Overview On Hardware Characteristics Of Virtual Reality Systems

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2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA) | 978-1-6654-6835-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/HORA55278.2022.9799932

***Abstract*— The scope of this paper is to present an overview of the different types of virtual reality (VR) systems from the hardware point of view. To conduct this survey first brief history of VR and classification of VR systems is presented. Next different types of input and output devices, necessary for the composing of a VR system, are described. After that, a comparison between the most common models head mounted displays is provided. As a result, common hardware characteristics of VR systems are summarized. The aim of the conducted analyses is to be in help of the users, so they easily can choose which type of VR system is suitable for their needs and then select the appropriate devices for their particular purpose. In addition, the use of VR technologies in education has been presented in order to outline the importance of implementation of virtual reality to enhance the conventional education.**

Keywords—Virtual Reality, Classification, VR systems, Comparison, Hardware Characteristics

I. Introduction

Virtual reality (VR) is a computer-based technology for simulating the effects (visual, auditory, tactile) of an artificially generated environment on the human senses, giving the user the impression that he is "immersed" in reality [1, 2]. VR is represented as a three – dimensional (3D) environment made up by a combination of software and compatible hardware for displaying this environment [3]. Its essential difference from other computer technologies for displaying information (for example: large displays, screens, etc.) is that there is „feedback "on human influences on it i.e., the virtual environment changes adequately to user's reactions through interactivity.

In the age of advanced technologies, software tools are used as a media to improve the quality of education. It is very important to find techniques that satisfy both students and educators in the learning process. Through various interactive devices, virtual reality and applications using artificial intelligence, the learning material can be presented in an adaptive and intriguing way. Modern information technologies allow the presentation of a variety of visual information in three-dimensional space. The development of computer technology has been changed the learning techniques. In recent years, 3D modeling and animation have been actively introduced in education, providing educators with new tools that help learners more easily to master studied material, increase their motivation and help them to acquire large amounts of information.

II. Brief History and Classification of VR and VR Systems

A. Brief History

For the first time in the late 1950s, Morton Helig demonstrated a prototype device called the Sensorama. The device was a simulator for one to four people, in which 3D images were projected with stereo sound, chair movements and realistic smells. It had most of the features of such VR environment, but without interaction [4]. This was the initial approach towards developing a virtual reality system.

The first head-mounted display with proper tracking and stereo views was invented by Ivan Sutherland in 1965 [5]. It was named The Sword of Damocles and it was the first hardware concept and prototype for a Virtual reality system. Oculus Rift is the first affordable high-quality Head-Mounted Display. It was introduced in 2012 as a Kickstarter project After that a large number of products are overflowing the market trying to implement the idea of the pioneer Ivan Sutherland and the Ultimate Display.

The term Virtual Reality was introduced for the first time from Jaron Lanier in 1989. After that many researchers give and evolve definitions concerning the term VR [6 - 10]. What they have in common is the existence of a simulated environment generated by a computer in which the user can be immersed. definition

B. Classification of VR

In this subsection, first will be presented key terms connected to the current research: "Desktop VR" and "augmented reality". After that briefly will be introduced different types of VR systems so that in the next section an analysis of the hardware characteristics can be made.

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In [11] the authors define the term Desktop VR as the use of animated 3D graphics to build virtual environment. The visualization is achieved using one or more computer screens. The user is not immersed in but can interact with the virtual world. Interaction is limited to the possibilities of a desktop computer mouse or a joystick, but it does not require any expensive hardware or software, so it is relatively easy to develop.

Augmented reality (AR) is a technology in which virtual objects are placed over the real world [12, 13]. Unlike VR, AR is rather additive to reality than completely replacing it. Thus, can be called local virtuality.

The authors in [14] specify three key characteristics associated to any VR system: immersion, interaction and visual realism. Immersion is achieved through virtual technologies and devices like virtual glasses, gloves with movement sensors, HMDs, surround sound and etc. [15] With the use of these devices the user feels that he/she are immersed in to a virtual world i.e., VR creates an immersive 3D spatial experience. For reliable perception is needed real-time interaction [16], so that the user requires instant response of his or her movements, position, and sensations. The user can react and send instructions to a computer by using input devices (trackers, gloves, keyboards) that simulate real-world user's reactions. The visual realism in VR system is reached through the output devices (visual, aural, or haptic), so that hardware and software should be able to render detailed and realistic virtual scenarios.

According to the degree to which the user is immersed in the virtual world, three types of VR can be distinguished. A taxonomy that classifies VR systems into non - immersive, semi-immersive, and fully-immersive is proposed by Muhanna in [17].

- Non-Immersive system

This category consists of a standard computer monitor and is the basic type of VR systems. Usually is called desktop VR and can be employed without any special input or output devices. These systems provide a lower level of presence and interaction.

- Semi-Immersive system

This group of VR systems is also called hybrid systems. It represents enhanced version of Desktop VR. They still use a conventional monitor (very often with LCD shutter glasses for stereoscopic viewing) but generally do not support sensory output. The interactivity within this type of systems is achieved through the use of devices such as a mouse, keyboard, glasses, and joystick. [18]. Prominent representative of semi-immersive systems is the augmented reality, as it brings together real-world objects with virtual ones.

- Fully-immersive system

This type of VR systems has the highest level of immersion and allows users to attempt virtual environments as the real world. They provide the observer with virtual scenes in a large field of view. Fully-immersive systems are based on computer interface devices, such as head-mounted displays (HMD) or projection screens surrounding the subject (CAVE systems), fiber-optic wired gloves, position tracking devices, and audio systems providing 3D sound [19].

III. HARDWARE CHARACTERISTICS

In this section is presented an overview of the VR system from a technological viewpoint in order to summarized common hardware characteristics for the three types of VR systems. Also, a comparison between the most common models HMDs has been conducted. The results are summarized and presented in Table I and Table II.

From a technological viewpoint, a VR system consists of three key components: input devices, output devices, and software. In general: input devices are responsible for interaction, output devices for the feeling of immersion and software for a proper control and synchronization of the whole environment [4] [20].

In the next subsections the survey will focus only on the first two components. Based on these key components (input and output devices) the authors summarized common hardware characteristics for the different VR systems. The result is presented in Table I.

TABLE I. VR SYSTEMS HARDWARE CHARATERISTICS

	Desktop VR	**Semi-Immersive VR**	**Fully-Immersive VR**
Visual Displays	Desktop LCD monitor	Desktop LCD monitor; AR glasses	Head-mounted displays: -wired -mobile
Input Devices	Keyboard, mouse	Keyboard, mouse, 3D joystick; gesture recognition(AR)	Controllers; Navigation devices
Tracking Devices	none	head-mounted sensors(AR)	Hands and body sensors
Auditory Display	loudspeakers or headphones	loudspeakers or headphones	loudspeakers or headphones

A. Output Devices

Output devices transmit continuously, computer - generated information to the user via multiple sensory modalities such as visual, auditory, and tactile feedback. The most important sensory modality is vision and most of VR applications rely on it. This is usually implemented through stationary displays or head-mounted displays (HMDs).

The stationary displays are used in Desktop VR and in some semi-immersive VR systems. The display for semi-immersive experience provides projected stereo images from the viewers' points of view, giving them the ability to see the third dimension on their two-dimensional desktop monitors.

The other category of visual displays, HMDs, are used for immersive simulations. HMDs are worn on the head and usually provide a stereoscopic view of the world by projecting a slightly different view of the virtual world to each eye. They can be divided into wired or mobile.

- Wired HMDs: A separate computer is required to be able to use these devices, because they don't contain any computing hardware except sensors. All data that will be visualized are processed to the connected computer. The main limitation of these headsets' performance is by the computational power of the computers that they are connected to. This allows them to work with more complex VR environments, in comparison with any other devices. The richest, high-quality VR experience is provided to the users by this category of HMDs [21].

- Mobile HMDs: Three subcategories are distinguished in the mobile systems [22]. The common characteristics that all of them share is that they are wireless and are able to be used without an additional PC.

The first sub-category in the mobile displays is called "simple casing ". These displays are basically a frame for smart phones having additional lenses mounted at a reasonable distance. They fully rely on the technology of the smart phone used.

The second mobile sub-category consists of ergonomically designed smart phone cases, which contain significantly better optics and are more comfort for wearing.

An additional sub category of mobile HMDs are the stand-alone systems that do not need an additional PC or a smart phone. They have integrated graphics processing units, generating, rendering and visualizing 3D virtual environment on the displays, and also contain embedded sensors that record the coordinates of the device, order to determine the correct user perspective when displaying the image.

TABLE II. COMPARISON OF COMMON VR HEADSETS

	Oculus Rift S	**HTC Vive Pro**	**Oculus Quest 2**	**HTC Vive Focus 3**
Device type	Wired	Wired/ Standalone with VIVE Wireless Adapter	Standalone VR	Standalone VR
Display type	LCD	AMOLED	LCD	LCD
Resolution	1280x1440	1440x1600	1832×1920 pixels per eye	2448 x 2448 pixels per eye
Field of view	90º	110°	89º	Up to 120°
Refresh rate	80Hz	90Hz	90 Hz	90 Hz
Controller movement type	6DoF	6DoF	6DoF	6DoF
Head tracking	Inside-out	Inside-out	Inside-out	Inside-out
Storage & Memory	—	—	128GB/ 256GB; 6 GB RAM	128 GB / 8 GB RAM with support up to 2TB microSD
Battery life	—	—	~2-3 hours	~2 hours

In Table II is presented a comparison between the most common models HMDs of the main competitors on the market: Oculus and HTC. The first two columns are representatives of wired HMDs and the next two columns are from stand-alone mobile HMDs category. One of the main differences between them (except mobility) is that the first group don't have limitations related to memory and battery life. Thus, make them a good choice for visualizing complex data requiring more computational power. In case that the users do not have concerns about battery and memory limitation mobile HMDs are better choice due to computer independence. Both mobile models, presented in Table 2, have improved resolution which provides a clearer visualization.

B. *Input Devices*

Input devices allow the user to interact with the virtual world, by capturing the user's movements and sending this information to the computer. Virtual reality systems also include various tracking devices, pointing devices, and audio devices.

In [22] the authors identify three different subcategories of input devices which are mainly associated with HMDs.

The first group is the controllers. They provide the user with the opportunity to communicate directly with the virtual environment. The controllers are hand worn and provide input in the form of buttons and continuous input by top-mounted joysticks or touchpads with additional 6 DOF tracking information. They can vary from wired to wireless. It is important to note that the controllers usually are offered as set of two similar, one for each hand. Controllers are provided with the opportunity for basic gesture recognition depending which finger actually touches the device based on capacity sensors.

The second group is composed by navigation devices. They provide the user with a more intuitive moving experience. These devices are used to give the user the illusion for travelling through the virtual world. The navigation devices vary from motion on a two-dimensional plane - the Omnidirectional Treadmills (ODTs), over slide mills (passive low-friction surfaces) and chair-based interfaces to foot tracking.

And the third subcategory of input devices consists of tracking technologies which can be divided in full body tracking and hand tracking. Wearable body tracking devices are attached to the user's body. Tracking is achieved through magnetic sensors or IMU sensor composed of accelerometers, gyroscopes and magnetometers. The gesture capturing can be either optically, via biofeedback or with data gloves. The data gloves are based on a strain gauge technology using fiber optics. One of the most popular representatives of optically gesture capturing devices is the Leap Motion. It is based on two cameras and infrared LEDs covering a hemisphere on top of the device.

Figure 1 shows three exemplary input devices – one from each group of input devices. The first one is the Oculus Half Moon which is the Oculus controller. It has capacity sensors which allow for basic gesture recognition depending which finger actually touches the device. The controller is shaped like half of a conventional gamepad with a large ring built around it, which is used for optical tracking. The capacitive buttons on the Touch controllers allow the system to infer things about user finger positions. The controllers can use these cues to conclude whether the user hand is in a fist or is pointing at something

The second one is the Virtuix Omni. It is active virtual reality platform that allow the user to walk, run, move backwards and sideways with 360-degree freedom of movement. The system works by using a concave disc and special shoes with low-friction surfaces. This allows the user to walk smoothly in any given direction. The user's stride is natural thanks to the concave shape of the disc, which uses gravity to pull the legs towards the center. A sensor capsule is placed in the upper part of each shoe. They track the position of the shoe and reproduce it in the VR application. And the last one is the Leap Motion.

Fig. 1 The Oculus Half Moon (left), the Virtuix Omni (middle), the Leap Motion(right)

IV. USAGE IN EDUCATION

The transition from analog to digital teaching practices is also changing the way how teaching looks like. The role of the educator changes from delivering content to facilitating content. They will be focused on creating research conditions instead of providing ready-made knowledge. Similar to all virtual reality applications, in education they are implemented through software, hardware and special stimulation devices.

The advantages of such an approach are obvious. Not only does it reduce distraction, but it can completely immerse the learner in the simulation. Some simulations are so well realized that the student begins to react, as in real life. Learners will not only gain important information, but will also be able to start practicing their skills from day one. Some of the benefits of virtual reality training that will help for better training are:

- Visual learning: Humans are highly visual beings. 90% of all information sent to our brain is visual. 93% of all our communication is visual. With virtual reality, learning becomes more visual, as the theme of the training is presented in a visually stunning 3D format.

- The trainings can be performed remotely: The world is moving to a decentralized workplace where people collaborate over long distances. Because virtual reality headsets can replicate any real environment, there is no need for expensive training centers. The learner can download training material from the company's website and use it wherever it is, without the need for an entire training center.

- Memorization and reproduction of what has been learned: As stated before, the key point to learning in virtual reality is its ability to create a highly captivating environment. Higher immersion in the virtual environment can also make it easier to memorize materials. Learners can practice their skills as many times as needed, knowledge becomes part of their muscular memory.

These are some of the features that make VR training much better than regular training.

A. Characteristics of VR in Education

The practical use of VR in education can be divided into two main groups: school / university training and workplace training. Practical applications of VR can be summarized as follows:

- Virtual walks, exhibitions - the most common and obvious use of VR is in the field of virtual tours to distant or physically inaccessible places;

- Special education - for people with physical disabilities who study and explore the world through VR glasses, this is a great opportunity to get an education;

- Content Creation - Virtual reality can be applied for content creation for classes to any topic;

- Medical education - much of the investment and efforts in medical education are spent in developing an applications that creates immersive VR experiences for training. VR immersion training is an effective teaching method to help medical and health professions students to practice different clinical cases and improve skills;

- Training – VR technologies can deliver an appropriate and manageable environment for all types of training. The main purpose of using virtual environments is to train users to perform real-world tasks and procedures.

- Distance learning - with VR online learning becomes more convenient and can even provide a sense of presence. In VR, students may take multiple perspectives on learning content. The student’s motivation and learning are boost due to the feeling of being “immersed” in the learning environment and being able to interact with it credibly.

V. CONCLUSION

VR technologies are one of the fastest evolving areas of the modern world, which in recent decades has found application in almost all sphere of society and everyday life, including education. One of the most important features of this technologies is that they can make the invisible - visible and the inaccessible - accessible.

In the variety of VR-related information, it would be useful for the users to easily find out what which type of VR system is suitable for their needs and then select the appropriate devices for their particular purpose. The main purpose of the presented paper is to provide summarized common hardware characteristics of VR systems so that this choice to be easier.

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