications since the twins were the oldest craniopagus twins with a fused brain to be separated. However, the charity reported that the surgery went smoothly because of the VR-guided practice runs.

The procedures took place in Brazil, with the direction of Noor ul Owase Jeelani, paediatric surgeon in Great Ormond Street Hospital, who took part in the surgery from the UK via virtual reality. Jeelani later told the press that it was great to see the anatomy and practice the surgery before putting the children at risk. He said it was really reassuring for the surgeons. He added that it was "man-on-Mars stuff" to do one of the hardest operations using Virtual Reality. Figure 4 shows the twins before and after the separation surgery [17-18].

Figure 4. The twins before and after the separation surgery [18]

5. Discussion regarding common research problems observed in previous studies

- **Small sample size**: It is observed that most of the trials conducted to determine the feasibility and reliability of virtual reality intervention during various medical treatments have had a very small number of participants. This does not help to conclude whether virtual reality could work when implemented on a larger scale.

- **Cyber sickness**: In virtual therapy for rehabilitation to improve mobility, posture or balance, HMD devices are used most commonly as they allow the patients to move around. But it is observed that the use of HMDs triggers nausea, drowsiness, headache or loss of balance in many patients. So virtual therapy had to be limited to the usage of computers and mouses or joysticks which do not provide appropriate exercises to improve the patient's condition [10].

- **Not suitable for all age groups**: Virtual therapy may not work as effectively on people in old age as compared to children and young adults.

- **Addiction**: Although virtual reality intervention reduced the reluctance of patients towards therapies or training, there is always the risk of users (especially children) becoming addicted owing to its immersive property.

- **Arduous process of designing personalised content**: For VR therapies to work for everyone in virtual rehabilitation or virtual exposure therapy, the 3D contents must be customised according to the needs of each patient. Designing these contents is a time-consuming, expensive and hard process.

- **Reluctant patients**: Not all patients are willing to use virtual therapy since it is still a novel technology in medical field without much evidence to prove its efficiency.

- **Ambiguity regarding exercise duration**: While many studies prove that virtual therapy could improve functions in limbs, posture and mobility, there is no clearly mentioned exercise duration that needs to be followed to achieve best results [7].

- **Cost :** VR systems are expensive which limits their availability in all healthcare facilities.

- **Complexity**: Virtual reality systems are complex and practitioners require special training to use them effectively [19].

6. Conclusion and future scope

This paper has elaborated that, with a few customisations, virtual reality has the potential to revolutionize the medical domain. It is being successfully used in pain management as a source of distraction and is helping to improve therapies for both physical and mental disorder. Virtual reality is also making education of dental students and training of surgeons easier and consistent. However, it is quite impossible for virtual rehabilitations and virtual training to replace the conventional methods at least in the near future. Moreover, creating 3D contents for virtual reality is a tedious and time consuming task. The future scope for VR might be using machine learning to create the virtual environments based on the unique needs of patients and doctors. Because high-end VR devices like Oculus Rift or HTC Vive make virtual treatment expensive, developments can be made to integrate virtual reality onto smartphones, making it affordable to all. At last, researchers must conduct randomised

trials on a larger population to precisely analyse the attributes of virtual reality interventions in various disciplines of medical field.

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