Sense Simulation in Virtual Reality to Increase:

Immersion, Presence, and Interactions

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Abstract

With the advancement in the field of Virtual Reality, the companies are focusing on increasing the level of immersion, presence, and interaction to make the user experience more realistic. This paper aims to investigate how the human senses can be simulated in Virtual Reality to have a realistic experience and how the human senses increase the level of immersion, presence, and interaction. It will describe every human sense which makes us feel present and immersed in the real-world and the new VR technologies that are simulating the human senses in VR. There are only two human senses that are fully simulated in VR that is sight and hearing other senses are not simulated in VR which makes it less immersive and realistic.

The paper starts with the introduction of Virtual Reality and explains its emergence, the role of immersion, presence, and interaction in VR. It then explains the five human senses that are sight, hearing, touch, smell, and taste. This paper also explains the technologies and the devices which are being developed to simulate the senses in VR. Moreover, giving a brief analysis of how these technologies are contributing to increasing the level of immersion, presence, and interactions. The simulation of senses in VR can open new possibilities for game developers and media developers to find new ways of interactions in VR, for example, with the simulation of senses, game mechanics can be increased.

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Abbreviations

VR - Virtual Reality

VE - Virtual Environment

MR - Mixed Reality

FOV - Field of View

HMD - Head Mounted Display

PPI - Pixels Per Inch

PPD - Pixels Per Density

ITD - Interaural Time Difference

IID - Interaural Intensity Difference

SD - Spectral Difference

HRTF - Head-Related Transfer Functions

Chapter 1

Introduction

The major breakthrough in the field of computer science was the development of human-friendly interactions with computer generally known as Graphical User Interfaces (GUI). Apple released the first GUI-based computer named Lisa to the public. Xerox PARC developed the prototype of this GUI in 1979 (Powell, n.d.). Steve Jobs the founder of Apple Company then traded the US $1 Million in stock to Xerox for a detailed tour of their projects (Powell, n.d.). With the development of motherboards, operating systems and Graphical Processing Unit (GPU) computers could even interact and process 3-D graphics. After that the 3-D industry was wholly changed, we got 3-D animations and Video games. The release of Virtual Reality was a big step in gaming industries and several other fields. It opens the doors for human interactions and perceptions in the virtual world which increases the possibility to perform and develop various things like simulating an aircraft, telepresence, virtual prototyping, Augmented Reality (AR) and Mixed Reality (MR). VR is more than just interacting in the 3-D world but also VR offers presence simulation in a remote location where we can control machines by not physically be there (Gobbetti & Scateni, n.d.). Before VR, Virtual Environments were there and used to simulations, but they were displayed on a panel screen, not on a head-mounted display (Chirokoff, 2017). The development in VR encourages various companies to enter in this field and develop equipment that people can use in their home and experience VR. VR equipments which are developed in recent years is Oculus Rift, HTC Vive, Samsung VR, Google Glass, Microsoft Holo Lens, Playstation VR and many more. To make VR experience more realistic and natural, it is essential to increase the sense of presence of a user in the virtual world. People have done so many research on how to improve the sense of presence and were successful in doing it. The user should have a psychological feeling that he is in a virtual environment. VR developers needed a robust GPU which was already there in the market; they needed to develop a virtual environment that looks smooth, and the user can interact with objects which is very important to feel the presence in the virtual world. VR is the ongoing research topic, and we will see more developments in future which will increase the level of immersion, presence, and interactions.

1.1 Motivation

VR is still in the stage of development. There are limitations of this technology and many possibilities to explore the field of VR like simulating more human senses in VR. Currently, two human senses are present in VR which are super active that is sight and hearing. Touch is also there in the form of remote vibrations and haptic feedback, but it is still underdeveloped. This paper will look at state of the art concerning the sense of presence and interaction possibilities in VR by understanding the current situation and how other remaining human senses can be included in VR to improve the sense of presence and interaction which can improve the user experience.

1.2 Objectives

After the increasing growth in the development of VR, many companies launched VR head-mounted equipment with a microphone, headphone or a speaker and controllers in hand. However, they do not allow the user to use all of his human senses that he use in real life to interact with surroundings. VR is used to increase the immersion, presence, and interaction but does VR equipment include all the human senses? How can all human senses can be includes in VR which can work together to increase immersion, presence, and interactions? This paper aims to extract all the possibilities how we can make all the human senses work together in a VR experience. The analysis of all the human senses and how they can include in VR will also contribute to expansion in this field. It will also suggest a design prototype that includes every human sense interaction which will be the combination of the technologies that we are going to discuss in this paper.

1.2 Chapters Breakdown

The first chapter will give a summary of the emergence of technology. It will also briefly explain the origin of GUI and emergence of Virtual Reality. The second chapter will explain the origins of Virtual Reality and the definitions of VR and VE. It will also look into the terms Immersion, Presence, and Interaction related to VR. The third chapter will discuss one oh the human senses know as Sight. This chapter will cover the current state and uses in VR, importance to feel the presence in Virtual Environment (VE). Similarly forth, fifth, sixth and seventh chapters will talk about Hearing, Touch, Smell, and Taste respectively. The final chapter is the concluding chapter in which it will be concluded how all human senses can work together in VR to enhance the user experience. Also suggests technique or equipment in conclusion that includes all human senses in VR.

Chapter 2

Virtual Reality

2.1 Definition of Virtual Reality

In 1996 Grigore C. Burdea and Philippe Coiffet defined VR as "It is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell and taste." (Burdea & Coiffet, 1996). Virtual Reality does not depend on one technology; it is dependent on a combination of technologies that work together to develop the Virtual Reality. It not just only include high-end computer hardware but also skills to use and build an immersive graphical world in which user can use all of his senses and interact with the virtual environment also. All these together form a world of Virtual Reality in which user forgets the real physical world and immerse in the virtual world.

"Reality is merely an illusion, albeit a very persistent one." – Albert Einstein (Parisi, 2015). According to Albert Einstein, nothing is real everything is perception. Our mind understands what get want to get (Clawson, 2014). There is only one primary task of Virtual Reality, to fool or trick the human mind, make it believe that user is in a different world. To do so, a combination of technologies work simultaneously that create an illusion. This combination of technologies activates all human senses to trick user's mind. Such different technologies will be discussed in next chapters.

2.2 History of Virtual Reality

With the development of computer graphics and Processing units, VR has also emerged over time. The history of VR is strong. From 19th-century, people were trying to demonstrate human visual perception through art and photographs which were known as stereoscopic photos. In 1838, Charles Wheatstone first demonstrated with the help of stereoscope that our eye captures different 2-D images and then send it to the brain, The brain then processes the images into a 3-D object (Society, n.d.). In 1956, Morton Heilig invented a prototype called The Sensorama which was based on arcade-cabinet design, and it was the first breakthrough in the field of VR. It changed the future of VR and opened new possibilities in this area. This was the first VR machine to include a stereoscopic screen with surround speakers, vibrating chair, and a controller for feedbacks and also had a smell generator (Society, n.d.). The Sensorama was the first machine to have almost every characteristic of VR.

Figure 2.1 Sensorama (Heilig, 1956)

Heilig continued his research and development in this area and invented the first Head Mounted VR Display, but still, it lacked to give the immersive experience of VR as it still does not have a motion tracking (Society, n.d.). However, in 1961 Comeau and Bryan developed Headsight which had a screen for each eye connected to the closed circuit the cameras. These cameras allowed the user to naturally move his head to look into the environment (Society, n.d.). It was the first big step in the evolution of Head-mounted VR displays as it also includes motion tracking (Society, n.d.).

Ivan Sutherland and Bob Sproull continued Heilig's work on Head-mounted Display (HMD). In 1968, Ivan Sutherland developed Swords of Damocles which had two Cathode Ray Tubes(CRTs) connected along user's ear. At that time CRTs were heavy, so they had to rely on mechanical arms to support CTS's and which also has the potentiometers to calculate user’s view direction (Burdea & Coiffet, 1996). They were using analog images by cameras then Sutherland realized to use computer-generated graphics which was the big step in the field of modern graphics processors. Ivan Sutherland had a vision of “The Ultimate Display,” a concept that uses all human inputs that are possible not only through joysticks but by looking at the screen, glancing or gesture inputs. He predicted force could be applied to the charged moving particle to give input, to do so he suggested kinesthetic display. He said:

> “If the task of the display is to serve as a looking glass into mathematical wonderland constructed in a computer memory, it should serve as many senses as possible. So far as I know, no one seriously proposes computer display of smell and taste. Excellent audio display exists, but unfortunately, we have a little ability to have the computer produce meaningful sounds. I want to describe for you a kinesthetic display. The force required to move a joystick could be computer controlled, just as the actuation force on the controls of a Link Trainer are changed to give the feel of a real airplane. With such a display, a computer model of particles in an electric field could combine manual control of the position, of a moving charge, replete with the sensation of forces on the charge, with visual presentation of the charge's position. Quite complicated "joysticks" with force feedback capability exist. For example, the controls on the General Electric "handyman" are nothing but joysticks with nearly as many degrees of freedom as the human arm. By use of such an input/output device, we can add a force display to our sight and sound capability.” – Ivan Sutherland (Sutherland, 1965).

Before all these developments there was not a proper name of this field, refer it as “Artificial Reality”. However, in 1987 Jaron Lanier, the founder of Visual Programming Lab (VPL) coined the term Virtual Reality (Steuer, 1992). He developed many VR hardware like datagloves, The AudioSphere, The EyePhone- the LCD screen in this HMD provide different images to create a sense of depth (Steuer, 1992). After 1990 many industries stepped into the field of VR like gaming industry and movie industry and launched gaming consoles and movies (Society, n.d.). Virtuality Group Arcade Machines was launched, companies like Sega and Nintendo released their first 3-D consoles. However, both of these companies were failed to create successful machines.

2.3 Immersion

Immersion is a popular word in the field of VR and is also a crucial element of VR. It means to dive oneself into another world or whole another dimension forgetting about the real physical world (Bockholt, 2017). In VR immersion is important because the meaning of VR is to give the user experience of the whole different world. Virtual Reality was developed so that user can be involved with the virtual world. To immerse in a virtual world user has to interact with the objects in the virtual world and the combination of these two elements is known as Telepresence (Society, n.d.). Jonathan Steuer classified variables that influence Telepresence along two lines: Vividness and Interaction (Steuer, 1992). He said, "Vividness means the representational richness of a meditated environment as defined by its formal features; that is, the way in which environment presents information to the senses." (Steuer, 1992). It means that a vivid device can be immersive only if it can stimulate human senses, the vividness of the device depends on the number of senses it can stimulate, a higher number of senses means highly vivid device. Vividness is dependent on two important variables: Depth of information and Breadth of information (Steuer, 1992). The depth of information means the resolution of each perceptual system or the quality of the senses involved in the device. More resolution means more depth of information. For example, a high-resolution movie is more immersive than a low-resolution movie; we can even see tiny details in the picture or movie. To achieve a greater depth of information, it requires a high-resolution display, powerful GPU and also the effectiveness of a medium that can transmit the data in real time with higher frame rates. Real-time data transmission is also a crucial factor to make the experience immersive (Society, n.d.). The breadth of information refers to how many senses are active during the experience. In the real world, our body uses all the human senses to stay focused. All the human senses work simultaneously to give us a sense of presence in the real world. Similarly to make the user experience more realistic in the virtual world, stimulation of human senses is important so that our mind can be tricked.

2.3.1 Interaction

Interaction refers to interacting with real-world objects or virtual objects that is to provide input to modify or manipulate the object. It is very important part of VR as to make the user experience immersive we need to interact. For example, if a person is talking to another person, but he is not replying or interacting with the person that means he is not focused or immersed. On the other hand, when two or three friends talk to each other, interacting with each other, they do not even know when time gets passed, this means they were immersed in their talk that they did not care what is happening in the surrounding world. According to Jonathan Steuer "Interactivity is the extent to which user can participate in modifying the form or content of a mediated environment in real time." (Steuer, 1992). For an immersive VE, interaction is stimulus based, user's body movements are also interaction in VE. In 1992 Sheridan described that the user interaction in a Virtual world is multi-dimensional and suggested two types of interaction possibilities (Sheridan, 1992). First, that in VE a user can change the information of the environment by changing his position or moving his head (Sheridan, 1992). This type of interaction is there in VE; to make it immersive, the VE information has to change according to the movements of a user in real-time which also helps in navigation in VR that is when the user moves in VE. This process should be very fast and smooth so that it looks realistic. The second possibility is when the user has to do changes in the VE like picking up an object. For this, the user's hands and fingers position are measured using datagloves. The hand is represented in VE to check whether there is any contact between objects and user's hand (Fuchs, et al., 2011).

2.4 Presence

We have already discussed the term Immersive and why it is an important feature of VR. Now, we will talk about the effects of immersion on the user's behavior, that is the sense of presence. According to Heeter in 1992, "A sense of presence in a virtual world derives from feeling like the user exists within as a separate entity from a virtual world that also exists" (Heeter, 1992). It is important that user can feel its existence in the virtual world as an avatar and also the existence of other avatars. This increases the feeling of being in a virtual world. Heeter discussed that there are three dimensions of the subjective experience of presence that is the personal, social and environmental presence (Heeter, 1992).

2.4.1 Personal Presence

Personal presence refers to the sense of being in the environment and interacting with the environment (Torisu, 2016). In 1992 Zeltzer proposed that the personal presence depends on a number of sensory input and output channels (Torisu, 2016). By stimulating human senses in VE can increase the feeling of a sense of presence in user. Personal presence is increased in VE by developing user's avatar and move it according to the user moves. VR devices today have developed much that they can simulate the feeling of personal presence in users with the help of two main human senses; sight and hearing.

2.4.2 Social Presence

Social presence refers to communicate with other avatars in the virtual world. It is defined as a sense of being together with others (Heeter, 1992). According to Heeter society or people around you play an important role in perceiving reality (Heeter, 1992). Like in the real world, we connect and communicate with other people which feels our presence in the environment; Similarly, in VR the user avatar socialize with other people so that user feel its presence in the virtual world.

2.4.3 Environmental Presence

"Environment presence refers to the perception that virtual world exists and the user is inside of the virtual world" (Torisu, 2016). In this state, a user feels the virtual world not just by seeing it but also by interacting with virtual objects. "Environmental presence is also dependent on the number of interactions between the user and virtual world" (Zimmerli & Verschure, 2007). For example, there is a door in the virtual world, to open the door user interact with that door. By modifying the virtual world, the user experiences environmental presence.

Chapter 3

Sight

Human vision is one of the dominant sense in humans; it helps the brain to understand our surroundings. The human mind and eye use different sources of information to measure the world in different ways, some of the important sources are Depth perception, Visual field and, Persistence of Vision (Cutting, 1997). VR headsets are developed using these sources to replicate the real world and makes the user experience more immersive. VR headsets are designed in such a way that they can fool our senses; however, they are not reached at the point where the can accurately display the virtual world as a real world that we see. They are not even close. In this chapter, we will discuss the source mentioned above and how they contribute to designing a VR display. Further, we will discuss some of the new technologies that can enhance our sense of sight in VR.

3.1 Persistence of Vision

The retina of the human eye has an electrochemical nature which introduces a reaction time into the visual process (Vince, 1995). When the human eye observes a short pulse of light, the potential of the rod receptors reaches a peak while the cone receptors react four times faster; the combination of these actions introduced the phenomenon of persistence of vision (Vince, 1995). Persistence of vision is also important to see the motion on the screen. This phenomenon is necessary for display technologies in Televisions, cinema, computers, and VR headset display. We see the illusion of motion by a rapid succession of images in our visual system. The images stay in our visual cortex for about 100ms which means 10 Frames Per Second (FPS) is the slowest speed that we could see in a continuous and smooth motion (LaValle, 2016). The computer graphics industry suggest that below 16hz, the frames will not display in continuous motion (Figure 3.1).

FPS	Occurrence
2	Stroboscopic apparent motion starts
10	Ability to distinguish individual frames is lost
16	Old home movies; early silent films
24	Hollywood classic standard
25	PAL television before interlacing
30	NTSC television before interlacing
48	Two-blade shutter; proposed new Hollywood standard
50	Interlaced PAL television
60	Interlaced NTSC television; perceived flicker in some displays
72	Three-blade shutter; minimum CRT refresh rate for comfort
90	Modern VR headsets; no more discomfort from flicker
1000	Ability to see zipper effect for fast, blinking LED
5000	Cannot perceive zipper effect

Figure 3.1 Various Frame rates of different screens. (LaValle, 2016)

Figure 3.1 shows how many FPS display technologies use so that we can see the motion without distractions. The modern VR headsets generally use 90 FPS or more so that the movement of the user is smooth. If the FPS is below the limit, then the movement will be not smooth. For example, the user turns his head, and the FPS is too low then the motion will not be smooth results in lag. VR headset display has higher refresh rates so that it can display higher frames to maintain the quality of immersion.

3.2 Depth Perception

Depth perception or perception of depth is a visual perception that helps us to see the three-dimensional world (Akai, 2007). We perceive depth in the world because of our two eyes that is binocular vision. Our eyes are about 6.4cm apart and receive slightly different images of the world onto each eye's retina which then sent to the brain and recombined by overlapping views of each eye, to provide the perception of the three-dimensional world (Akai, 2007). The overlapping views of two eyes are known as binocular disparity. Depth perception is usually based on different types of information which then combined to give the user a three-dimensional view of a scene (Armbrüster, et al., 2008). Pictorial, oculomotor and binary depth cues are combined where pictorial depth cues are two-dimensional, oculomotor depth cues have accommodation and convergence which are also dependent on binocular depth cue's stereopsis (Armbrüster, et al., 2008). VR display uses the principle of the stereoscope and creates a binocular disparity by projecting two images of the same object, each captured from different angles which are set on display in such a way that each eye perceives one image. The angles are based on the user's interpupillary distance (IPD), which is generally

6.4cm but may vary from 5.4cm – 7.2cm; Most VR headsets provide a feature to adjust IPD according to the user.

3.3 Field of view

Field of view (FOV) is the area of space seen by either of the eyes at a single moment (Fuchs, et al., 2011). In VR display, the points in space are seen by both eyes simultaneously and have a binocular overlap. The human eyes have two types of FOV that are Molecular FOV and Binocular FOV which work together to form human vision (Jay, 2016). The FOV of a normal human eye is 180 degrees without any movement and around 270 degrees with eye rotations and head movement (LaValle, 2016). No such display provides a FOV of 270 degrees, not even close to that. However, it is not necessary to have the same FOV as of the human eye for an immersive experience, VR displays generally use 90 – 100 degrees of FOV (Hayden, 2017). Research and development are going on in this field to increase the FOV in VR display. The limiting factor in VR displays' FOV is the lenses used in VR headset to provide a better FOV. If the lenses are thin and away from the screen then to properly see the virtual world then we have to move the display away from the lens, and if the lens is thicker, then the distance between the lens and display has to be decreased. However, thicker lens means short focal length and high magnification due to which a high-resolution display is needed (Jay, 2016). VR headsets generally have a thicker lens, less distance from the lens to display and also less distance between lens and eyes. The thicker lens makes VR headsets heavier to overcome this problem VR headset companies started using Fresnel lens (Jay, 2016). Now VR headsets can provide a FOV of approximately 100 degrees which is still not closer to the human eye FOV.

3.4 Immersive Display

Screen Resolution is another important aspect of a VR headset. Companies are including high-resolution display in VR headset to show maximum detail and depth in the scene. The standard resolution used by VR headsets is 2160x1200 PPI (pixels per inch) used by popular headsets like HTC Vive and Oculus Rift which gives a FOV of 100 degrees (Thompson, 2016). The human eye had 198 PPD (pixel per degree) and based on this resolution an advanced VR headset in the market provide only 15.8 PPD with 2160x1200 PPI resolution which is 1/13th of the human eyes (Thompson, 2016). In order to increase FOV in VR, VR headsets use the lens to distort the screen which in turn reduces the quality of resolution near edges. However, it was beneficial to provide most PPD to the center of each eye. To reach a level of the human eye, we need 20K display that is 576 Megapixels (Thompson, 2016), and we only have 8K display till now. Thanks to the eye-tracking technology which helps to overcome these problems and makes the experience more immersive. Eye Tracking technology in VR headset display tracks the eye movements of the user and according to that enhances the immersion and interaction. “It is a unique toolset for creating a natural, immersive VR experience (Tobii, 2017)”. The human eyes always reveal where their focus is at, also the emotions of a human being. In VR, eye tracking is also used for social interactions with other avatars. For example, other avatars will get to know when the user is looking at them and also about the feeling of the user and other avatars (Tobii, 2017). This technology can introduce new possible gameplay mechanics which will be more interactive and immersive (Rizzotto, 2017). We express many emotions through our eyes; we have different eye movement and postures to show our emotions. With eye tracking, it is possible to show emotions in the virtual world using our eyes. Eye tracking in VR headsets enables better focus on an object using foveated rendering. The computer knows where the user is looking, so the computer has to render only that part of the VE in high-resolution which is in the center of user’s vision of, the area around the center of vision is rendered in low-resolution (Stephenson, 2017). This saves a lot of computer’s power and time.

Eye tracking was one of the biggest steps in merging Artifical Intelligence and Virtual Reality. It enables major improvement in expressing user’s emotions and immersing into high-resolution graphics. People are working for many years to improve the sense of sight in VR to enhance the user’s experience of immersion and sense of presence. A lot of work has been done to improve VR headset display. In 2017 Varjo a VR technology company announced Varjo 20/20 headset (Figure 3.2). Varjo 20/20 has a bionic display which tracks the user’s eyes in real-time (Varjo, 2017). Varjo wants to make a human eye resolution display for VR, and Varjo 20/20 is there best product they have developed. Figure 3.3 shows that Varjo 20/20 in comparison to other VR headsets like Oculus Rift and HTC Vive has 70% higher resolution (Hayden, 2017). Varjo uses Sony’s MicroOLED high-resolution display that has 3000 PPI and HTC Vive, and Oculus Rift has 447-461 PPI (Hayden, 2017). Higher resolution means the higher depth of details our eyes can see. However, MicroOLED displays do not have a greater FOV so, Varjo combines few methods like the bending of light and different lens which gives Varjo a FOV of 100 degrees (Hayden, 2017). Varjo 20/20 is still in development.

Figure 3.2 Varjo headset (Varjo, 2017)

Comparative matrix	Effective resolution	Field of view
Varjo 20|20	70 MP	100°
Oculus, Vive	1.2 MP	100°
VR in 5 years *	16 MP	140°
HoloLens	1 MP	32°
ODG R9	2 MP	50°
Meta II	1.8 MP	100°
* Prediction 2016 by Oculus Chief Scientist Michael Abrash at Oculus Connect 3		

Fig 3.3 Comparision of FOV and Resolution in different VR headsets. (Hayden, 2017)

Similar to Varjo, This year Pimax a Chinese startup announced their first 8K resolution display in VR headset (Figure 3.4). Pimax also claims to have first 200-degree FOV in VR headset (Pimax, 2018). It uses two displays of resolution 3840x2160 which means each eye can see a resolution of 3840x2160 on screen (Pimax, 2018). However, to display 8K on a screen requires a very powerful graphics card. Nvidia Gtx 1070 and 1080 are the best GPU available in the market which can deliver 4K resolution in real-time which can be upscaled to 8K for Pimax (Graham, 2018). It still has some problems related to eye-strains but as Pimax is in development stage and prototypes have been testing. VR displays are getting more advanced every year with the aim to reach a level of the human eye to make VR experience more realistic and immersive. It is expected to see the release of Pimax 8K at the end of the year.

Figure 3.4 Pimax 8K (Pimax, 2018)

3.5 Analysis

The sense of sight is the first sense we use in VR to see the virtual world. However, VR is still not reached the level of the human eye. We have only developed 8K resolution display, and these are also not used by everyone because of its price. As we discussed in this chapter the human eye the resolution of the human eye is 20K that is 576 Megapixels, and we have only reached at 8K that is 33.2 Megapixels. However, we have nearly reached to the FOV of the human eye that is 270 degrees horizontally with eye movements. The FOV and resolution are essential for the immersion in VR. The technologies we discuss above like Pimax 8K uses 8K display and also has a 200-degree FOV. Pimax 8K can display fine details in the virtual world that increase the level of immersion of the user in VR. Consider the user is playing a shooting game, it is important that user can see the fine details on the screen so that he can see another player even from a greater distance. This makes the user experience more immersive in VR. That is why all the display companies are working on to increase the resolution and FOV to get even more closer to the level of the human eye.

Chapter 4

Hearing

The sound is another important aspect of VR to create a sense of presence in the virtual world. In the real world, we are very much dependent on sound to locate the objects or people around us. There are several results which state that the interaction between different senses such as sight and hearing can achieve a high sense of presence and which further enhances the perception of immersion (Serafin & Serafin, 2004). VR industry has begun to see 3-D audio as an important factor of VR due to the more realistic features of 3-D audio than stereo (Larsen & Pilgaard, 2015). In VR games, interactive sounds and environmental music is an important factor to enhance the user experience by immersing the user into gameplay (Murphy & Neff, 2004). In this chapter, we are going to discuss how humans locate objects using their sense of hearing and how VR use the technique to make the user experience immersive.

4.1 Binaural Hearing

Binaural Hearing is an ability in the humans to perceive sound in the real world; we also locate the position of sound source regarding distance and direction (Larsen & Pilgaard, 2015). Binaural hearing occurs because we have two ears which are separated by some distance and have some physical objects in between such as head, shoulders, pinna, and torso. Binaural hearing occurs due to three major components which are Interaural Time Difference (ITD), Interaural Intensity Difference (IID) and Spectral Difference (SD) (Larsen & Pilgaard, 2015).

ITD is generally caused because of the distance between human ears. When a sound source is placed either on the sides of a person, then the sound wave reaches to one ear before another (Larsen & Pilgaard, 2015). If the sound source is placed in front of a person, then the ears will receive the sound waves at the same time. Humans can perceive minimum ITD of 10 microsecond which is approximately 1 degree and a maximum of 650 microseconds, based on average head size (Larsen & Pilgaard, 2015).

IID is primarily caused because of our head which is in between our ears; the head absorbs the energy of a sound signal due to which both the ears receive sound signals of different intensity (Larsen & Pilgaard, 2015). For example, if a sound source is kept near to left ear, then the right ear will receive sound signal of less intensity as compared to the left ear; this is because our head absorbs some of the intensity. So, IID is used to determine the location of the sound source based on different intensities (Larsen & Pilgaard, 2015).

SD is also the difference in intensity from one ear to other. However, in SD the difference is based on reflection and absorption that occurs in the body of the listener (Larsen & Pilgaard, 2015). It involves different parts of the body like head, shoulders, pinna, and torso. ITD and IID are used to determine the location of the source horizontally. However, SD is the only cue which helps us to locate the source vertically that is above the head or below the head (Larsen & Pilgaard, 2015).

4.1.1 Cocktail-party Effect

The cocktail-party effect can be described as when a person is talking to another person in a crowded and noisy place then also the person can focus on what other person is saying, this is because of the Cocktail-party effect caused by binaural hearing. It filters out the individual sound source in an environment where multiple sound sources are present (Larsen & Pilgaard, 2015).

4.2 Human Sound Localization

Localization is very important in VR environment just like in a real world. It refers to locating sound sources in the virtual world (Correa, 2017). Localizing the sound source in the virtual world is based on different factors that are explained below (Oculus, 2017):

1) **Lateral Localization**

   Lateral Localization is based on binaural hearing components that are ITD and IID. It helps in localizing the sound source in a virtual world horizontally. In VE it is easy to locate the sound source horizontally because of headphones and speakers. When the source is on the left side, then the intensity on the left side of the headphone will be high that the right side and also there will be a small delay in the right side of the headphone.

Figure 4.1 Lateral Localization (Oculus, 2017)

2) Elevation

Elevation includes various human body objects like the head, shoulder, and torso. To cue the sound sources, the brain uses different reflections and intensity of waves occurred due to the head, shoulder, and torso (Correa, 2017). We can locate the sound sources vertically because of SD in binaural hearing.

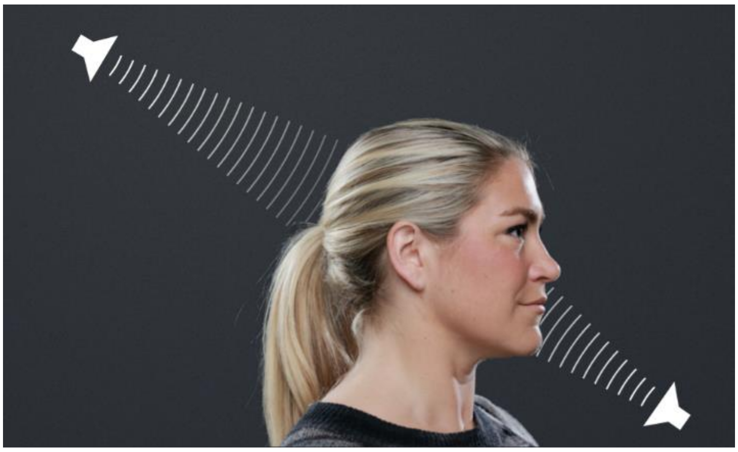

Figure 4.2 Elevation (Oculus, 2017)

3) Pinna

Pinna is the outer part of the ear. Pinna has different shapes, and sizes depend on person to person. Pinna is also one of the parts of the body that helps in the localization of sound sources. It also reflects and absorbs sound signals. Pinna collects the incoming sound and filters it. The filter operation provides cues to the brain for determining the location of the sound source (Oculus, 2017).

Figure 4.3 Types of Pinna (Oculus, 2017)

4) Back and Front

When there is one sound source in the front and one in the back of a person then the brain needs certain spectral characteristics of sound which are changed by the head, shoulders, and torso. There are two sides of the human body which helps to locate sound sources that are Resonating (Front side) and Shadow (Backside). Both the side changes the frequency of sound wave differently before reaching to ear. With the help of these frequencies, the brain locates the sound source.

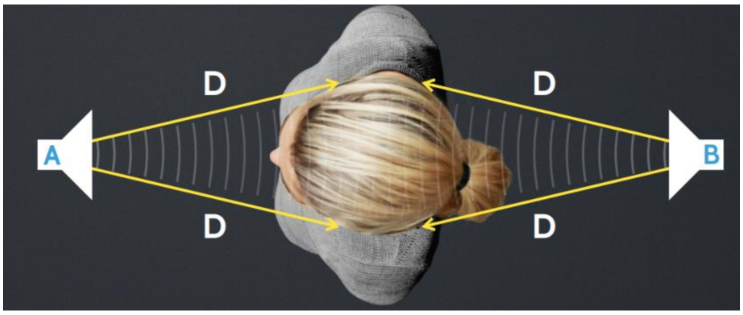

Figure 4.4 Back and Front (Oculus, 2017)

5) Distance

Localization depends on different factors for distant and close sound sources that are loudness, initial time delay, a mix of direct and indirect sound, high-frequency damping, and motion parallax (Oculus, 2017). Loudness is very obvious, if the sound is loud that means the source is near the listener and if it is not loud, that means the source is away from the listener. Initial time delay refers to the time taken to reach the listener after reflections. A mix of direct and indirect sound refers to closer the source means more direct sound and indirect refers to far the source more reverb will be in sound because of reflections (Correa, 2017). High-Frequency damping refers to, if the frequency is high that means it is faster, so the source is near to the listener and vice versa. Motion parallax is the apparent movement of sound in space. It indicates distance, as a nearby source exhibit greater degree of parallax than the far source (Oculus, 2017).

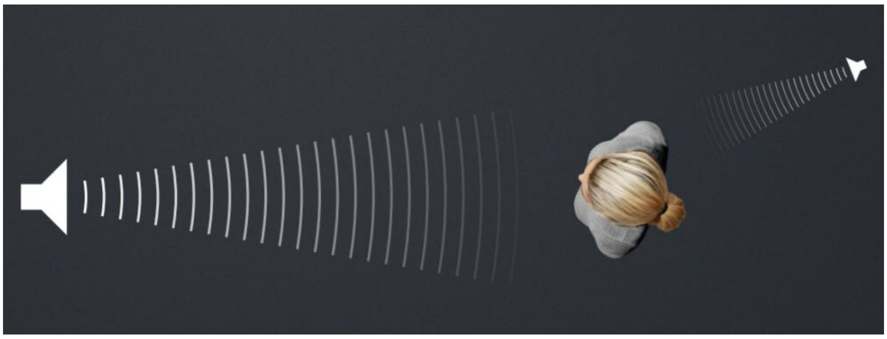

Figure 4.5 Distance (Oculus, 2017)

4.2.1 Localization Errors

While localizing a sound source, people can make errors regarding direction and distance. This phenomenon is known as the cone of confusion (Larsen & Pilgaard, 2015). When ITD and IID are equal, then only SD is used to localize the source. The source placed in front/back is difficult to localize and often seen as a front-back error (Larsen & Pilgaard, 2015). This phenomenon can be eliminated by head movements in the real world and head tracker in VR.

4.3 3-D Audio Spatialization in VR

Spatial Audio is the simulation of how the human beings perceive sound in the virtual world (Bonasio, 2017). Spatialization is an important factor of presence as it provides powerful cues to trick the brain which in turns increase immersion in VR (Oculus, 2017). There are two components in spatialization that is Direction and Distance which are used to create 3-D audio in VR. Distance spatialization uses the same factors which are mentioned above, but they are simulated in software using algorithms with a varying degree of accuracy (Oculus, 2017). Directional Spatialization is based on the geometry of the human body parts. These different effects form the basis of Head-Related Transfer Functions (HRTFs) which is used to localize the sound. HRTF's provides a marker for the sound waves to hit our bodies from different angles (Brief, 2018). Since we all have different body shape and size of the head, shoulder, torso and, pinna result in different sets of HRTFs. HRTFs are captured by placing microphones in both ears and play sound from each direction possible. The microphone capture the sound from every direction and the captured sound is compared with original one to compute HRTF. However, that will be only one person’s HRTF which maybe not accurate for other people with different shape and size bodies. The sound in VR generated according to HRTF. There is a large public database of custom HRTF according to which spatial audio is generated.

Head tracking is another good feature in new VR headsets. When a sound source is near a person, and the person changes the direction of his head then the sound signals is also changed as now the human body position is changed, so the reflection points are also changed. Similarly in VR head tracking is important to give the user a feeling of reality. The headset tracks the position of the head and changes the sound signals. Oculus Rift has the ability to track listener's head which provides data to sound package so that it can project the sound accordingly (Oculus, 2017). This technology is also installed in headphones by many companies like Ossic who are working on Ossic X, a headphone in which head tracking is implemented to design immersive 3-D audio playback in VR.

4.4 Analysis

The hearing is another most important sense in human beings. As we discussed in this chapter that human beings also use the sense of hearing to locate the sound sources which makes us aware of our environment. Similarly, it is essential in VR that we can locate the sound sources from all directions as we do in the real world. It increases the level of realism and immersion in VR. The sense of hearing is much developed in VR now that we can hear sound from all the directions and this is currently implemented in VR. Consider the user is playing a shooting game in VR with other 99 people where the user has to find others and shoot them to win the game. The 3-D audio is very important in this case so that he can hear the gunshots from every direction to locate other players and also to hear the footsteps of other people who are approaching towards the user. This increases the focus of the user in the game which indeed increases the level of immersion and presence in VR.

Chapter 5

Touch

The sense of touch is essential in the human body. With the help of sight we can see the object, but with the sense of touch, the human body gets to know about the properties of the object like texture, shape, temperature, hardness, and softness of the object (Saddik, et al., 2011). The sense of sight can also determine some of the properties of the object, but with a sense of touch, we explore more about the object. The sense of touch is all over in the human body, human beings and animals have skin to feel the touch. It increases the presence of living in real-world. There are millions of nerves underneath our skin which transmit signals to the brain when something comes in contact with skin. We detect touch through our skin whether it is a light touch or pressure, cold, hot and pain. Humans and animals are very sensitive to touch, and the sensitivity varies in different body parts (Saddik, et al., 2011). Combination of two or more touch feelings, we can tell the texture, composition, and characteristics like moisture, vibration, and roughness of an object (Saddik, et al., 2011). The sense of touch is integrated into VR using haptic feedback. Most of the advanced VR headset comes with a controller for each hand which are used to give inputs in VE, and they also vibrate when the user touches the virtual objects. This creates a sense of presence in the virtual world. In this Chapter we care going to discuss about haptics in VR and some new development in the field of haptics, we will also understand the role of haptics in VR to increase the level of immersion, presence, and interactions.

5.1 Haptics in Virtual Reality

Haptics is related to the ability of the user to touch and manipulate the object in the real or virtual world (MANSOR, et al., 2017). The development of haptic technology is advanced because of VR. Haptics allows the user to touch and feel in the virtual world, which enhances immersion and the sense of presence in VR (Khan, 2011). The sense of sight and hearing that we discussed in above chapters were unidirectional that is the computer provides output to the user. However, haptics is bidirectional (Khan, 2011); the user gives some input (position of the hand and orientation) to the computer and gets the output/feedback (vibration, force, pressure, and temperature). The human-computer interactions in the form of haptics are important in VR to increase the sense of realism. For example, when the user grabs a virtual coffee cup in the virtual world, they feel a little vibration when they grab the cup. However, they cannot feel the cup in real (pressure, temperature, and force) like we do in the real world. Haptic feedback is the combination of touch (tactile) and force feedback.

5.1.1 Tactile Feedback

The tactile feedback conveys the real-time information on the virtual objects' geometry, slippage, texture, and temperature (Burdea & Coiffet, 1996). Unfortunately, the commercial VR headsets available in the market does not convey any of the information about the virtual object. Current VR devices come with two controllers that have sensors to track the position of the user and determines the contact between the user’s avatar and virtual object. When the user touches the virtual object, the computer sends a feedback to the user in the form of vibrations in the controllers. The duration of feedback can be dependent on how much time the user is in contact with the virtual object.

In 1995 Virtual Technologies released the CyberTouch Glove which was capable of providing vibrotactile feedback to the user (Saddik, et al., 2011). CyberTouch consists of six vibrotactile actuators that contain a small DC motor. Five actuators are placed on the back of each finger, and the last one is placed in the palm. The motors can produce vibrations of frequency ranging 0-125 Hz, and each actuator applied a force of 1.2 N (Burdea & Coiffet, 1996). The 3D tracker attached to the wrist are used to track the position of user’s hand. The CyberTouch glove was only suitable for giving feedback when the contact is through the fingertips and palm, as the actuators are placed on the fingers and in the palm. However, more than one actuators or combination of different actuators can provide feedback in complex situations. Many improvements and different technologies were released after CyberTouch to enhance the sense of touch in VR.

Figure 5.1 CyberTouch Gloves (CyberTouch, 1995)

Tactile feedback also conveys the information about the temperature change. Humans are homoeothermic which allows us to make the thermal exchange by convection, conduction, and evaporation (Khoudjal, et al., 2003). Temperature feedback can be helpful while navigating in a warm and cold environment in the virtual world (Burdea & Coiffet, 1996). By adding temperature feedback in current VR technology can increase the sense of presence and immersion. A thermal feedback glove which can also stimulate the touch will be very helpful in VR. The temperature feedback glove that was build to stimulate temperature change worked on the Peltier principle (Burdea & Coiffet, 1996). In which a DC flows through a conducting material in contact with the glove which heats up the material and creates the sensation of heat in the user. However, the glove was not much used and was in development because it can heat up the material but could not cool it down and it could also burn the skin of the user. Time to cool down and heat up is very important to feel realism in the virtual world. To create a sense of realism in the user's mind, another important factor is generation of warm wind and cold wind in VE. In 2016, Ambiotherm (Figure 5.2) was developed to generate wind and warm sensation. This device was an addon to the existing VR headsets. Ambiotherm has two fans that generate wind and a thermal simulation attached to the neck of the user (Melnick, 2017).

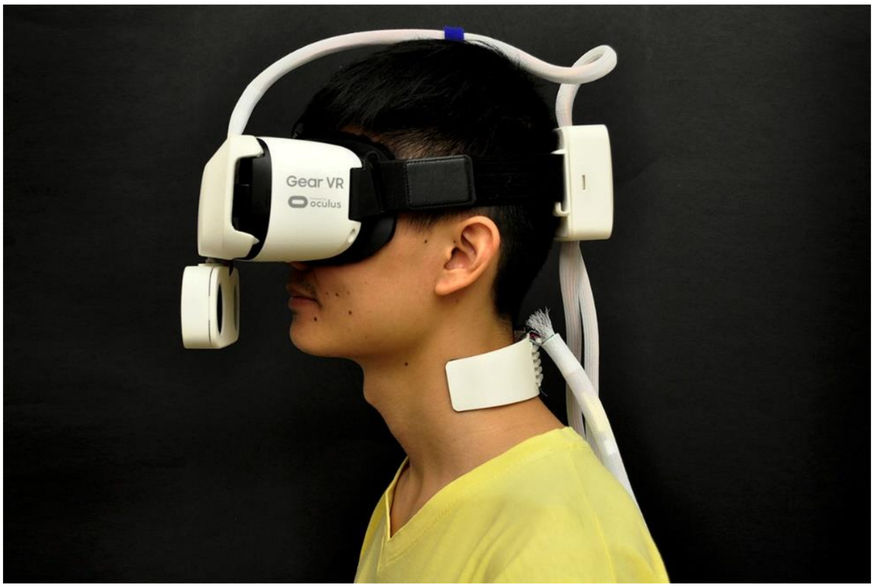

Figure 5.2 Ambiotherm (Revell, 2016)

5.1.2 Force Feedback

Force feedback conveys the real-time information on virtual objects' weight and the type of material. Force feedback devices can also manipulate the virtual object by determining how much force the user is applying which is used to manipulate the object. As we discussed the sense of touch is bidirectional. When the virtual object touches the user, then the user should feel its weight and with how much force the object is coming towards the user. For example, holding a cricket bat or catching a ball. According to Newton, "every action has an equal and opposite reaction"; if the user is catching a virtual ball, then the forces should be applied on both that is the user and the ball.

CyberGrasp glove (Figure 5.3) is a haptic device with force feedback (Burdea & Coiffet, 1996). There are 3-D trackers to track user's wrist movement which collects the data to the Force Control Unit (FCU) of CyberGrasp which then sends the data to the computer. The computer detects the movement of the hand and checks the contact between the hand and the virtual object. The computer then sends an input to FCU about the contact forces of each finger (Burdea & Coiffet, 1996). The FCU generates the analog current according to the data for each finger to the force actuators. The force actuators then apply force on each finger. The maximum force an actuator can apply is 16 N (Burdea & Coiffet, 1996). However, because of an external FCU, it makes the glove less portable and also limits the movement of the user.

Figure 5.3 CyberGrasp Glove (CyberGlove, 2017)

5.2 Ultrahaptics

Ultrahaptics is the company that was founded in 2013. Ultrahaptics are working on haptic tactile feedback which does not require any wearable device to provide feedback to the user that is a mid-air touch and feedback. Ultrahaptics focused on ultrasound to project discrete points of tactile, haptic feedback through the display/device and directly on to the users' bare hands (Carter, et al., 2013). Focused ultrasound is used to stimulate skin receptors (neuroreceptors) in the human body. With focused ultrasound, it is possible to stimulate tactile, thermal, itching, tickling and pain sensations (Gavrilov, et al., 1977). Ultrahaptics use focused ultrasound onto the user's skin which induces a shear wave in skin tissue. The displacement occurred by the shear wave which triggers mechanoreceptors inside the skin and generates haptic sensation (Carter, et al., 2013). Focused ultrasound waves can also generate temperature sensations, By increasing the intensity of focused ultrasound we can feel sensation or warm and cold. It is possible to create a warm sensation but, it is not possible to create a cold sensation through focused ultrasound (Gavrilov, et al., 1977). Current Ultrahaptics system uses two methods to send focused ultrasound wave that is acoustic transparent display and individual feedback points. The Acoustic transparent display has transducer array placed behind the screen. The screen allows ultrasound waves to pass through it without changing the focus and intensity of the wave. Car companies are using this technology in their sound system and navigation screens. When the passenger touches in mid-air in front of the screen, due to the ultrasound wave, it detects the position and gives the output with haptic feedback to the user's fingertip.

In 2017, HaptX (Figure 5.4) formerly known as AxonVR announced HaptX Gloves which are capable of generating tactile and force feedback. "HaptX uses a flexible, silicone-based smart textile which contains an array of pneumatic microfluidic air actuators" (HaptX, 2017). The actuators provide haptic feedback by filling it with air and push against the user's skin in the same way when the humans touch the real objects. The miniature valves inside the actuators control the pressure of each actuator to create a sensation of touch (HaptX, 2017). The pressure is controlled in a way that the user can even feel the texture, shape, and size of the virtual object (HaptX, 2017). "HaptX can produce a variety of actuators of different shapes and density with the thickness of less than 2mm" (HaptX, 2017). The exoskeleton of HaptX is capable of providing force feedback by same actuator technology. These actuators enable the light-weight exoskeleton to apply force on each finger so that, we can feel size, shape, weight of a virtual object (HaptX, 2017). HaptX is also capable of providing the sensation of temperature. To do so, HaptX uses reservoir box which is filled with water and have the capability to heat and cool down the water (Rubin, 2017). The water flows through the controlled channels from the reservoir to the user's skin. To simulate hot objects hot water flows in the channels (hot enough to simulate virtual objects, but not hot to cause burns) and to simulate cold or even ice cold object, the water is cooled down to the necessary temperature by the reservoir. HaptX is capable of creating sensations ranging from the brush of a butterfly's wing to a bullet or a punch (MANSOR, et al., 2017). HaptX is developing more than a glove they are working on a full body haptic feedback to increase more realism in the virtual world and to increase the immersion in VR.uv

Figure 5.4 HaptX (HaptX, 2017)

5.3 Analysis

The sense of touch is bi-directional that is when a person touches an object, the person also feels the touch of the object. Similarly, in VR the sense of touch is essential, when the user touches a virtual object, there should be a feeling in user that he touched the object. This makes the user feel a personal presence in the VR which is very important to increase the level of immersion. The technologies discussed in this chapter helps to increase the interactions and creating a sensation of touch in user so that user can be more immersed in the VR. These technologies are simulating the real-world experience in VR like the HaptX is capable of creating the sensation of butterfly wings to a punch. Consider a person in the virtual world touch the user or have a handshake, when the user feels the hand like he is used to feeling in the real world then the user feel real and gets more immersed in the VR. The technologies are still under development and are going to release in future.

Chapter 6

Smell

The sense of smell is very important in human beings and animals. It plays a significant role in helping us to appreciate an environment (Brkic & Chalmers, 2010). As we concluded from the above chapters, the human perception of an environment depends on all human senses. The human senses work together to perceive an environment efficiently. When creating a virtual world, it is important to simulate all the senses for the sense of realism and immersion. In VR sense of smell is currently not used as much as the sense of sight, hearing, and touch. However, smell plays an essential part in VR to create a sense of presence in the virtual world. Consider the user is having coffee in the virtual world, by adding smell, touch, temperature, and taste could trick the mind that the user will feel present in the virtual world. The sense of smell can also enhance the gaming experience by adding smell for example when the user plays a shooting game by adding the smell of gunpowder can increase the immersion in VR.

6.1 Olfaction overview

Olfaction in humans and animals refers to the ability to smell. The molecules that emit smell are inhaled by the human nose which has tissues of Olfactory Epithelium. The receptors then convert the chemical composition information into a neural signal that reaches to our brains which creates the sense of smell in the human beings (Brkic & Chalmers, 2010). The sense of smell is also important for our ability to survive. Our nose can detect dangerous situations like leakage of gas or the food which is expired, without the sense of smell we could not survive (Carulli, et al., 2015). The sense of smell helps us in tasting the food; Our tongue can only detect four taste that is sweet, salty, bitter and sour. However, smell plays an important role in tasting the food (Small & Prescott, 2005). Smell is even capable of altering our mood (Brkic & Chalmers, 2010). It impacts our mood and feeling like we feel good in a pleasant smell, but we are not comfortable in an unpleasant smell. It influences other several human psychological states like attention level, human activities, and relaxation. Moreover, the smell is also linked with memories, for example, a human can memorize the smell of a person.

Every person has different feelings and moods for different smells. It is not necessary if a person likes a smell other also like it. Consider a person likes the smell of food from his country because he is used to that smell and his mood gets happy with that smell. However, maybe another person from a different country does not like the smell and prefer not to eat. Many industries like perfume industry use smell to attract customers because of the smell which is pleasant and makes people happy (Bordegoni & Carulli, 2016).

One of the best ways to generate smell in any environment is by diffusers. Many companies produce diffusers which uses liquid scent to generate smells. People use these diffusers to generate smells that they like to uplift their mood or alter their feelings. This year Agan Aroma company released Moodo (Figure 6.1) which is a smart home fragrance box (Moodo, 2018). Moodo uses scent capsules to diffuse different smells. It allows the user to create their fragrance using their app available on Apple store or by voice commands (Moodo, 2018). Moodo can use maximum four capsules at a time, and all can work simultaneously (Moodo, 2018), the battery provides current to the capsules which then converts liquid scent into gas. There are four different fans to control the amount of scent released by the capsules (Moodo, 2018); the user can control and mix the fragrances according to preferences and can alter his mood.

Figure 6.1 Moodo (Moodo, 2018)

6.2 Smell Stimulation in Virtual Reality

Now with the other senses like sight, hearing, and touch, we can now generate the sense of smell in VR. The sense of smell cannot be created electrically as our nose responds to the chemical properties of molecules. So, in VR smell is generally generated by diffusion and controlled fan technology. In 1996 Krueger proposed a system in his report, he said, The smell can be generated using HMD(Head Mounted Display) because in VR the user already wears a HMD in which smell generators can be included (Krueger, 1996). The scent that will be released should be minimum that is required for perception. Only the inhaled air should be scented, and the exhaled carbon dioxide should be evacuated (Krueger, 1996). Otherwise, there will be no fresh air to breathe. In VR system, the fragrance will also be controlled according to the user's movement in the virtual world. The scent should be released when the user is close to the virtual object which can be calculated by position trackers (Krueger, 1996). The advantage of adding smell generator in VR headset is the small pumps that deliver fragrance to the user. When there are two or more than two virtual objects, and the user moves his head quickly, the small pumps can quickly switch in between while the user is inhaling (Krueger, 1996). The most common option to include smell in VR is through controlled micro air pumps. However, the micropump can be noisy which can disturb the user's focus and presence. So with time and advancements, the design was shifted to fans and vaporizers (Iwata, et al., 2003). In 2015, FeelReal (Figure 6.2) announced Multisensory VR Mask which can generate cold wind using micro-coolers and hot wind using microheaters (Real, 2015). FeelReal Mask has an ultrasonic ionizing system which is used to produce water mist in VR (Real, 2015). It has nine different removable cartridges to generate smell in VR (Real, 2015). The DC of battery in the mask is used to vaporize the liquid scent in the cartridges, and the micro fans are used to control the quantity of smell reaching the user. FeelReal VR mask is an add-on device which can be connected to different VR headsets like Oculus Rift, PlayStation VR, Samsung Gear VR and Zeiss VR one (Real, 2015). It can be mounted to these headsets and can be synced according to the virtual world. FeelReal mask also has microphones that help the user to interact with other players in VR (Real, 2015). FeelReal mask can generate the smell of gunpowder, burning rubber and other important smell which are available in the game or movies (Real, 2015).

Figure 6.2 FeelReal Mask (Real, 2015)

Similarly, in 2017 a Japanese company Vaqso announced Vaqso VR (Figure 6.3) device which can be mounted to any of the VR headsets and also can be synced according to the virtual world (Vaqso, 2017). Vaqso VR supports five cartridges of scent which are easy to place and remove. It can generate smells of fish, ramen, burn, grassland and lady also more scent cartridges can be added in future (Vaqso, 2017). Vaqso VR is smaller and lighter as compared to FeelReal Mask. However, both can generate smell in VR.

Figure 6.3 Vaqso VR (Vaqso, 2017)

6.3 Analysis

The sense of smell is very essential for human beings if we cannot see anything with our eyes, still we can perceive our environment through the sense of smell. As we discussed in this chapter that the smell also affects our feelings and emotions. So, in the virtual world, it is also important that we can feel our environment and by including the smell in VR the level of personal presence can be increased. In the real world, we are very much dependent on the sense of smell to perceive our environment if we do not like the smell we also don't like the environment. Similarly to increase the realism in VR, the sense of smell is important. These technologies that are discussed above are trying to increase the level of presence and immersion by adding smell in VR. The devices are still under development and testing phase but, in upcoming years they are planning to release these devices.

Chapter 7

Taste

The sense of taste is the last frontier of the VR (Iwata, et al., 2003). There are very less research and developments done in stimulating taste in VR. Although taste can be stimulated electrically and chemically (RANASINGHE, 2012) but, implementing that in VR is a difficult task especially while playing a game. The popular way to stimulate taste is by electrical and thermal conduction to the human tongue. In this chapter, we are going to discuss how taste can be stimulated using electrical and thermal conduction and some of the new technologies which are trying to implement this in VR to increase the level of immersion and realism in the virtual world. The sense of taste in VR can also increase the interaction and presence in VR. Consider the user is having coffee in VR, the user can feel the touch of the coffee and also smell the coffee but, the user cannot feel its taste. It will decrease the realism in VR. However, what if the user can have the taste of coffee the with other senses also. This can increase the level of realism and immersion in VR.

7.1 Taste Perception

The sensation of taste is perceived by the tongue which contains gustatory sensors (taste buds) (Aoyama, et al., 2017). The chemical characteristics of food are responsible for its taste quality. Different chemical composition stimulates different taste sensations (RANASINGHE, 2012). These chemical characteristics can also be stimulated using electrical and thermal conduction (RANASINGHE, 2012). There are five primary taste sensations that are sweet, salty, sour, bitter, and umami(MSG savouriness). However, according to Ayurveda, there are six primary taste sensations that are sweet, salty, sour, bitter, pungent (hot and spicy taste), and astringent (dry and light) (RANASINGHE, 2012). In 2012, According to the experiment conducted by Nimesha Ranasinghe, these tastes can be stimulated electrically and thermally by placing two silver electrodes on both surfaces of the tongue. By providing a current of a certain magnitude and increase or decrease the temperature of the silver electrode, the primary taste sensations can be stimulated (RANASINGHE, 2012). The results of this experiment were impressive and resulted in sour, salty and bitter taste were experienced by electrical conduction, and remaining tastes required the hybrid approach of electrical and thermal conduction. Sour taste can stimulate by providing the magnitude of current ranging from 60µA to 180µA, while for salty taste the magnitude of current should be up to 50µA (RANASINGHE, 2012). Bitter taste requires the magnitude of current between 60µA to 140µA but, on the bottom surface of the tongue. Minty taste can be stimulated by decreasing the temperature of the silver electrode from 22ºC to 19ºC, while spicy taste stimulated by increasing the temperature from 33ºC to 38ºC (RANASINGHE, 2012). The sweet taste was observed when the current was inverted, and the temperature is increased up to 35ºC and then continuously decreased from 35ºC to 25ºC (RANASINGHE, 2012).

After this experiment, Nimesha Ranasinghe also developed Digital Lollipop (Figure 7.1). Digital Lollipop was based on his previous experiment only by electrical stimulations on the human tongue to stimulate different taste sensations (Ranasinghe, 2013). It has electrodes which are connected to the computer that transmits minute variations in current and temperature to the tongue. The Digital Lollipop can stimulate taste like sour, sweet, bitter and salty. “The Digital Lollipop was selected as one of the top 10 best inventions in 2014 by netexplo and UNESCO” (Ranasinghe, 2013). He continued his work and developed other products like Taste+ and Taste over IP which is similar to his previous work. However, Taste over IP can send the taste to anyone over the Internet using the taste device (Ranasinghe, 2013).

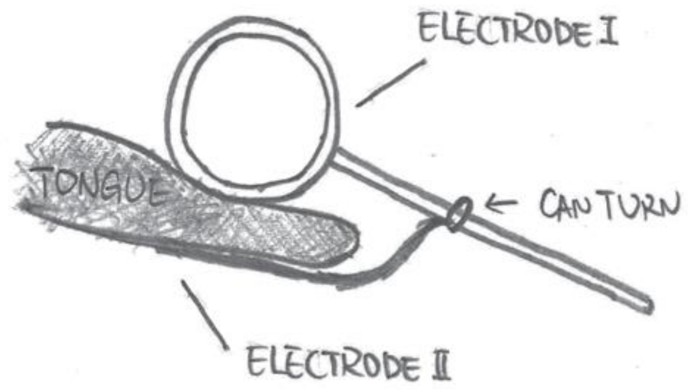

Figure 7.1 Digital Lollipop (Ranasinghe, 2013)

7.2 Taste Stimulation in VR

People usually misunderstand that the complete sensation of taste is through our tongue. However, before we eat something, we get the smell of food before the taste. There is only five basic taste, but the flavor is a complex perception and is a combination of taste and smell (RANASINGHE, 2012). Smell is very important to guess what we are eating, for example, if you give someone apple and block his nose and eyes then it will be difficult for him to guess what he is eating just using the taste. In 2017, Ranasinghe and his team developed Vocktail (Figure 7.2) which is a virtual cocktail. It is a cocktail glass which has electrodes on the rim of the glass, aroma tubes, LEDs and a control panel in the bottom (Ranasinghe, et al., 2017). It has three scent cartridges and micro fans to control the quantity of aroma. Vocktail can convert normal water into any drink preferred by the user when the user drinks the water through this glass; the silver electrodes touches the tongue and stimulates taste while the aroma of the drink creates a perception of flavor in the user's mind (Ranasinghe, et al., 2017). This could be the future of drinking without any calorie intake.

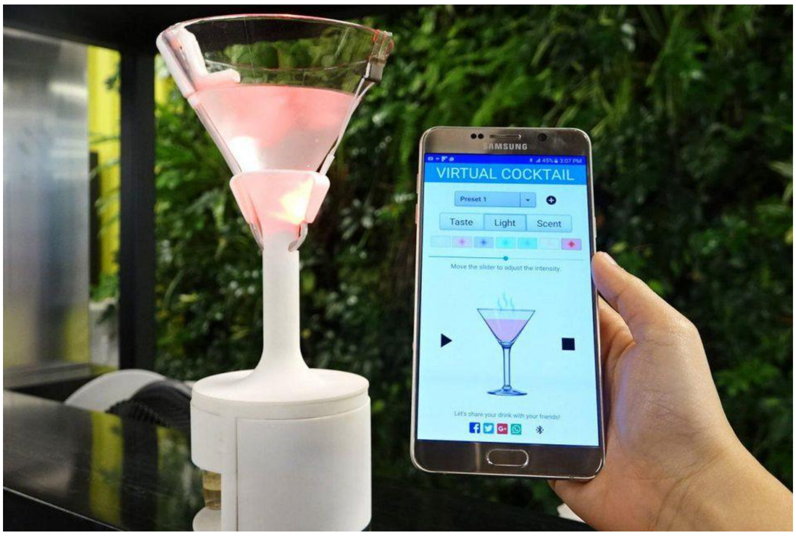

Figure 7.2 Vocktail: The Virtual Cocktail (Forbes, 2017)

Similarly, in 2015 Takuji Narumi presented Virtual Cookie. It was used to trick the brain by changing the flavor of a normal cookie to any flavored cookie using aroma (Klose, 2015). Virtual Cookie uses a VR/MR headset through which user sees a normal cookie in his hand but smaller than the real size. When the user eats the cookie, the aroma tubes releases the aroma of strawberry or chocolate because of which the user's mind gets tricked, and he thinks that he is eating a strawberry or chocolate cookie. The research and developments are still ongoing to include taste in VR.

In 2016 Jinsoo An and his team announced Project Nourished (Figure 7.3). Project Nourished comprised of a VR headset which provides a virtual simulation of the environment and alters the aesthetics of food, an aroma diffuser which dissipates the smell of various foods using ultrasonic and heat (An, 2016). It also has a bone transducer which mimics the chewing sound, a virtual cocktail glass that stimulates taste of beverages, a 3-D printed food for articulating texture, taste, and consistency, and a gyroscopic utensil which allows the user's physical movement to be translated into VR (An, 2016). Project Nourished can be helpful to solve many problems like dieting; people can now enjoy their favorite food anytime they want without thinking about the calories (An, 2016). People having diabetes can taste sweet food without eating it. However, Project nourished can only be used to simulate an environment where movements of the user are limited like a restaurant environment, people who cannot go to different countries to taste their food can taste food from different countries.

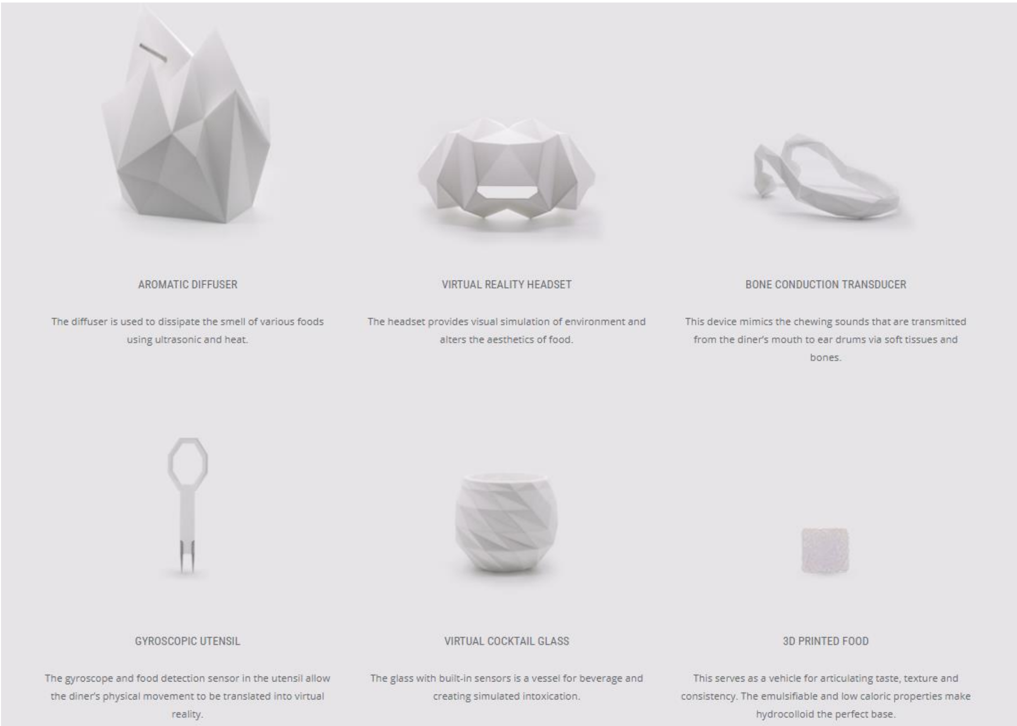

Figure 7.3 Project Nourished (An, 2016)

7.3 Analysis

The sense of taste is not so developed in the field of VR but, people are working to include the taste in VR. As we discussed in Chapter 2, Virtual Reality is a simulation of the real world, and in the real world, people use all the human senses to feel present and immersed in the environment. The sense of taste can be the biggest step to complete the VR which can simulate all the senses just like in real word. The technologies that we discussed like Project Nourished can increase the level of realism in VR, and the level of immersion will be more than that it is now. Taste can be used in games also like the winner will get a sweet treat and loser will get bitter. This could increase the level of immersion of the player in the virtual world.

Conclusion

We started this paper by asking some question like does VR equipment use all the human senses? Clearly not current VR headsets only simulate the sense of sight and hearing also the sense of touch but, touch is not fully implemented. We also asked the question can all human senses work together in VR to increase immersion, presence, and interaction? We have discussed immersion, presence, and interaction in Chapter 2 which clearly states that the device can be immersive only if it can simulate human senses and the vividness of the device depends on the number of senses it can simulate. So, the immersion, presence, and interaction can be increased by simulating a maximum number of human senses in the virtual world. All the technologies we have discussed needs to be implemented in VR to increase the level of realism.

The devices for touch, smell and taste are still in the development and testing phase. However, we know that these devices use the technology that can be implemented in VR to make it more realistic. We can combine technologies like Pimax 8K, 3-D audio, HaptX, FeelReal VR Mask, and taste simulators to develop a full body suit that makes VR experience more real and immersive. HaptX actuators can be used in this suit to simulate the sense of touch in the body and FeelReal mask to simulate the wind, water mist, and odor. Game developers can develop a game with more possible game mechanics for serious gamers who want an immersive gameplay experience. This still can be difficult to implement because of compatibility issues, but we can say that in the near future it is possible to simulate all the human sense in VR to make the experience more immersive. The field of VR is emerging, and people are doing more research and developments in this field to make VR experience more realistic and immersive.

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