Virtual Reality current trends and proposed research agenda

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***Abstract*— Among the hottest fields in Information Technology, together with AI/Machine Learning and Blockchain, just to name of couple more, Virtual Reality (as well as Augmented Reality and Extended Reality) are gaining momentum all the more every day. This is mainly because it is heavily applicable on a broad range of business and scientific domains reshaping the way human activities are done now and leaving promises for the near and far future. This short review study aims to provide some insights on the status of the main aspects of VR and some challenges to address as well as provide some possible research directions for anyone interested to delve into the field.**

Keywords*— *Virtual Reality (VR), Haptic feedback vibration, Cyber-sickness

I. Introduction

It goes without saying that the concept and technology of Virtual Reality (VR) (as well as Augmented Reality, (AR), and Extended Reality, (XR)) is among the hottest fields in the Information Technology together with Artificial Intelligent (AI)/Machine Learning (ML) and Blockchain. The reason is that humans are multimodal perception creatures [1]. The human brain has the ability to combine and analyse information from different sensory modalities, i.e., vision, audio, touch, smell, and taste, identify if they belong to the same event, and enable a meaningful experience. Any changes in one sense may also affect another, e.g., a variation of particular elements within the soundtrack can increase the vividness of the three-dimensional (3D) environment [2], [3].

The concept of VR dates back to 1930's with the "Link Trainer", the first example of a commercial flight simulator. This vacuum-based technology device allowed the training of the, then, pilots without the need of actual flying in a real plane. This was followed, soon after in 1935, by the "Pygmalion's Spectacles" a pair of goggles that made the user to experience an imaginary world [4]. A serious effort has been made to improve its characteristics in order to increase the feeling of immersion to emulate the real world as close as possible [5].

The potential of the use of VR was recognized since its first introduction in many fields including the medical profession, engineering, architecture, and education, just to name some of the most frequently discussed [6], [7]. In the case of the medical profession, the students are enabled to be trained effectively and repeatedly with emerging surgical techniques and technologies in virtual labs [8]. In the case of engineering, the students can model their work in the virtual space using the same laws as in the reality and testing their structures like in the real world [9]. In the case of architecture, the students in visualisation labs can add dimensions and generate 3D computer models to explore in praxis that which is not possible with the traditional forms of representation, i.e., testing hypothetical designs, plan configuration of different building heights, interact with photorealistic walkthroughs, design simulated buildings and cityscapes [10].

In the case of education, VR has multiple uses with powerful impact. There is the ability to be immersed in a virtual classroom or auditorium with conversation and collaboration between students and teachers. Teachers can give lectures and presentations with 3D models. Students and teachers can participate from anywhere across the world. The difference between the two-dimensional (2D) online tutorials and a VR experience is the immersion and interactivity. In higher education in particular, the institutions planned, well in the past, to utilise VR as much as possible in their course delivery and, perhaps, assessment [11].

The purpose of this desktop review study is to introduce some of the most important challenges the VR technologist face and form a research agenda with some possible directions of how to address these challenges.

II. Background

Multi-sensory cues like the combination of visual, auditory, and haptic cues have been proven to increase the feeling of immersion in VR by emulating the real world [12]. VR allows the users to have a simulated experience in a computer-generated environment as close to reality as possible [13]. Although the Head-Mounted Display (HMD) blocks visual access to the real world, the users can completely immerse in a replicated environment with full vision and audio properties.

A. Computer Graphics/Sound

Originally, the focus was on ensuring the resolution quality, the fidelity level, and the refresh rate of the visual characteristics are a given. In the recent past, there were a lot of studies concerned with the visual part of VR, i.e., its computer graphics. There is a lot of improvement in that field [14], [15]. Now, computer graphics used in VR are much more advanced than in the past with far improved resolution and fidelity. In parallel, there was an effort that the relevant qualities of sound properties in the VR experience were also high. Developments related to the sound in VR are also following closely [2] with improved characteristics.

The two senses, i.e., vision and sound, addressed by the above (i.e., computer graphics and sound/audio) helped raise the cognition level of the experience allowing, presumably the better progress of the students. For these reasons, although people, especially youngsters, are still engaging in Video Games and Videos and Tutorials online, however, they discuss and try all the more VR products and related experience, be it entertainment, videos, gaming, etc., leading to the rapid growth in the production of VR products both hardware and software (e.g., VR games). Again, the reason is very simple: Vision and sound is very important for the human brain to experience things bringing reality in a higher cognition level than sitting in front of a 2D monitor.

Given the relatively high number of studies related to the rapid developments of computer graphics and audio/sound in VR, and the level of depth of these studies, it is becoming increasingly more difficult to work on the relevant parameters of a VR environment. Yet, there is still room for improvements that allows for further research in the fields of computer graphics and audio/sound. Table 1 below points out the main advantages and disadvantages of a VR experience as compared to the regular 2D Video Games, Videos and Video Tutorials. The main point suggested in the Table 1 is that VR products and services are very promising and have the potential to surpass the rest in both immersiveness but also in attractiveness and interest as fully resembling (in the near future) the real world.

Table 1: VR vs. 2D Video games, 2D Online Videos, 2D Online Tutorial

Attributes/ Characteristics	VR	2D Video games	2D Online Videos	2D Online Tutorial
Video resolution	Medium to high quality, improving	High quality	Medium to high quality depending on the channel	
Video refresh rate	High rate and improving	High rate	Usually, high rate	
Fidelity [16]	Medium quality, improving	High quality	Mostly high quality	Usually, high quality
Sound	Medium quality and improving	High quality	Mostly high quality	Usually, high quality
Price	Medium price and dropping	Relatively low price	Usually free or low priced	
Comfort	Medium and improving	High comfort	Medium to high comfort	Usually, high comfort
Physical stress	Some nausea at gradually reduced levels	Very little or none	Very little or none	
Immersive-ness	High levels gradually improving	Low levels or none	Low levels or none	
Interaction [16]	High levels and improving	Medium to high levels	Usually medium to low levels	

B. Haptic Feedback

If the VR environment is based only on vision and/or sound, the whole experience looks more like a dream. When other senses are also involved, the brain receives the experience at higher cognition and can confirm better whether the experience is real or fake. One such important sense is that of touch which further increases the feeling of immersiveness and enhances the feeling of reality as compared to dreaming [6].

There are two different ways to study the effect of touch in any VR related experience: haptic (vibration) feedback and force's feedback. There are several serious differences that almost dictate that in the case of a Computer Science research the former is preferable. In the case of the Force's feedback, there is the need to compute the physical properties of the feedback in detail solving many equations relevant to the detailed laws of physics that involve knowledge and skills in higher mathematics [16].

Haptic feedback is of vital importance in manipulative and exploration tasks of the daily life [17]. In real life, when touching an object, haptic and forced feedback are both present. In the case of haptic devices, they are wearable and not impede the natural movements of the fingers [18], [19]. The main characteristics of haptic (vibration) feedback are the amplitude, the duration, and the frequency. It is a field that has been established technically for some time [20]–[22]. However, there are not many studies examining the settings of different configurations of these parameters and their effect in reducing the number of iterations and time [23]. In VR applications the vibration provides haptic feedback and it is important to study it since it helps the users to feel virtual objects and improve their imagery (Table 2).

Table 2: provides a quick reference of a basic comparison between haptic (vibration) feedback and force's feedback.

Characteristics	**Haptic (Vibration) feedback**	**Force's Feedback**
Need for mathematics	Low demand for solving mathematical equations because of only one property, i.e., vibration	Higher mathematics to solve many equations relevant to the laws of physics [16]
Interaction with objects	Extended functionality in manipulating objects, interact/ grasp objects with low demand in mathematics	Deeper functionality with very high demand in solving large number of mathematical equations [16]

Haptic (vibration) feedback devices include gloves and exoskeletons, finger-mounted actuators, and handheld controllers, just to name a few. Gloves and exoskeletons are usually grounded to the user's wrist, require careful putting on, offer high fidelity, and transmit forces to the fingers and other parts of the body; however, they are rather expensive. Finger-mounted actuators transmit feedback onto the user's fingertip and provide feedback on several fingers at the same time. Handheld controllers are palm grounded, easy to wear, and can host haptic elements to provide rich effects. [16].

In many commercial applications, the controllers are used in rather primitive context. For example, in a game with simple controllers, one has just the feeling of the vibration except when using peripheral hardware like haptic suits, haptic wheel, haptic gloves, etc. [16], [23], [24].

Since vibration often needs only random timing, random amplitude, and random frequency, the demand for solving mathematics equation is dramatically reduced (indeed very low). Another positive point about haptic feedback is that it helps manipulate objects, interact and/or grasp them, again without the need for higher mathematics [25].

C. Cyber-Sickness

Not everything is bright concerning VR. The technology is still facing some serious problems. One of the downsides of working with VR and using HMD devices is cyber sickness. Some people are sensitive to that, and it is difficult to predict it due to many factors related to Hardware and Software (i.e., position tracking errors, lag, and flicker), Individual Differences (e.g., health, behavioural conditions, age, race, ethnicity, etc) and Environmental Factors (e.g., temperature, relative humidity, light, air quality, ambient noise etc.) [26]–[29]. The side effects and symptoms of cyber-sickness are similar to the motion sickness, i.e., headache, eye strain, pallor, excessive sweating, nausea, vomiting, fullness of stomach, ataxia, vertigo, dizziness, disorientation, fatigue, strange hand eye coordination, and dryness of mouth. Most of them are temporary or can linger for a few hours or days. Cyber and motion sickness are not necessary the same thing, although there are similar symptoms [27], [29].

Researchers have identified three major theories for the existence of cybersickness which are the Sensory Conflict Theory, the Poison/Intoxication Theory, and the Postural Instability Theory [27], [29]. Based on the "Sensory Conflict Theory", which is the most accepted theory, cyber sickness is coming from the difference of what a user can see through HMD and what user feels with his body vestibular system at the same time [27].

Some strategies often adopted to mitigate the effects of cybersickness are [26], [28]:

1. By utilizing Teleportation locomotion methods that allow users to instantly teleport to a location by pointing at it. This is because continues motion tends to make an individual disconnected between what the person sees while moving and what that same person feels. This causes the brain to get confused and that makes the person motion sick. With teleportation, one moves from a spot to another by just pointing at it without observing the whole process. The only problem to be solved in this case is the initial disorientation resulting from the instant experience of the new place.
2. By reducing the amount of visual information and optical flow available to the user. This can be done as follows:
    a. By modifying the Field Of View (FOV) with a black filter around the edges of the user's vision, reducing the angle they can view their surrounding in the simulation.
    b. By reducing the visual details through image blurring effects, i.e., by dynamically blurring the image presented to a user in an HMD.
    c. By using the "circle effect" or the "dot effect" to alter the visualization of the application in the peripheral area of the perceived visual image to reduce effective optical flow.
3. By resting frames like stationary objects that users can focus their attention on even when in motion. As Figure 1 suggests there are, basically, three main types of resting frames, i.e., those with cues in the foreground as cockpit with the foreground matching the inertial cues, those with cues in the background causing congruence between visual and background & inertial cues, and cues in the foreground in the form of a virtual nose or wireframe box with the foreground cue matching the inertial cues.
4. By stimulating the vestibular system through bone conducted vibrations with an external devise.

A person that suffers cybersickness when using a VR application will most likely never want to use that application again. Many VR providers recommend users to avoid, for at least an hour, any risky activities, e.g., driving [29] after a VR immersive experience. HMDs in immersive VR applications, allows users to control the position and the orientation of the viewpoint. The basic locomotion technique, without the aforementioned methods to address cybersickness, is good for large virtual environments because they cannot fully observe when walking normally in the environment. In all cases the locomotion design has to be good to avoid the users' distraction, or reduced immersion, or cybersickness [30].

Supplementary to the above main strategies there are several techniques that are employed by the researchers and VR professionals over the years to address the problem or go around it. These are often referred to as Cyber-sickness protocols. Table 3 below lists and briefly describes some of those considered more important.

Table 3: Cyber-sickness protocols

Mobility techniques	• Force the subject/user to move slowly in the VR environment. • Keep the subject/user in an upright position, i.e., at the world level, and keep gravity pointing down when rotating around to change direction. This can be done by rotating the world around the vertical axes. • Show a helmet, a cockpit, etc., in a minimal amount of graphics lag between the user input/frame rate. e.g., at 90 frames per second for Oculus. This is because, the more lag there is, the more likely the user will get motion sick.
Configuration techniques	• Use a 360^0 low-latency (i.e., minimal delay of processing data) head tracking. • Use as fast frame rates as possible (the current configuration is at 90Hz) to avoid cyber-sickness.
Reduce/eliminate sensory conflicts [31]	• Introduce peripheral blur. • Configure the motion base (vestibular cues). • Add dynamic FOV (Figure 2).
Postural Maintenance [31]	• Utilize common leading indicators. • Introduce active viewpoint control. • Add physical leading indicators (Figure 3).
Formative Evaluation Logic [31]	• What are the effects of the content parameters, e.g., of the duration of an explosion, or the content design? • What are the effects of the visual parameters, e.g., of the frame rate & the tracking rate? of the constant ratio, the brightness, and the screen resolution? of FOV and HMD design? • What are the effects of the motion parameters, e.g., the visual motion, the axes motion, the oscillation (?), the G-Force?
Human and other constraints	• What are other possible visual constraints, i.e., effects of interpupillary distance range, effects of visual-vestibular somatosensory mismatches, effects of virtual object location? • What is the effect of possible physical constraints, i.e., effects of position, restraints, Chinstraps, effects of a person's height, age, gender, effects of various environmental factors including sound? • What are the personal constraints related to disorientation, Oculomotor, nausea, etc?
Mobility techniques	• Force the subject/user to move slowly in the VR environment. • Keep the subject/user in an upright position, i.e., at the world level, and keep gravity pointing down when rotating around to change direction. This can be done by rotating the world around the vertical axes. • Show a helmet, a cockpit, etc., in a minimal amount of graphics lag between the user input/frame rate. e.g., at 90 frames per second for Oculus. This is because, the more lag there is, the more likely the user will get motion sick.

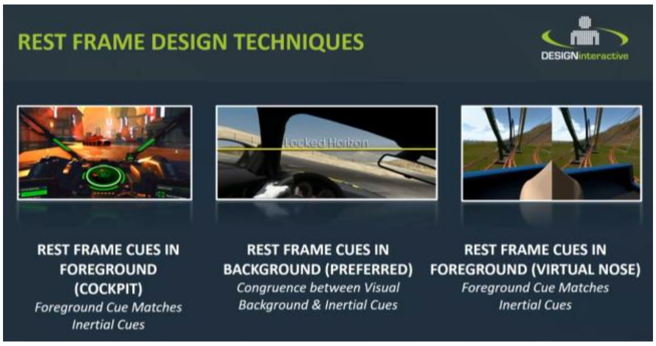

Figure 1: Resting Frame Design Techniques [31]

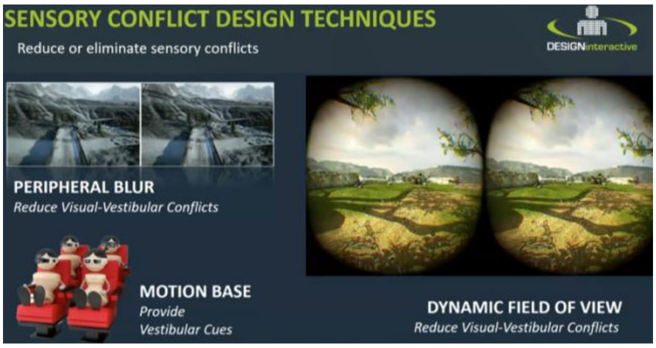

Figure 2: Sensory conflict techniques [31]

Figure 3: Postural maintenance techniques [31]

III. Research Directions

The previous sections provided a brief outline of the basic research problems to address when dealing with VR (and even AR or XR). These are by no means exhaustive. There are more to them. What is more important, and indeed deeper and more interesting, is that the above research ideas can even be mixed to produce much deeper, more complicated, and way more "intriguing" research themes as Table 4 suggests.

Table 4: Research themes based on the suggested research ideas

Main research themes	**Parameters to study**	**Possible research**
Graphics/ Sound	Graphics resolution, Sound parameters.	The effect of sound parameters and graphics quality and resolution in the immersive experience of a VR environment.
Haptic Feedback	Haptic parameters of amplitude and frequency.	The effect of changing the haptic parameters of amplitude and frequency in the immersive experience of VR.
Forces Feedback	Modelling the parameters of forces feedback in based on the laws of physics and mathematics.	Use the laws of physics and mathematics to find the optimum values for the parameters of forces feedback for the improvement of the immersive experience of a VR environment.
Cyber-sickness	Possible parameters causing cyber-sickness in a VR.	Addressing the problems of cyber-sickness by adjusting the possible parameters that affect it.

The above research directions can be enhanced, and their depth increased, if examined from a particular viewpoint of a field and its applications, say Tourism, Military, Health, Education, with literally endless possibilities. The importance of such research is further stressed in the current Covid-19 pandemic that affects all the aspects of human activity.

IV. Conclusions

Virtual and Augmented Reality are here to stay. In a sense, the implications of their applications in many aspects of every day human activity, including business, tourism, military, education, health, etc., are very similar to what happened the past 20 years with the rapid advent, proliferation, and dominance of eBusiness/eCommerce. Two decades ago, rumors had it that by 2020 a business would be present online, anyhow, or would not exist at all. Today, rumor has it that soon, perhaps as early as 2030 (or even earlier), a business or other entity will be present on the metaverse (i.e., a rather recently introduced technology term referring to the new virtual/augmented environments emerging over all kinds of human activities) or will not attract interest at all. Therefore, it is of outmost importance to get engaged in this field and stay tuned with its developments.

In this short introductory desktop research, the authors only suggested some current issues, potential, and possibilities related to the future research on the field. There are numerous more not referred to and the reader is invited to further investigate and pinpoint the one of interest. The potential appears to be unlimited. The long list could be formed by combining the human or business activity to focus on, i.e., business, education, health, military, tourism, etc., the technology focus, i.e., graphics/sound, haptic feedback, forces feedback, cyber-sickness, etc., and the level of engagement, i.e., clients/visitors, middle or top management, etc.

The authors' plan is to focus more on the field of education, higher education to be more precise, where to investigate possible applications of virtual reality and its effect in the assessment part, with particular focus in the effect of haptic feedback on the improvement of the students' learning and assessment progress.

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