



People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University of Mohamed Khider – BISKRA
Faculty of Exact Sciences, Science of Nature and Life
Computer Science Department

Ordre N° : IVA /M2/2020

THESIS

submitted in fulfillment of the requirements for the Masters degree in

Computer Science

Option : Image and Artificial Life

"AcroFree", a virtual reality serious game application for overcoming Acrophobia.

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Session 2020

Acknowledgements

All praises to Allah, the Most Gracious, the Most Merciful, the Lord of the 'Alamin.

I would like to thank Almighty Allah for giving me the determination and strength during the whole process of preparation, compiling and writing of this thesis.

I would like to express my deepest gratitude to my supervisor, Professor Mohamed Chaouki Babahenini, for his support, insightful comments, immense knowledge, patience and most importantly, his vision in regard to research. His door office was always open with a warm spirit when the road got tough. It was a great privilege to complete this thesis under his guidance. As I continue on my journey, I will always be thankful for this inspiring and impactful experience.

I extend my sincere thanks to all members of the jury for agreeing to review my work and to participate in and enrich the defense of this thesis.

My humblest gratitude to all the concerned people who contributed to this thesis and supported me in one way or the other.

Dedication

الشكر لله أولاً وأخيراً

الذي انزل على نبيه أعظم وأرسخ كلمة في الكون ... اقرأ

إلى من حفر في صخر الأسئلة عميقاً

إلى من رفع الستار في عز العنمة لأرى الشمس في أوج البزوغ

إلى من كفكف قلقي لأرى الطريق آمناً... محفوفاً بالضوء

إلى أستاذي وأبي الثاني البروفيسور بابا حنيني

إلى منجم الأفكار وخزان المحبة والفضائل

إلى الكائن النوراني الذي ترعرعت في كنفه فتعلمت بأن الحياة كيميائية أخرى

ناصية للشرف

و بأن البقاء للنقاء

إلى من مد يده البيضاء لي منذ نعومة الحلم

أبي الاستثنائي البروفيسور شريف فضيل

إلى التي أدخلتني ملكوت اللغة لتطرز عمري بالكلمات و رصعت لحظاتي شعراً و دفناً

و اختارت لي هذا الاسم ... أمي الفريدة بحبها

إلى اخوتي ... وثام غفران رأفة يحيي

إلى من تشابكت أيدينا لرسم وجه الغد

إلى شريكتي في المستحيل... حين حلمنا ذات حنين بأن الطيران يبدأ من كلمة صداقة...

إلى رفيقة الدرب و العمر ... الغالية درين

إلى من وضعت الميكروفون في يدي و زرعت الممدد في دمي ...

العزيزة بدرة مسعودي

Abstract

Acrophobia, or the extreme irrational fear of heights, is a widespread and debilitating anxiety disorder affecting as many as 1 in 20 adults. The resulted distress has a significant impact on restricting the functioning of the everyday life and affecting performance in different domains that are related to being far from the ground. Fortunately, this disorder is curable when providing the right treatment. Along with the growth of technology in the last decade, virtual reality (VR) has proved to be as effective as the traditional forms of exposure therapy (VRET) for treating this mental disorder.

Therefore, and in order to provide an efficient tool for treating acrophobia, we developed a VR based serious game application "AcroFree" that exposes the patient to several anxiety-provoking situations in an interactive and fully immersive 3D environment using the HTC Vive headset. The project comprised of 3 levels with different height-related scenarios and challenging tasks allowing the patient to get used to heights while learning how to handle their phobic responses in a secure and controlled context repeatedly until creating new memories of safety. A realistic experience with a high sense of immersion and smooth interactions was achieved taking the advantage of the new VR technologies.

ملخص

رهاب المرتفعات ، أو الخوف الشديد الغير منطقي من المرتفعات، هو اضطراب قلق واسع الانتشار ومنهك يصيب ما يصل إلى 1 من كل 20 بالغاً. إن الانتكاسات النفسية الناتجة لها تأثير كبير على تقييد سير الحياة اليومية وتعقيدها مما يؤدي إلى عرقلة و تراجع الأداء في مختلف المجالات كلما كانت هناك مسافة تباعد بين المصاب بفوبيا العلو و الأرض. لحسن الحظ ، يمكن علاج هذا الاضطراب عند تقديم الوسائل العلاجية المناسبة. في خضم التطور التكنولوجي في العقد الماضي، أثبت الواقع الافتراضي (VR) نجاعته في علاج هذا النوع من الاضطرابات مثلما نجحت الطرق التقليدية الأخرى التي تعتمد على العلاج بالتعرض " VRET " .

في سبيل توفير تقنية فعالة لعلاج رهاب المرتفعات، قمنا بتطوير تطبيق "AcroFree" يركز على تكنولوجيا الواقع الافتراضي على شكل لعبة هادفة تعرض المريض للعديد من المواقف المثيرة للرهاب في بيئة غامرة ثلاثية الأبعاد باستخدام نظارات الـ "HTC Vive". يتكون التطبيق من 3 مستويات متعددة السيناريوهات تحاكي مشاهد مختلفة الارتفاع مزودة بتحديات تحفز المصاب على مواجهة خوفه بشكل متكرر من أجل التعود على المواقف المماثلة في الواقع و تعلم كيفية التعامل مع استجاباتهم الرهابية في سياق آمن و موجه إلى أن يصنع ذاكرة جديدة و سليمة اتجاه المرتفعات. حققنا من خلال هذا المشروع تجربة واقعية تمنح إحساسا عاليا من الغمر بالإضافة إلى تفاعلات سلسلة مع الواقع الافتراضي بالاستفادة من تقنيات الـ "VR" الجديدة.

CONTENTS

Acknowledgements	i
Dedication	ii
Abstract	iii
المخلص	iv
Contents	v
List of Figures	ix
List of Tables	x
Acronyms	xi
Introduction	
Insights into Virtual Reality	15
1.1 Introduction	16
1.2 Definition of Virtual Reality	16
1.3 History of Virtual Reality	17
1.4 What is VR? What is VR not?	20
1.4.1 Levels of immersion in VR systems	21
1.4.2 Characteristics of Immersion in VR	24
1.4.3 Virtuality Continuum	24
1.5 How Virtual Reality works	25
1.6 VR applications development	26
1.6.1 Construction of virtual worlds	26
1.6.1.1 Modeling	26
1.6.1.2 Filming (Video capture)	27

1.6.2	Interacting with virtual worlds	29
1.6.2.1	Camera Control	29
1.6.2.2	Navigation	29
1.6.2.3	Selection (object picking)	30
1.6.2.4	Manipulation	30
1.6.3	The challenges of creating a VR application	30
1.7	Application of Virtual Reality	32
1.7.1	Motivation to use VR	32
1.7.2	Medicine	32
1.7.3	Education and Training	32
1.7.4	Entertainment and Sport	33
1.7.5	Engineering and Architecture	33
1.7.6	Data Visualization	33
1.7.7	Phobia Treatment	34
1.8	Conclusion	34
	Phobias Overview	35
2.1	Introduction	36
2.2	Definition of phobia	36
2.3	Classification of phobia	36
2.3.1	Social phobia	37
2.3.2	Agoraphobia	38
2.3.3	Specific phobia	39
2.4	Severity	39
2.5	Traditional therapy for phobias	40
2.5.1	Cognitive Therapy	40
2.5.2	Exposure Therapy	41

2.5.2.1	In Vitro	42
2.5.2.2	In Vivo	42
2.5.2.3	Systematic Desensitization.	43
2.5.2.4	Flooding	43
2.5.3	Assertiveness Therapy	43
2.5.4	Limitation of CBT.	44
2.6	Virtual Reality Therapy	44
2.6.1	Advantages of virtual reality therapy	45
2.6.2	Previous work on VR therapy for treating phobias.	46
2.7	Conclusion	49
	System Description and Architecture Design	50
3.1	Introduction.	51
3.2	Acrophobia	51
3.2.1	Definition of Acrophobia	51
3.2.2	Virtual Reality Exposure Therapy for Acrophobia	52
3.3	Proposed System for Acrophobia treatment	53
3.3.1	System objectives	53
3.3.2	System Architecture Design	54
3.3.2.1	Virtual World	55
3.3.2.2	Patient	55
3.3.2.3	Virtual World-Patient Interaction	56
3.3.2.4	Moderating Factors.	56
3.3.2.5	Quality.	57
3.4	Phases of the methodology.	58
3.4.1	Application Assignment phase	58
3.4.2	Analysis phase	59

3.4.3	Creation phase	62
3.4.4	Testing phase	62
3.4.5	Implementation phase	62
3.5	Conclusion	63
	Implementation, Results and Evaluation	64
4.1	Introduction	65
4.2	Technical Description	65
4.3	Development Environment	66
4.3.1	Hardware	66
4.3.2	Software	68
4.3.2.1	Steam VR	68
4.3.2.2	Unity3D	68
4.4	Development Process	70
4.5	Prototype Content	71
4.5.1	Graphical User Interface	71
4.5.2	Designed Environment	74
4.5.2.1	Navigation inside the building	74
4.5.2.2	Elevator Animation	75
4.5.2.3	Interactions Mechanism	76
4.5.2.4	Application Levels	77
4.6	Application Usability by the therapist	85
4.7	Conclusion	85
	Conclusion and Perspectives	86
5.1	Summary	86
5.2	Future Work	87
	Bibliography	88

List of Figures

Figure 1-1: Sensorama simulator device (De Faria, Figueiredo, & Teixeira, 2015).....	17
Figure 1-2: The first Head Mounted Display (Dom, 2019).....	18
Figure 1-3: GROPE force feedback display (Mazuryk & Gervautz, 1996)	18
Figure 1-4: The BOOM (Beier, 2008).....	19
Figure 1-5: Autonomy, interaction, presence in VR – Zeltzer’s cube (Zeltzer, 1992).....	21
Figure 1-6: Example of a non-immersive system (Vasyl, 2019).	22
Figure 1-7: Example of a semi-immersive system (Vasyl, 2019).....	23
Figure 1-8: Example of a fully-immersive virtual environment (CAVE system) (Cave, 2020)	23
Figure 1-9: The Reality-Virtuality Continuum (Mangrovejane, 2017).....	25
Figure 1-10: 360° Degree Panoramic Development Process (Ricardo & Masoud, 2019).....	28
Figure 2-1: Phobia Classification.	37
Figure 2-2: The vicious cycle of Social Anxiety (Anxiety Canada, 2017)	38
Figure 2-3: Block Diagram of CBT Techniques.....	40
Figure 2-4: Thoughts, behaviors and feelings affection circle (Aaron, 2020).....	41
Figure 2-5: Briana Clifford and Dr Sophie Li during an exposure therapy session for overcoming fear of spiders (Miller, 2017).....	42
Figure 2-6: Miss Muffet demonstrates she is no longer afraid of real spiders after VR therapy (Garcia-Palacios A. , Hoffman, Carlin, Furness Iii, & Botella, 2002)	46
Figure 2-7: Scenes from the OxfordVR acrophobia therapy (Freeman, et al., 2018)	47
Figure 3-1: Past 10 years of publications in Virtual Reality Exposure Therapy (Herbelin, 2005).....	53
Figure 3-2: System Architecture	54
Figure 3-3: Expected responses when using AcroFree.	57

Figure 3-4: Phases of the methodology	58
Figure 3-5: Activity diagram of the user/VR system interactions.	60
Figure 3-6: Algorithm of the patient/elevator behavior.....	61
Figure 4-1: Technical description of the application requirements.....	66
Figure 4-2: Components of the VR system HTC Vive.	67
Figure 4-3: Schematic setup of the VR system HTC Vive with interaction area (blue) (Michael & Chris, 2018).....	67
Figure 4-4: SteamVR Tracking System Overview (Morgan, 2017).	68
Figure 4-5: Diagram of Software and Hardware work flow.....	70
Figure 4-6: Data flow level 1 Diagram.....	71
Figure 4-7: Main Menu User Interface.	72
Figure 4-8: Controller Gestures.....	72
Figure 4-9: Patient navigation inside the building (Teleportation using the touchpad).	75
Figure 4-10: Elevator State Machine (Ascending/descending).	76
Figure 4-11: The exterior of the office room.	77
Figure 4-12: The office room before completing the tasks (The circles illustrate the interactable objects).....	78
Figure 4-13: Patient view while doing the level 1 tasks.	79
Figure 4-14: The level two patient view.....	79
Figure 4-15: Patient view while doing the level 2 tasks.	80
Figure 4-16: Breakout space after completing the level 2 tasks.	81
Figure 4-17: Patient view of the glass bridge of level 3.	82
Figure 4-18: The level 3 tasks in the breakout space.	83
Figure 4-19: Crossing through the glass bridge to the office kitchen.	84

List of Tables

Table 2-1: Overview of (Garcia-Palacios A. , Hoffman, Carlin, Furness Iii, & Botella, 2002) study on spider phobia and (Freeman, et al., 2018) study on and acrophobia.48

List of abbreviations

VR	Virtual Reality
VE	Virtual Environment
VRE	Virtual Reality Therapy
VRET	Virtual Reality Therapy
CAD	Computer-aided design
WoW	Window on World
LCD	Liquid Crystal Display
HMD	Head Mounted Display
AR	Augmented Reality
MR	Mixed Reality
HUDs	Head-Up Displays
NBA	National Basketball Association
NFL	National Football League
CBT	Cognitive behavioral therapy
WL	waiting list
ISO	International Organization for Standardization
API	Application programming interface
UI	User Interface
GUI	Graphical User Interface

Introduction

Today, with the visual experiences offered by virtual reality (VR) and displayed either on a computer screen or through special stereoscopic displays, it becomes possible for people to step into the world of computer graphics that is not accessible in real life or even not yet created and interact with it in meaningful ways instead of just watching a picture on the monitor. This fascinating term that was first introduced by the scientist Jaron Lanier back in 1987, refers to “an immersive, interactive, multi-sensory, viewer centered, 3D computer-generated environment and the combination of technologies required to build such an environment” (Cruz-Neira, Virtual reality overview, 1993).

Thanks to the development of CAD software, graphics hardware acceleration, head mounted displays, and database gloves, VR in current decade becomes overwhelmingly popular and used to describe a wide variety of applications commonly associated with immersive, highly visual, 3D environments, including the health care sector in which the VR business market is growing day by day as the high-performance graphics systems going to be more cost-effective.

By the growth of technology, virtual reality graded exposure therapy (VRET), in which the patients are exposed to virtual anxiety-provoking stimulus in fully controllable environments, became one of the most effective applications of VR as another solution for assessment, understanding, and treatment of mental health disorders. The first VR application in this field was about treating acrophobia, an intense and irrational fear of heights, which is the most prevalent of all specific phobias subtypes. This therapy consists in creating realistic artificial situations that can be individually controlled, replicated, and tailored to the patient's experiences which triggers phobic responses similar to those of the real world.

Aside from demonstrated effectiveness for specific phobias, and acrophobia in particular, VRET has a number of additional advantages over traditional “in vivo” treatment, such as the engaging and entertaining experience that offers more control and flexibility to the therapy with less time consuming and a larger variety of scenarios. Moreover, an efficient psychological treatment for acrophobia requires a direct active learning and coaching facing the height-related situations, whereas most patients are too afraid of confronting the real

feared stimulus and most therapists have little time for sessions outside the clinic. Therefore, conducting a VR therapy within the confines of the therapist's office rather than having to go outside enhances a higher acceptance by patients, and thereby ease an efficacious procedure of psychotherapy.

Since acrophobia can become chronic and increase the risk of developing other mental disorders, such as anxiety and major depression if left untreated, and due to high treatment costs, long waiting lists, a general reluctance to seek traditional treatment, and the limited number of VR therapy tools, there is an evident need for affordable and scalable VR interventions. Therefore, the overall purpose of the thesis was to develop a VR based serious game application called "*AcroFree*" as a psychological intervention for treating acrophobia. This application exposes the patients gradually to different height-related situations through a series of motivating scenarios in which they face their fear to develop memories of safety and learn how to control their phobic responses before confronting the real world stimulus.

The proposed project thesis is organized into several chapters. In chapter 2 detailed definitions and a historical overview of virtual reality are presented, basic terminology and aspects on how VR systems works are listed, followed by VR tools development methods, challenges and application areas. Chapter 3 introduces and categorizes phobias, their severity, the different traditional methods of treatment, and finally presented a general overview of virtual reality exposure therapy (VRET) and the relevant work done for treating specific phobias. Chapter 4 provides the research proposed solution and methodology used in this thesis for treating acrophobia. It starts by clarifying the importance and the basic concepts of developing a virtual reality exposure therapy application for overcoming fear of heights based on the statistics and research in the past ten years. Then, it presents the detailed system description and architecture design with the basic idea of the prototype. Finally, it demonstrates the methodology process for the implementation. Chapter 5 depicts the entire setup of this project that incorporates the hardware, software, and the technical description of the VR application. This chapter also describes the prototype of the project including user interfaces, the environment design, the game levels and scenarios, and presents the final results of the system. Chapter 6 concludes the research that has been done and proposes future work.

Chapter 01

Insights into Virtual Reality

1.1 Introduction

According to (Rheingold, 1991), one way to view virtual reality (VR) is as a “magical window into other worlds, from molecules to minds”, and since science fiction has always played the role in not only foretelling but also advancing our scientific and technological directions, virtual reality has been reaching lately the unlimited point of artificial experience. Abstract worlds and phenomena that were previously only describable through words and crude diagrams, become as immersive as life itself with the virtual reality art of simulating a physical presence for the users in places both real and imaginary allowing them to feel they are part of the action. Today, with the fast progress in both hardware and software technology virtual reality is no longer restricted to research universities, large corporations, and the military for training, but rather it is becoming open and useful to a much wider population. Very few people, however, really know what virtual reality is, what its basic principles, its application areas and its challenges are. Therefore, an insightful overview of VR is done in this chapter.

1.2 Definition of Virtual Reality

Virtual reality is defined as a highly interactive, computer-based multimedia environment in which the user becomes the participant in a computer-generated world (Kim et al., 2000; Onyesolu, 2009; Onyesolu & Akpado, 2009). It is the simulation of a real or imagined environment that can be experienced visually in the three dimensions of width, height, and depth and that may additionally provide an interactive experience visually in full real-time motion with sound and possibly with tactile and other forms of feedback. VR is a way for humans to visualize, manipulate and interact with computers and extremely complex data (Isdale, 2005)

Therefore, the experience provided by any virtual reality technology must have two characteristics – immersion and navigation (Rheingold, 1991). Immersion refers the technology’s ability to trick your brain by creating an illusion of being in a different simulated environment than your real world. The more the user is immersed in the environment, the harder it is for the him to distinguish it from his normal sensory input. On the other hand, navigation refers to the user's ability to move around, interact and manipulate objects within

that environment. By offering the highest levels of either or both, we can break down the barriers between humans and computers.

1.3 History of Virtual Reality

The very first idea of VR was presented by Ivan Sutherland in 1965: “make that (virtual) world in the window look real, sound real, feel real, and respond realistically to the viewer’s actions”. A lot of research has been done since then and status quo: “the Sutherland’s challenge of the Promised Land has not been reached yet but we are at least in sight of it” (Brooks, 1995).

Let us have a short glimpse at the last three decades of research in virtual reality and its highlights (Balaguer et Mangili 1993, Cruz-Neira 1993, Gigante 1993, Holloway & Lastra 1995):

- **Sensorama** – in years 1960-1962 Morton Heilig created a multi-sensory simulator. A prerecorded film in color and stereo, was augmented by binaural sound, scent, wind and vibration experiences. This was the first approach to create a virtual reality system and it had all the features of such an environment, but it was not interactive.



Figure 1-1: Sensorama simulator device (De Faria, Figueiredo, & Teixeira, 2015).

- **The Ultimate Display** – in 1965 Ivan Sutherland proposed the ultimate solution of virtual reality: an artificial world construction concept that included interactive graphics, force feedback, sound, smell and taste.
- **“The Sword of Damocles”** – the first virtual reality system realized in hardware, not in concept. Ivan Sutherland constructs a device considered as the first *Head Mounted Display* (HMD), with appropriate head tracking. It supported a stereo view that was updated correctly according to the user’s head position and orientation.

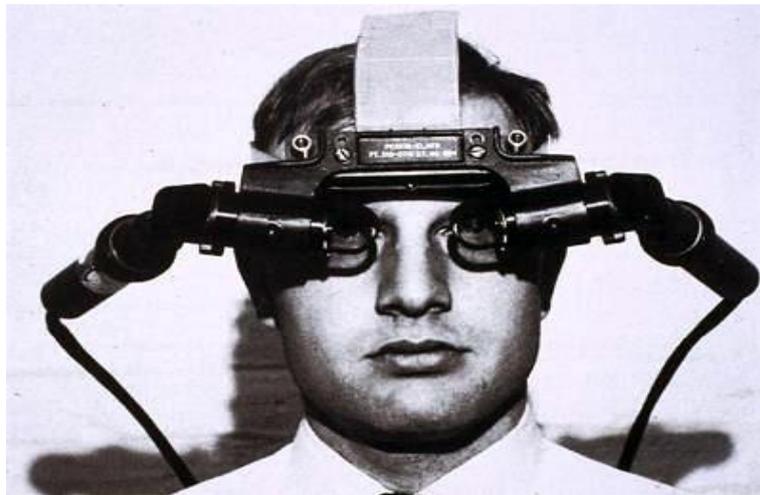


Figure 1-2: The first Head Mounted Display (Dom, 2019).

- **GROPE** – the first prototype of a force-feedback system realized at the University of North Carolina (UNC) in 1971.



Figure 1-3: GROPE force feedback display (Mazuryk & Gervautz, 1996).

- **VIDEOPLACE** – Artificial Reality created in 1975 by Myron Krueger – “a conceptual environment, with no existence”. In this system the silhouettes of the users grabbed by the cameras were projected on a large screen. The participants were able to interact one with the other thanks to the image processing techniques that determined their positions in 2D screen’s space.
- **VCASS** – Thomas Furness at the US Air Force’s Armstrong Medical Research Laboratories developed in 1982 the Visually Coupled Airborne Systems Simulator – an advanced flight simulator. The fighter pilot wore a HMD that augmented the out-the-window view by the graphics describing targeting or optimal flight path information.
- **VIVED** – Virtual Visual Environment Display – constructed at the NASA Ames in 1984 with off-the-shelf technology a stereoscopic monochrome HMD.
- **VPL** – the VPL company manufactures the popular DataGlove (1985) and the EyePhone HMD (1988) – the first commercially available VR devices.
- **BOOM** – commercialized in 1989 by the Fake Space Labs. BOOM is a small box containing two CRT monitors that can be viewed through the eye holes. The user can grab the box, keep it by the eyes and move through the virtual world, as the mechanical arm measures the position and orientation of the box.

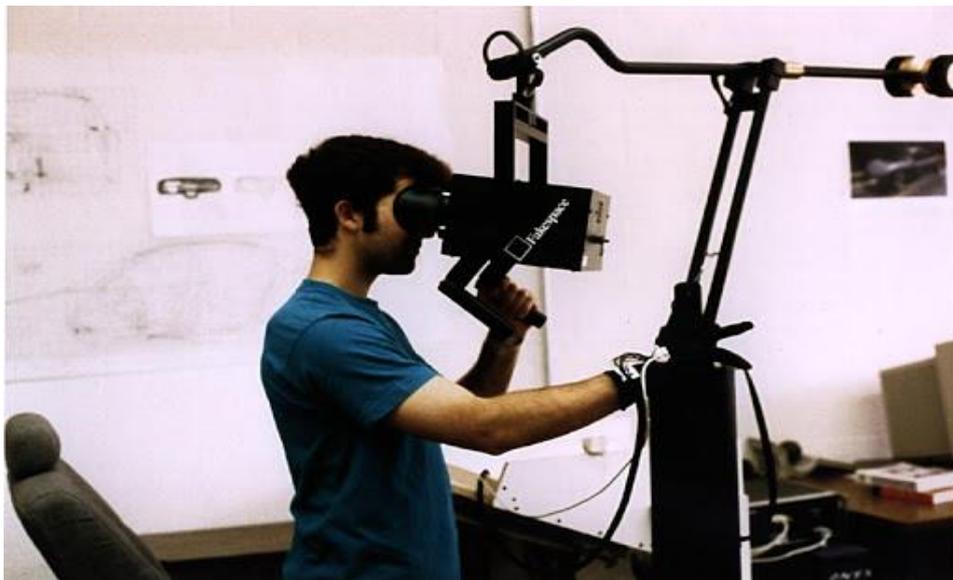


Figure 1-4: The BOOM (Beier, 2008).

- **UNC Walkthrough project** – in the second half of 1980s at the University of North Carolina an architectural walkthrough application was developed. Several VR devices were constructed to improve the quality of this system like: HMDs, optical trackers and the Pixel Plane graphics engine.
- **Virtual Wind Tunnel** – developed in early 1990s at the NASA Ames application that allowed the observation and investigation of flow-fields with the help of BOOM and DataGlove.
- **CAVE** – presented in 1992 CAVE (CAVE Automatic Virtual Environment) is a virtual reality and scientific visualization system. Instead of using a HMD it projects stereoscopic images on the walls of room (user must wear LCD shutter glasses). This approach assures superior quality and resolution of viewed images, and wider field of view in comparison to HMD based systems.
- **Augmented Reality (AR)** – a technology that “presents a virtual world that enriches, rather than replaces the real world” (Bryson, 1993). Which means augmenting the reality with a combination of three-dimensional virtual objects and the real world. This technology was previously used to enrich fighter pilot’s view with additional flight information (VCASS). Thanks to its great potential – the enhancement of human vision – augmented reality became a focus of many research projects in early 1990s.

1.4 What is VR? What is VR not?

The stormy development in the field of virtual reality and its promising technologies that becomes extremely popular and used nearly in all sorts of applications, capture greater interest of people than e.g., computer graphics. However, until now the majority of those people misuse the term in many cases and still can't make the difference between what is VR and what is not, which explains the fuzzy border between 3D computer graphics and Virtual Reality.

The main difference between traditional media and VR systems lies in three dimensionality of Virtual Reality structure. *Immersion, presence and interactivity* are the main features of Virtual reality that draw it away from other representational technologies, and this combination determines the level of advance of VR systems.

There are different definitions of Presence and Immersion. Most of them mention presence to the subjective sensation of “being there” experienced, which means the account of user's particular psychological response to a virtual environment. In the other hand, Immersion is the ability of computer displays to deliver that virtual environment to the senses of the user. The components of immersion are limited to software and hardware of the system. However, different users can experience different levels of presence with the similar virtual reality system depending on life experience: memory, ability, past experience, emotional state, and other factors.

The third key factor of VR experience is Interactivity with a virtual environment. Virtual reality system must able to capture inputs from users so the virtual environment can be changed endlessly (Kundalakesi, Swathi, Ashapriya, & Sruthi, 2017). When the user for example move the haptic device to smash something, the visual display of virtual reality system must reply to his physical movement and simulate force back to the tool.

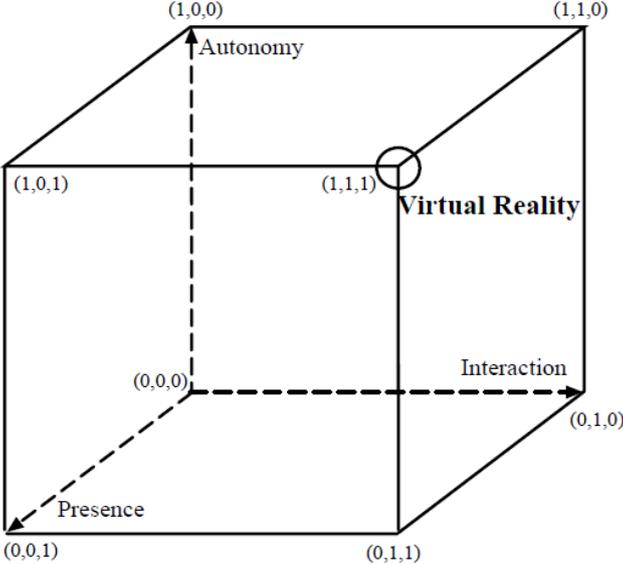


Figure 1-5: Autonomy, interaction, presence in VR – Zeltzer’s cube (Zeltzer, 1992).

1.4.1 Levels of immersion in VR systems

In a virtual environment the type and the quality of the sensory impressions generated by the computer system and delivered to the human senses determine the level of immersion and the feeling of presence in VR. Ideally the system should present high-resolution, high-quality and

consistent over all the displays, information to all of the user's senses. Moreover, the environment should also react realistically to the user's actions. However, the practice is very different from this ideal case. We can group the VR systems accordingly to the level of immersion they offer to the user (compare with (Isdale, 1993; Von Schweber & Von Schweber, 1995)):

- **Non-Immersive (Desktop VR) systems** – sometimes called Window on World (WoW) systems. This is the simplest type of virtual reality applications. It uses a conventional monitor to display the image (generally monoscopic) of the world. No other sensory output is supported.



Figure 1-6: Example of a non-immersive system (Vasyl, 2019).

- **Semi-Immersive (Fish Tank VR) systems** – improved version of Desktop VR. These systems support head tracking and therefore improve the feeling of “of being there” thanks to the motion parallax effect. They still use a conventional monitor (very often with LCD shutter glasses for stereoscopic viewing) but generally do not support sensory output.



Figure 1-7: Example of a semi-immersive system (VasyI, 2019).

• **Immersive systems** – the ultimate version of VR systems. They let the user totally immerse in computer generated world with the help of HMD that supports a stereoscopic view of the scene accordingly to the user's position and orientation. These systems may be enhanced by audio, haptic and sensory interfaces.



Figure 1-8: Example of a fully-immersive virtual environment (CAVE system) (Cave, 2020).

1.4.2 Characteristics of Immersion in VR

We can summarize the unique characteristics of immersive virtual reality as follows (Mandal, 2013):

- Head referenced viewing provides a natural interface for the navigation in three dimensional space and allows for look around, walk around, and fly through capabilities in virtual environments.
- Stereoscopic viewing enhances the perception of depth and the sense of space.
- The virtual world is presented in full scale and relates properly to the human size.
- Realistic interactions with virtual objects via data glove and similar devices allow for manipulation, operation, and control of virtual worlds.
- The convincing illusion of being fully immersed in an artificial world can be enhanced by auditory, haptic, and other non visual technologies.
- Networked applications allow for shared virtual environments.

1.4.3 Virtuality Continuum

In addition to virtual reality, other terms of synthetic reality are recently emerging: *Augmented Reality (AR)* and *Mixed Reality (MR)*. Each technology represents a different way to experience information, yet there is a lot of confusion and misunderstanding about what each version of reality is and what exactly differentiates them. Therefore, the Reality Virtuality Continuum, also called Milgram's Continuum conceived by Paul Milgram for the first in 1994 is introduced in Figure 1-9 to grasp the actual meaning of those terms by describing all possible combinations of reality and computer-generated images in head-up displays (HUDs). At the far left, there is the real environment, our physical universe unmodified as our eyes see it. At the opposite side of the continuum, we can find the virtual environment generated by a computer to simulate a real or an imaginary world. The area between the real environment and the virtual environment represents the mixed reality as a combination of real world objects and virtual objects with various degrees of overlapping between reality and virtuality. This term encompasses a wide range of technologies from augmented reality (AR) which consists in adding a digital content in a real environment to augmented virtuality (AV) that consists in adding physical content in a virtual environment.

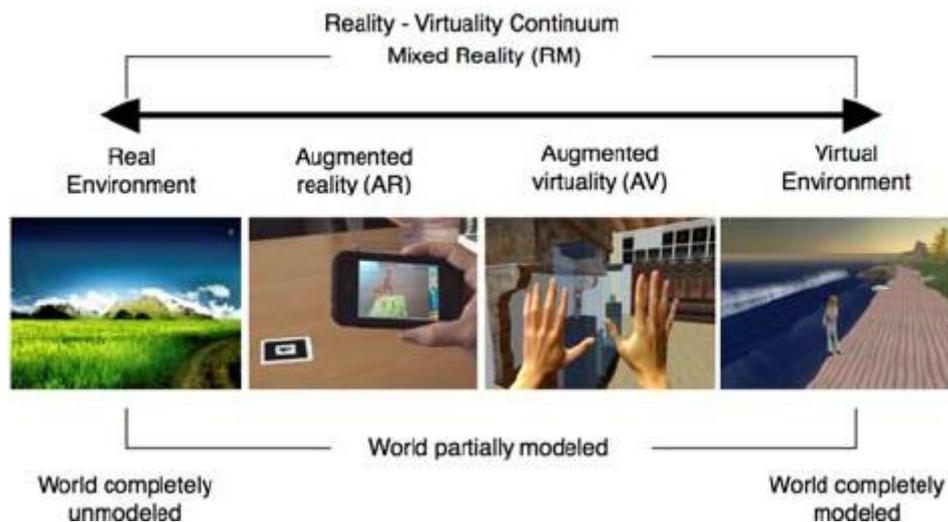


Figure 1-9: The Reality-Virtuality Continuum (Mangrovejane, 2017).

1.5 How Virtual Reality works

The idea behind VR is to deliver a sense of being there by giving at least the eye what it would have received if it were there and, more important to have the image change instantly as the point of view is changed (Smith & Lee, 2004). The perception of spatial reality is driven by various visual cues, like relative size, brightness and angular movement. One of the strongest is perspective, which is particularly powerful in its binocular form in that the right and left eyes see different images. Fusing these images into one 3D perception is the basis of stereovision.

The perception of depth provided by each eye seeing a slightly different image, eye parallax, is most effective for objects very near you. Objects farther away essentially cast the same image on each eye. The typical dress code for VR is a helmet with goggle-like displays, one for each eye. Each display delivers a slightly different perspective image of what you would see if you were there. As you move your head, the image rapidly updates so that you feel you are making these changes by moving your head (versus the computer actually following your movement, which it is). You feel you are the cause not the effect (Onyesolu & Eze, 2011)

1.6 VR applications development

Every VR application must be effective by means of performance and interaction. This requirement can be only fulfilled when all system parts – input, interaction and output – are properly integrated one with the other. Nowadays, even the best hardware cannot support this by itself – it needs software assistance for precise control, resources management and synchronization.

1.6.1 Construction of virtual worlds

Construction of virtual environments involves many different aspects that were not present in standard computer graphics. The biggest challenge to trade is performance vs. natural look and behavior. However, these requirements are contradictory: more convincing models and better physical simulation demand more resources, thereby increasing computational cost and affecting overall performance. Several methods are currently used for creating realistic and coherent virtual worlds.

1.6.1.1 Modeling

Nowadays, 3D graphics is experiencing a real breakthrough. The rendering of virtual worlds is becoming more and more realistic, boundaries between virtuality and reality are being erased and creation of 3D worlds is faster and better. Many different kinds of models representing virtual environments can be imagined: from simple models like a single unfurnished room, to extremely complex ones like a the whole city with many buildings containing a lot of chambers, each modeled with high amount of detail. Every year, the possibilities to improve and enhance realistic impressions are becoming better thanks to more powerful hardware and software. With the increasing power of computers there are more possibilities of larger image resolution, dimensionally improved objects, realistic textures, and, last but not least, realistic scene illumination (shadows, reflections, refraction, etc.)

Physical simulation

Virtual reality may be a clone of physical (real) reality or a kind of closer not defined (cyber) space that has its own rules. In both of these cases a simulation of the environment has to be done. In case of newly defined cyberspace the task is relatively easy – we can invent new laws or use simplified physics. The real challenge is to simulate the rules of physics precisely, because they are very complex phenomena: dynamics of objects, electromagnetic forces, atomic forces etc. For the human-computer interaction purposes a subset of them has to be considered. Newton's laws are the basis when simulating movements, collisions and force-interaction between objects (Vince, 1995).

The simulation, collision detection (Zyda, Pratt, Osborne, & Monahan, 1993; Fang, Clark, & Simmons, 1995) and animation of autonomous objects, may be a very complex and time-consuming task, so other approaches must be applied than in standard (i.e. non-real time) animation. The simulation process that manages the behavior of the whole environment (including interaction between different users) should be run in the “background” – decoupled from the user's interaction (Shaw, Liang, Green, & Sun, 1992; Shaw, Green, Liang, & Sun, 1993) in order to support the full performance. The construction and maintaining of physically based, multi-user and therefore distributed virtual environments is not an easy task. Beside usual expectations of high efficiency support for lag minimization, it also demands hardware independence, flexibility and high-level paradigms for easy programming, maintaining and consistent user interface.

1.6.1.2 Filming (Video capture)

Another method is the capturing and processing of 360° panoramic images, which must be adapted to be played on different devices, and VR peripherals. 360° panoramas create highly realistic and detailed replication of real-world spaces while giving users a high sense of presence and immersion. To produce these complex interactive representations, a 360° panorama must be captured from the real locations or places and translated into the virtual space for visualization (see Figure 1-10).

The capture of a 360-degree panorama entails the construction of an equirectangular projection in a two-dimensional plane. Comparable to a map projection, the process requires

software algorithms for the systematic transformation from a 2D plane into a sphere, cylinder, or cube and vice versa. Finally, the VR360 experiences can be viewed on a personal mobile display and/or a VR head-mount-display (HMD). Both of these displays allow users to look around a spherical panorama using the interaction of gaze-control, hands-free navigation, or other user interface methods.

However, for dynamic scenes, where there are impossible to capture fast moving objects (and it is impossible to capture them by one camera in the same place at the same time) the most expensive option is offered by multiple capturing by more cameras at a same time. Such filming is technically the most complex method, because the environment is necessary to shoot at 360°. This requires at least three cameras with wide angle lens, or 6 GoPro cameras placed in a special holder that firmly holds the direction of rotation and the proximity of the cameras. When shooting with one lens, the panoramic head gives an exact rotation in the axis of the nodal point, so there is no parallax and no change point of view. Sensing object must keep enough distance; otherwise unrecoverable errors occur at joints of panorama images. Another technical precondition for flawless engagement is synchronization of all cameras. Claims for accuracy make the type and speed of the scene. The proven technical solution is a wireless 2.4 GHz band, either proprietary technology or using standard WiFi. Synchronization deviation varies widely between a few milliseconds, which are sufficient accuracy for most scenes. Functionality is normal even at a distance of tens of meters from the transmitter, but is reckoned with interference caused by other devices operating on the same frequency (Bluetooth, microwave oven, other WiFi devices, remote controls RC models, etc.).

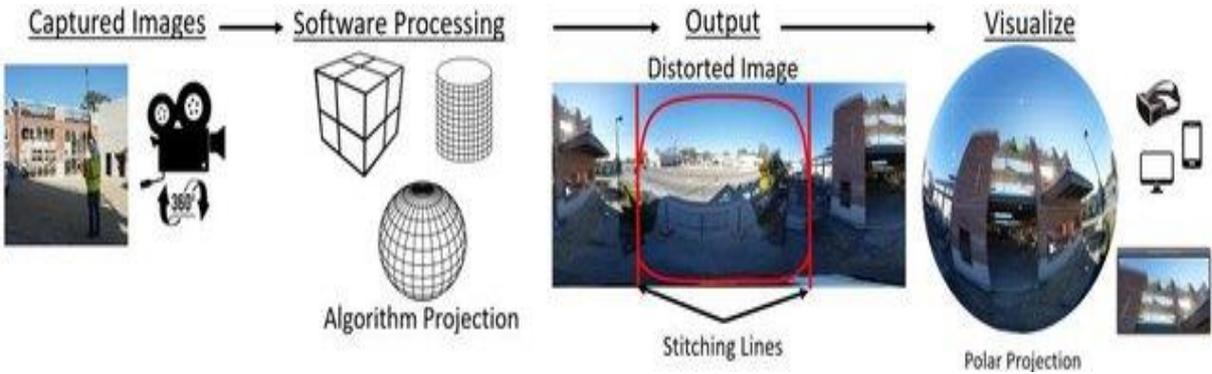


Figure 1-10: 360° Degree Panoramic Development Process (Ricardo & Masoud, 2019).

1.6.2 Interacting with virtual worlds

The ultimate VR means that no user interface is needed at all – every interaction task should be as natural as in (real) reality. Unfortunately this is not possible today because of technical problems. However, many techniques may be used to enhance the interaction model (Balaguer & Gobetti, 1995), but they still use some metaphors to make human-computer dialog easier.

The human hand is most dexterous part of our body – in reality we use them intuitively to perform a variety of actions such as grabbing or moving objects, typing, opening doors, precise manipulations etc. The most natural way of interacting with the computer is probably by using the hand. Therefore the majority of VR input devices are coupled to our palm. They represent a broad variety of levels of advance, complexity and price, so for different applications other devices and modes of interaction are used. Basic interaction tasks in VEs are: camera control (for observation), navigation, object manipulation and information access.

1.6.2.1 Camera Control

Observation of the scene is essential to the user, because it provides information about his/her location in virtual world. Intuitive camera control is fundamental for the immersion feeling. In the ideal case, where head-tracking is available the point of view is directly set by rotating and moving the user's head.

1.6.2.2 Navigation

Inside the virtual world, the user may want to explore the whole environment. Walking over long distances cannot be realized so easily, because of the limited tracking range. Therefore an appropriate transport medium is needed. In general, with the help of some input devices we can define the motion of our body in virtual space. Depending on the type of application this may be either driving (in 2D space) or flying (in 3D space). The principles of these navigation paradigms are however the same. The hand's orientation and position can be used to determine the direction of the motion based on different mode to specify the required direction: *pointing or crosshair* mode. Looking direction (head orientation) can also specify

the line of movement and it is called *gaze direction*. Another approach consists of using input devices like joysticks, 3D mice, spaceballs to specify the motion direction. They allow precise control, but often the lack of correspondence between device and motion may be confusing. However, construction of special devices for certain applications may increase the feeling of immersion (e.g., steering wheel for driving simulation).

1.6.2.3 Selection (object picking)

To perform any action that causes the change of virtual world state, the user must first select the object that will be the subject of manipulation. There are two primary selection techniques (Mine, 1995): local and at-a-distance. In the local mode, selecting is done when the collision between user's hand represented with e.g., 3D cursor and object is detected. In the at the distance mode, a ray is shot in to the scene to pick the object. The selection-ray can be determined by hand's orientation or gaze direction. An alternative selection-mode may be done by choosing entries from the virtual menu (Jacoby, 1993).

1.6.2.4 Manipulation

Once the object is selected the user must be able to manipulate it: move, rotate, scale, change attributes etc. This can be achieved by defining special button presses, hand gestures or menu entries that choose a proper tool (Sturman, 1993). These tools can be driven by physical input devices like mice, joysticks, sliders, gauges, hand position tracking (Ware, 1990) or even by a nose-gesture interface (Henry, Yeatts, Hudson, Myers, & Feiner, 1992).

1.6.3 The challenges of creating a VR application

Since our brain has evolved for millions of years to perceive the natural reality, creating a virtual reality that our brain can accept subconsciously and feel really present in it during the whole experience is the biggest challenge of VR. Creating a good VR application is more than simply having a stereoscopic camera that rotates with one tracker. These are some factors that we need to take in consideration to avoid breaking the user's fragile feeling of presence :

- **Latency** : In VR systems latency is the first enemy. If the user moves his head and the resulting image takes time (one second for example) to appear, his brain won't accept that this image is related to his head movement and the virtual world appears unstable. Moreover, the user experiences motion sickness. Thus, for a realistic experience, we need to make sure that the latency is minimal.
- **Interactions** : Since in VR systems we don't have access to a regular mouse or keyboard and interacting in 3D is a complex problem that depends on the user, the hardware and the application, strong expertise is needed to choose the right interaction technique according to the context.
- **Avatars** : In the VR experience we can't see our own bodies anymore in the virtual world. Therefore, displaying a virtual representation of ourselves, called avatars, is very important. It can be a simple task to create realistic avatars if the system provides full body tracking, and if the avatar required has the same dimensions as a real person. In the other hand, if the system only has a few trackers and the avatar requires different dimensions than that person, it can be very difficult to adapt the body posture to a different virtual body and to extrapolate the limbs' positions that couldn't be tracked.
- **Running on different VR hardware** : When we want to run our VR application in a different hardware than the one used in the development phase, we have to modify it according to the new screens (by managing the virtual cameras and viewports), the new trackers, and the cluster synchronization. The interactions will probably need to be modified, because we don't necessarily have a perfect tracking volume. Thus, The application deployment on different VR systems can prove to be a very difficult and time consuming task.
- **A Coherent World, Not Necessarily a Realistic One** : The VR system doesn't only need to fool our senses, but also our mind in order to offer a cognitive presence that results from the credible effects of our actions on the virtual environment. Therefore, the VR simulation must be coherent with consistent rules to maintain the feeling of presence for the whole experience. If the user for example can grab a particular bowl, but can't grab another one, the cognitive presence will be broken, and it will be very difficult to fix it again.

1.7 Application of Virtual Reality

1.7.1 Motivation to use VR

In the last few years, virtual reality becomes overwhelmingly popular and fashionable. This fascinating technology that gives the user the chance to explore the world in other dimension or even to experience what we can't access in the real life, offers great benefits in many application areas which accelerated a tremendous achievement. Since the users manipulate and interact with the simulated environment in the same way they act in the real world, many applications like flight simulators, architectural walkthrough or data visualization systems were developed relatively fast.

1.7.2 Medicine

Nowadays, VR is changing the healthcare experience for both patients and medical professionals. This includes variety of tasks such as computational neuroscience, molecular modeling, ultrasound echography, and others. One of the most promising applications in the medical industry is the use of 3D models by surgeons to plan operations, which offers them a clear 3D visualization of complicated organs. Medical VR has also proved its efficiency when treating chronic pain and cure soreness in the hospitalized patients. There are a number of software created to help ailing patients by deflect their minds to focus more on VR worlds that can help them relieve stress. VR training simulations is another medical application that is used to develop surgeons surgical skills, without causing any harm to animals or human being.

1.7.3 Education and Training

VR technology is so well embraced by the educators and trainers because of the rich and interactive experience that provides. The fully Immersive and engaging learning and training environment helps them develop their skills without the real world consequences of failing through a wide variety of terrains, situations and scenarios. Therefore, various simulators have

been developed for all types of tasks such as planes operation, tanks, submarines, helicopters, car driving and others.

1.7.4 Entertainment and Sport

VR is also applied in the field of sport, for instance, users can be immersed into a virtual reality sports arena where they can play whenever they want in their own rooms. Oculus Rift, HTC Vive, and PlayStation VR have built platforms for VR gaming which creates a life-like experience for players. Apart from being the athlete yourself, VR can revolutionize the way we watch sports and attract more new viewers. The matches needs to be captured using 360° video cameras, then the audience can watch the events as an immersive experience through headsets or mobile. NextVR is one of the most successful startups that provides such experience by broadcasting most popular leagues such as NFL, NBA, and Wimbledon through VR.

1.7.5 Engineering and Architecture

The field of engineering is one of the most important usage for VR. The application of VR changes the lifeless drawings of engineering components and enable them to be virtually made, viewed, gathered and tested with low cost and low time-consuming prototype production. For instance, architects and engineers can walk themselves and their clients through their 3D models and designs at full scale using VR. These walkthroughs break down that technical barrier between the architect and the clients by providing them with a real feel for the design so they can explore it freely and give useful feedback based on an actual understanding.

1.7.6 Data Visualization

Coming on the heels of the big data revolution, rather than using the traditional mapping geometric objects, VR is the right tool at the right time that offers decision-makers a larger scale for visualization to understand and interact with large amounts of complex data without sacrificing details.

1.7.7 Phobia Treatment

Virtual reality has also been used extensively to treat different types of phobias and post traumatic stress disorder. This therapy has shown effectiveness in the academic setting, which is based on exposing patients to the anxiety -provoking situation virtually so they can overcome their fear and improve decision in a real health emergency. Thus, today, several commercial entities offers helpful VR therapy applications to therapists and patients .

1.8 Conclusion

Virtual reality has become one of the most important technologies to be discussed regarding its applications, usage, different types and potential to change our lives and the real world. This technology has cut across all facets of human activities, and it is used widely today in almost all sorts of fields including Science, Engineering, Technology, Medicine and much more. As the cost of virtual reality goes down and it becomes more mainstream, we can expect more serious uses with high degrees of immersion, trustworthy, and interaction, to come to the floor. This chapter introduced the concepts of VR systems, challenges, applications and other essential elements to better understand this technology.

Chapter 02

Phobias Overview

2.1 Introduction

As human beings with feelings, everybody has something that frightens them when facing it. These fear reactions from any potential danger are essential to activate the automatic “fight-or-flight” response as an alert for our survival. However, people can also experience unreasonable and irrational fear towards objects, animals, activities, situations or persons and this is actually what we call it "Phobia". Phobias are the most commonly occurring anxiety disorders and it can be very exhausting and disabling to live with the intense fear and anxiety that goes with having one, that the phobic persons go to great lengths to avoid the feared stimulus or even change their whole life style so that they feel relief. Although it is often extremely difficult for the people to face all these conditions, it helps to know that phobias are highly treatable and understanding them is the first step to provide efficacious treatment options for those in need.

2.2 Definition of phobia

Phobia is a sort of anxiety disorder, characterized by intense irrational fear triggered by specific objects or situations the affected person go to great lengths to avoid (American Psychiatric Association, 2013). This excessive amount of fear and nervousness typically disproportionate to the potential amount of danger of stimulus. According to clinical psychology, despite the fact that people suffering from phobias experience intensive psychic symptoms (anxiety, loss of control, fear) and vegetative symptoms (increased heartbeat, fainting, sweating, problems with breathing), There are also a compulsive characteristic - concern that the feared situation could happen outside the real time and place which can trigger an evasive behavior and a persistent anticipated fear.

2.3 Classification of phobia

Since the nature of the phobic stimulus can vary greatly, phobias are generally classified as three main categories according to the stimulus triggering the anxiety as shown in Figure 2-1.

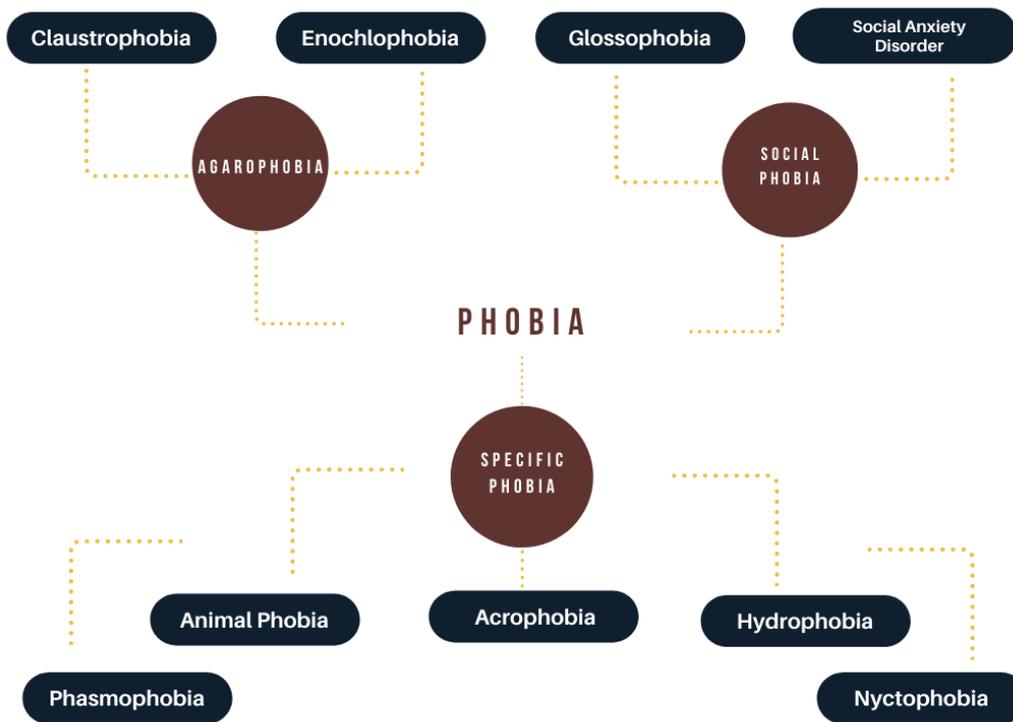


Figure 2-1: Phobia Classification.

2.3.1 Social phobia

Recently referred to as Social Anxiety Disorder, is usually connected with fear of people, fear of critique and fear of overcrowded places. It may be induced by performing publicly, eating or drinking in public, travelling in various kinds of transport or sometimes just by general communication with an individual. People with this disorder has a low self-confidence and a significant discomfort about being humiliated, embarrassed or rejected in social interactions which lead them to avoid the feared situation or endure it with unbearable anxiousness.

- Glossophobia : Fear of public speaking.
- Social anxiety disorder : Fear of being judged, negatively evaluated/rejected in social or performance situation.

Since the bodily symptoms of anxiety can be unpleasant and scary, people may think that there is something physically wrong, or that something awful is going to happen.

This in itself can cause more feelings of anxiety and more symptoms, and so a vicious cycle of anxiety can develop as shown in Figure 2-2.



Figure 2-2: The vicious cycle of Social Anxiety (Anxiety Canada, 2017).

2.3.2 Agoraphobia

Agoraphobia the fear of places or situations , *i.e.* standing in line, fear of closed and confined places, or on the contrary, fear of being in open and overcrowded spaces. The patients in the case of these types of phobia are often concerned that the escape may be difficult or the immediate help might not be available when their panic symptoms get triggered. Untreated agoraphobia can become so serious and lead to complete isolation from the outside world, where patients are unable to leave their houses. This phobia can only be diagnosed if the fear is intensely disturbing, or if it causes significant problems in functioning which interferes with normal daily activities.

- Claustro phobia : Extreme fear of confined places.
- Enochlophobia : Fear of large crowd and gatherings of people.

2.3.3 Specific phobia

Also known as isolated phobia, is persistent and excessive fear of a specific object, situation or activity that is generally not harmful (American Psychiatric Association 2017) , *i.e.* fear of spiders, snakes, bacteria, heights, blood, lightning, dark etc.. These fears cause such distress that some people go to extreme lengths to avoid the feared objects and situations and sometimes, any mention or depiction of them.

- Animal phobia : Fear of snakes, spider, cockroaches, etc.
- Nyctophobia : Fear from darkness.
- Hydrophobia : Fear from water.
- Acrophobia : Fear from height.
- Phasmophobia : Fear of ghosts.

2.4 Severity

The severity of phobias and its symptoms vary among individuals. Some can avoid the phobic stimulus and only experience mild anxiety, while others can exhibit full-fledged panic attacks when faced with the feared objects or situations. The patients often report sweating, dizziness, shortness of breath, trembling or shaking, increased heart rate or palpitations, loss of bladder or bowel control and feelings of pain. If the phobia is serious and severe, even thinking about the phobic stimulus can trigger these symptoms.

Phobias are the most common type of anxiety disorder. They can affect anyone, regardless of age, sex and social background. According to the (American Psychiatric Association 2017), in any given year the estimated percent of U.S. adults with various phobias are:

- **7 to 9 percent:** specific phobia.
- **7 percent:** social anxiety disorder.
- **2 percent:** agoraphobia.

2.5 Traditional therapy for phobias

Cognitive behavioral therapy (CBT) has been shown to be effective for treating a wide variety of mental health disorders, including anxiety disorders (Chambless & Ollendick, 2001). CBT treatment for phobias is a short-term, skills-focused treatment aimed at un-pairing the patients' anxiety response from the feared object or situation by identifying problematic or irrational thinking patterns, and changing those thoughts and behaviors with new helpful and realistic ones when facing their fears. The complete course of CBT which can be provided individually or in group, is of 6 weeks to 6 months depending on the patient's level of disorder. Through this highly-targeted process of changing thoughts and behaviors, most people show significant improvement by their fifth session.

CBT varies from patient to patient, and is tailored to each person's unique needs. However, CBT for phobias typically involves some combination of the following components shown in Figure 2-3.

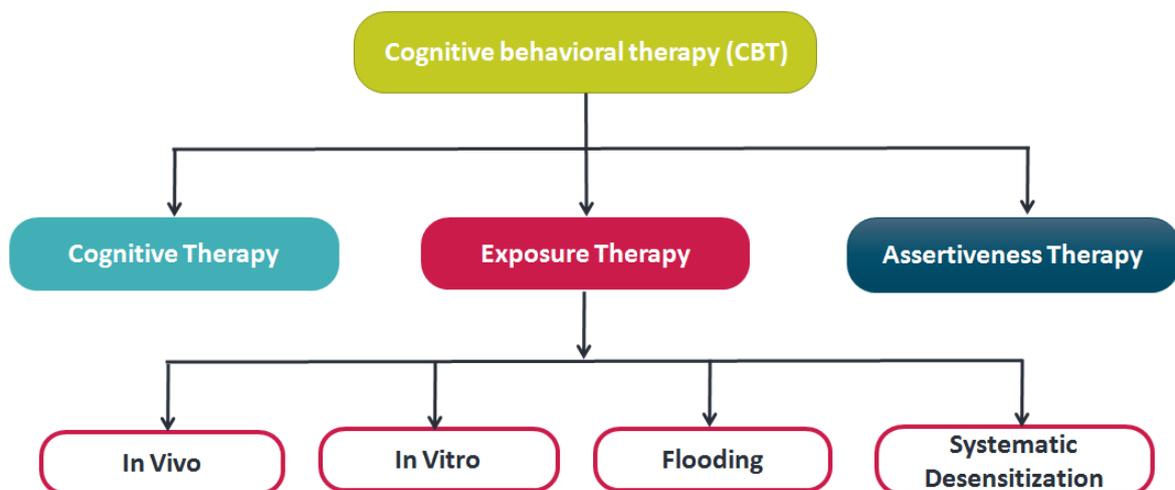


Figure 2-3: Block Diagram of CBT Techniques.

2.5.1 Cognitive Therapy

Cognitive therapy is a type of psychotherapeutic treatment that is based on the idea that the way we think about things affects how we feel emotionally and how we act according to the situation. This technique focuses on three main key parameters present thinking, behavior,

and feelings rather than on the patient's past experiences. Thus, it helps to identify the negative destructive thought patterns and replace them with more objective, realistic ones by communication, journaling, mental distractions and other strategies. This therapy has been applied to solve a broad range of mental problems including phobias, anxiety, depression, eating disorders, bipolar and addictions.

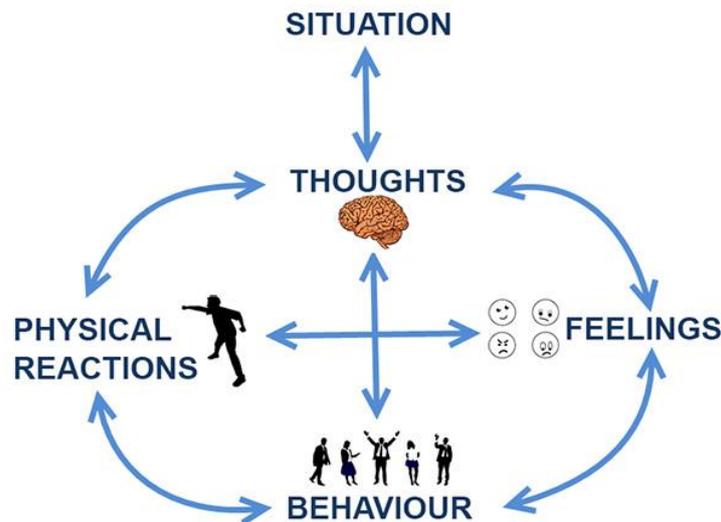


Figure 2-4: Thoughts, behaviors and feelings affection circle (Aaron, 2020).

2.5.2 Exposure Therapy

This therapy is based on exposing the phobic patient to the feared stimuli or the anxiety source. From a behavioral perspective, most patients avoid the phobic stimuli which doesn't give them the opportunity to learn how to tolerate the fear that will come down on its own with time when facing it, and that their feared outcomes often do not come true or are not as terrible as they imagine. Thus, the exposure therapies are designed according to the patient's condition to encourage him/her to enter the feared situations either in reality or through imaginal exposure in order to learn how to remain in those situations. In this type of therapy, the selection of situations are tailored based on the fear hierarchy that starts with mild anxiety-provoking stimulus and builds up gradually to the most frightened encounters.



Figure 2-5: Briana Clifford and Dr Sophie Li during an exposure therapy session for overcoming fear of spiders (Miller, 2017)

2.5.2.1 In Vitro

In this type, the counseling sessions are based on imagination of real world situations that triggers the anxiety symptoms. However, it can be difficult for patients who have a poor imagination, who avoid imagining their phobic-stimulus, or who tend to overwhelm themselves with images.

2.5.2.2 In Vivo

This treatment is also given by counseling sessions and it involves actually confronting the feared stimuli gradually in order to learn how to interact with it in real life. For example, suppose a patient has spider phobia, the therapist tries to convince him/her to look first at a picture of a spider and eventually with practice touches a large tarantula. The multiple sessions usually last a number of hours. Although a wide range of specific phobias respond positively to In vivo treatment, the dropout of patients can be a problem. Research has found that in vivo techniques are more successful than in vitro (Menzies & Clarke, A comparison of in vivo and vicarious exposure in the treatment of childhood water phobia, 1993).

2.5.2.3 Systematic Desensitization

This therapy involves exposing the patient to fear-evoking thoughts and images or to real life phobic stimulus, while pairing the exposure with relaxation techniques. Treatment using systematic desensitization consists of two steps for example, if the patient has acrophobia the therapist starts by giving him/her relaxation exercise such as meditation and then lastly expose him/her to the phobic stimuli to decrease the normal fear response. It is widely used to treat anxiety disorders and phobias but it tends to take longer than in vivo exposure.

2.5.2.4 Flooding

A more extreme behavioral therapy is flooding. In which the patients are exposed to the most frightening situations immediately rather than exposing them gradually to their phobic stimulus. It is based on the principle that fear cannot last forever, and eventually when the individual is unable to avoid their phobia and through continuous exposure, anxiety levels decrease. For example, a person with phobia of height would be asked by the therapist to directly jump from heightened building. Although flooding is considered an effective solution especially for specific phobias, it is highly traumatic for patients and causes a high level of anxiety. The experience is too stressful therefore many do not complete their treatment.

2.5.3 Assertiveness Therapy

Assertiveness can be defined as a statement in which one communicates and expresses oneself in a direct and truthful manner in interpersonal situations. This therapy is based on the principle that we all have the right to speak up openly and share our thoughts, feelings and needs with others, as long as we do respect their rights and dignity. Assertiveness training can be an effective treatment for people who have social phobias, speaking disorders and communication difficulties. The treatment is given by motivational sessions in order to build up the patient's self-confidence and teach him/her assertive behaviors and then practice them with the help of a professional therapist.

2.5.4 Limitation of CBT

In addition to the advantages of Cognitive Behavioral Therapy (CBT), it also has some limitations that affect the phobias treatment effectiveness.

- Attending regular CBT sessions with all the extra work is time consuming especially that the patient must follow the sessions properly without missing any of them.
- The patient must be motivated and their behavior must be serious during the therapy which is not always the case.
- Because of the organized nature of CBT, it may not be reasonable for individuals with more complex mental health needs or learning challenges.
- When the therapy takes place in the therapist's office the stimulus is often absent and the imagination cannot trigger the same response as the real life stimulus. In the other hand, when the patient is treated in a public place, the experience can be embarrassing, costly and physically endangering.

Following the above limitations we can observe that we can improve the traditional therapy by making it :

- Realistic, lifelike, immersive and convincing.
- Independent of the treatment environment.
- Respect the patient's privacy.
- Safe.
- Controlled by the therapist and/or patient.

2.6 Virtual Reality Therapy

Virtual reality exposure therapy has correspondingly been used to treat a range of disorders including phobias. This computer based simulation technology places the patient in a computer-generated world and exposes him/her to anxiety-inducing stimuli related to their phobia as if he/she were in a real situation. Through the sessions, the therapist guides the patient in different controlled environments and scenarios that provoke gradually higher levels of anxiety until he/she learns how to control automatic responses when facing the feared situation in the real world. This therapy that replaces traditional cognitive and behavioral

therapy, has demonstrated efficacy and has showed incredible results in the treatment of phobias, especially when the in vivo therapy may be difficult or impractical such as in height phobias and flying phobias.

2.6.1 Advantages of virtual reality therapy

Virtual reality therapy and its therapist-controlled, simulated environments for the treatment of phobias offer distinct advantages over the real exposure to stimulus. These includes :

- Greater safety and unlimited repetitions office (Rábago CA, 2011)– VR therapy provides controlled and standardized environments for a safe experience that can be repeated until the achievement of the therapeutic goals.
- Better use of therapy session (Resnik, Etter, Klinger, & Kambe, 2011)- The therapist expose patients repeatedly and gradually to their phobic stimulus until it is mastered without going into the real world, which shortens the treatment time required in comparison with traditional therapies.
- Easily scheduled, confidential sessions (Suarez, Ferreira, Nogueira, & Arocena, 2011)– Since the therapy sessions take place in the therapist's office and each one fits within the standard 45 to 50 minutes, patients can schedule multiple sessions within the same week and without the risk of being panicked or humiliated in a public place. Thus, this treatment is associated with fewer dropouts than live exposure, and it is less costly for the patient and less restrictive for the therapist who doesn't need to accompany the patient every time to be exposed to the real stimulus.
- Flexibility which can encourage more people to seek treatment. Indeed, one assessment of students with a fear of spiders showed that almost 90% would prefer VR exposure over in vivo exposure therapy (Garcia-Palacios A. , Hoffman, See, Tsai, & Botella, 2001)

2.6.2 Previous work on VR therapy for treating phobias

Many researchers have been worked for years on the treatment of phobias using VR. Albert Carlin of HITLab, Azucena Garcia-Palacios of Jaume I University in Spain (a HITLab affiliate) and the research team have shown that virtual-reality exposure therapy is very effective for reducing spider phobia. The first spider-phobia patient, nicknamed Miss Muffet, had suffered from this anxiety disorder for nearly 20 years and had acquired a number of obsessive-compulsive behaviors. When she finally sought therapy, she was able to reduce her fear through 10 one-hour VR sessions and she could hold a live tarantula, which crawled partway up her arm, for several minutes with little anxiety (Garcia-Palacios A. , Hoffman, Carlin, Furness Iii, & Botella, 2002). A subsequent controlled study was then made for other patients who suffered for years from spider phobia as shown in Table 2-1.



Figure 2-6: Miss Muffet demonstrates she is no longer afraid of real spiders after VR therapy (Garcia-Palacios A. , Hoffman, Carlin, Furness Iii, & Botella, 2002)

A team led by Professor Daniel Freeman from the University of Oxford's Department of Psychiatry has developed a VR application in which psychological therapy is delivered by a computer-generated virtual coach. Between Nov 25, 2017, and Feb 27, 2018, a group of individuals with acrophobia were enrolled and underwent randomisation, they were followed up at every time point, meaning that the treatment effect estimates were unbiased by missing data (Freeman, et al., 2018).

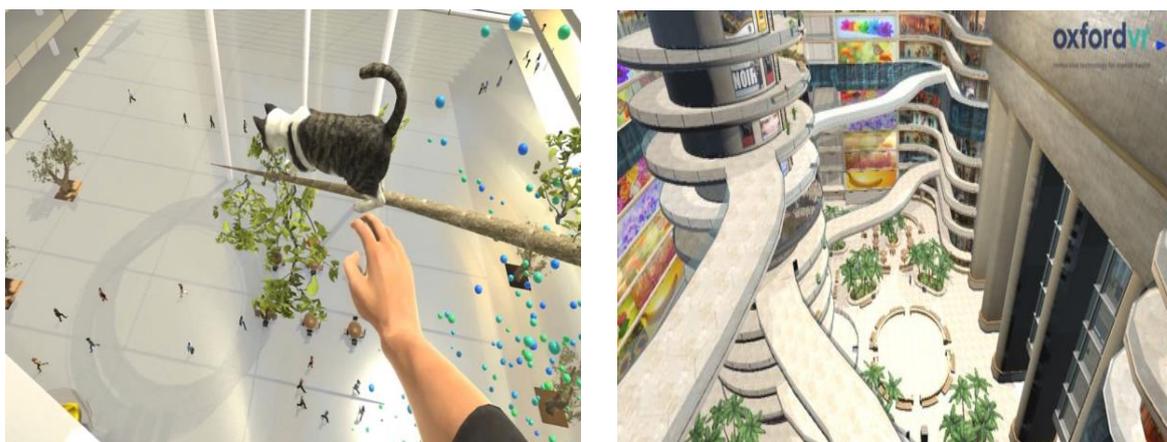


Figure 2-7: Scenes from the OxfordVR acrophobia therapy (Freeman, et al., 2018)

In the two previous studies the uptake was very high, which indicates that the VR sessions are an attractive technique that can motivate more people to seek treatment. Moreover, the final results proved that the psychological intervention delivered by the VR exposure therapy is highly effective for reduction of fear of heights and spiders. According to (Freeman, et al., 2018), the treatment effects produced were at least as good as—and most likely better—than the best psychological intervention delivered face-to-face with a therapist. The following table summarizes the studies and provides the principal factors affecting the results. A group of participants of each therapy were assigned to a control group (waiting list WL) which means that they don't receive any treatment, the others were exposed to the VR stimulus (VRE).

Table 2-1: Overview of (Garcia-Palacios A. , Hoffman, Carlin, Furness Iii, & Botella, 2002) study on spider phobia and (Freeman, et al., 2018) study on and acrophobia.

	Spider Phobia	Acrophobia
Study participants	23 took part in the study 12 in the VRE group. 11 in the WL group.	100 took part in the study 49 in the VRE group. 51 in the WL group.
Phobic stimulus	The treatment was composed of gradual exposure tasks. It started by the participants approaching the virtual spider in the kitchen. During the following session/s, participants picked up a virtual “spider vase” with their cyberhand. When they let go of the virtual vase, an animated spider with wiggly legs drifted to the floor of accompanied by a brief sound effect. Participants repeated this task until they reported little anxiety. During the last therapy sessions, the participants were encouraged to physically touch the virtual spider image with their cyberhand while their real hand explored the toy spider attached to a stationary Polhemus position sensor.	A virtual therapist, voiced by a real person and with a computer-generated avatar, guided the patients through the therapeutic work. They started by explaining their fear to the VR-coach. Then, they entered the virtual building and at each of the ten floors performed tasks, starting with standing near the edge while a safety barrier moved away or dropping a ball. It then progresses to more challenging problems, such as crossing the expanse on a bridge.
Before the VR therapy	The mean reported duration of their fear was 21 years.	The mean reported duration of their fear was 30 years.
The uptake rate	All the participants completed the sessions (an average of four, one hour VR therapy sessions).	90% of the participants completed the sessions (an average of two hours in VR over five treatment sessions).
Study Results	83.0% of the participants in the treatment condition met strict criteria of clinically improved and none of the patients in the waiting list condition did so.	All participants in the VR group showed a reduction in fear of heights, with the average reduction being 68.0%.

2.7 Conclusion

Phobias are not just a case of "nerves" that can be ignored or wished away but a very common type of anxiety disorder that triggers intense distress and irrational fear. People with phobias often shape their lives to avoid facing the anxiety-provoking stimulus which prevents them from functioning normally and changes the impact of their phobias from being annoying to severely disabling with an increase risk of experiencing dangerous panic attacks. Thus, receiving the right treatment and support is very important for those in need to overcome their phobias. Fortunately, virtual reality can immerse patients gradually into various phobic situations in a safe context until they get comfortable facing the feared stimulus in the real life which increases access to treatment. The focus of this chapter was the definition of phobias, their classification, their severity, and the different methods of phobias therapy. The potential of VR exposure therapy, its advantages and efficiency were also explained.

Chapter 03

System Description and Architecture Design

3.1 Introduction

Specific phobias have a high prevalence rate in epidemiological data, both in adolescents (Essau, Conradt, & Petermann, 2000) and in adults (Boyd, Rae, Thompson, Burns, Bourdon, & Locke, 1990). In the ECA Study, which was comprised of 20,000 participants, 4.7% of the participants have been diagnosed with acrophobia (Chapman, 1997). Another study by (Fredrikson, Annas, Fischer, & Wik, 1996) presented similar results with 6.3% of men and 8.6% of women fulfilled the criteria for a diagnosis of acrophobia. This disorder tends to evolve to chronicity (Burns, 1980) largely due to the pervasive avoidance of a wide range of height-related situations that form part of everyday living, which becomes with time incredibly dangerous to the social and emotional events in a person's life. Being afraid of heights severely limits the amount of activities that a patient can partake in, including simple tasks such as taking the elevator, using the stairs, climbing or even living or being in a high building.

Therefore, due to its high prevalence, chronicity, and cumulative social impact, it is imperative for an acrophobic to seek psychiatric assistance to overcome his fear and maximize his potential. As shown in the previous chapter, traditional methods have demonstrated their efficacy in the treatment of phobias including acrophobia. However, they suffer a high drop-out rate because of too low or too high patient engagement in treatment. In the other hand, Virtual Reality therapy holds great promise as a therapeutic tool for enhancing acrophobia treatment outcomes. With this in regard, and since the new generation of VR systems are becoming more affordable and accessible for therapists at the clinics and patients homes, we aim in our project to develop a VR therapy application that can help people with acrophobia to overcome their fear in a safe and realistic simulated environment.

3.2 Acrophobia

3.2.1 Definition of Acrophobia

Acrophobia, an abnormally excessive and persistent fear of heights, is a widespread anxiety disorder considered as a specific phobia affecting approximately 1 in 20 adults, with twice as many women affected as men (Juan, Baños, Botella, D, Alcañiz, & Monserrat, 2005). This

phobia triggers unpleasant symptoms which creates a logical barrier for people to avoid a variety of height-related situations, such as: stairs, mountain, terraces, bridges, elevators, plane trips, apartments and offices located in high buildings. Considering the striking breadth of feared situations and stimuli, People with acrophobia can experience a panic attack when being in high places and become too agitated to get themselves down safely. Thus, it is not surprising that individuals with acrophobia feel impaired and restricted in their movements, even in comparison to sufferers of other specific phobias (Menzies, 1994). If left untreated, acrophobia could significantly reduce the quality of the phobic life.

3.2.2 Virtual Reality Exposure Therapy for Acrophobia

Virtual Reality Exposure Therapy (VRET) is an exposure therapy using artificial or computer-generated sensory experiences, which elicits fear-related responses in an objectively safe context that resembles real-life situations and enables a patient to interact with three-dimensional virtual scenarios in the same manner as with the real environment (Rothbaum, Anderson, Zimand, Hodges, Lang, & Wilson, 2006). VRET provides advantages over traditional ET where time and environment are restricted and difficult to control, or that may potentially expose a patient to danger if delivered in vivo. When using a VR system, the therapist and the patient do not need to leave the consulting room. This preserves the patient's confidentiality, brings the benefit of not risking possible public embarrassment and implies a saving of time and money. Moreover, it allows for better experimental methodology and design as it improves protocol standardization, and control over duration and type of stimuli delivered (Norcross, 2013). Therefore, currently, VRET is seen as a viable alternative to exposure in vivo since it can provide an alternative tool to facilitate engagement for avoidant patients by offering the ability to render realistic height-related situations that are not easily accessible to the therapist and patient, e.g. a high-rise building, bridges etc. thereby functioning as an alternative mode of inducing exposure.

VRET was introduced more than two decades ago to treat fear of heights. (Rothbaum, Hodges, Kooper, Opdyke, Williford, & North, 1995) conducted the first published controlled study on VRE therapy for acrophobia. Participants were repeatedly exposed to virtual foot bridges of varying heights and stability, outdoor balconies of varying heights, and a glass elevator that ascended 50 floors. VRE therapy has shown significant efficiency in reducing fear of and improving attitudes toward heights, whereas no change was noted in the wait list

control group (i.e., those participants who did not receive any treatment but agreed to be included in the study as a comparison group). More importantly, 7 of the 10 VRE therapy patients who completed treatment willingly placed themselves in height situations in real life during treatment, although they were not instructed to do. Physical symptoms of anxiety described by the participants while in virtual height situations included sweating, abdominal discomfort usually described as "butterflies," loss of balance or light-headedness, heart palpitations, pacing, tremulousness or shaking, feeling nervous or scared, weakness in the knees, tightness in the chest, and feeling tense (Rothbaum, Hodges, Kooper, Opdyke, Williford, & North, 1995).

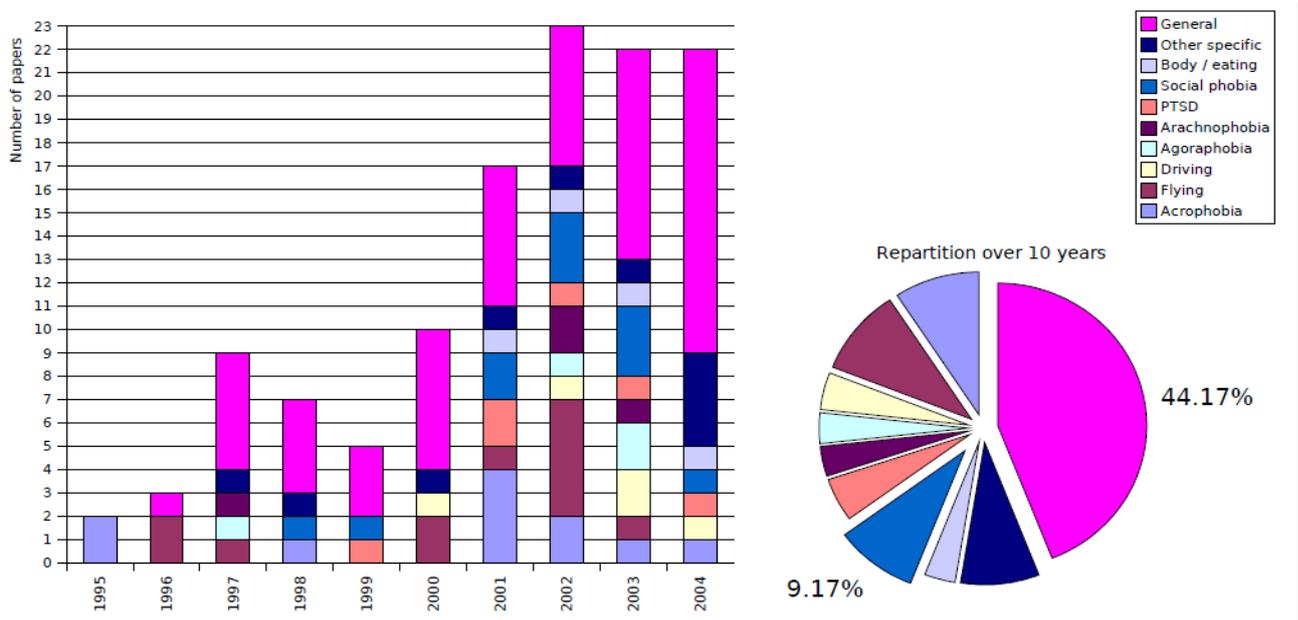


Figure 3-1: Past 10 years of publications in Virtual Reality Exposure Therapy (Herbelin, 2005)

3.3 Proposed System for Acrophobia treatment

3.3.1 System objectives

The proposed solution, and particular aim of this work, is the development of a Virtual Reality based Serious Game platform called "*AcroFree*" for overcoming acrophobia. Acrophobic patients will be exposed to the anxiety-provoking stimulus that resembles real-life situations in a 3D, high fidelity, virtual environment. Inside, they can face their fear of heights gradually and repeatedly in an objectively safe context where they can move and interact with

different simulated scenarios in the same manner as with the real world. In that in regard, this tool needs to encompass all capabilities of VR application: immersion, high-fidelity, presence and interactivity. Therefore, a focus on the visual design and creation of high fidelity, realistic assets, is required to improve the immersion of the patient and to trigger fear-related responses . Moreover, to help increase the effectiveness of the phobia treatment and challenge the participant to complete his VR therapy, *AcroFree* includes joyful environment, motivational tasks, and set of goals to be achieved.

3.3.2 System Architecture Design

In this section, we will focus on the overall structure of our system and its components. Our system architecture was developed in order to systematically include various determinants that influence the quality and thereby the success of the VR therapy application. It includes *virtual world* and *patient characteristics* as well as *the virtual world - patient interaction* and *moderating factors* (the resulting factors from the actual use situation) as determinants of a VR application’s quality. The factors selected for the empirical study that can validate the work are also provided as illustrated in Figure 3-2.

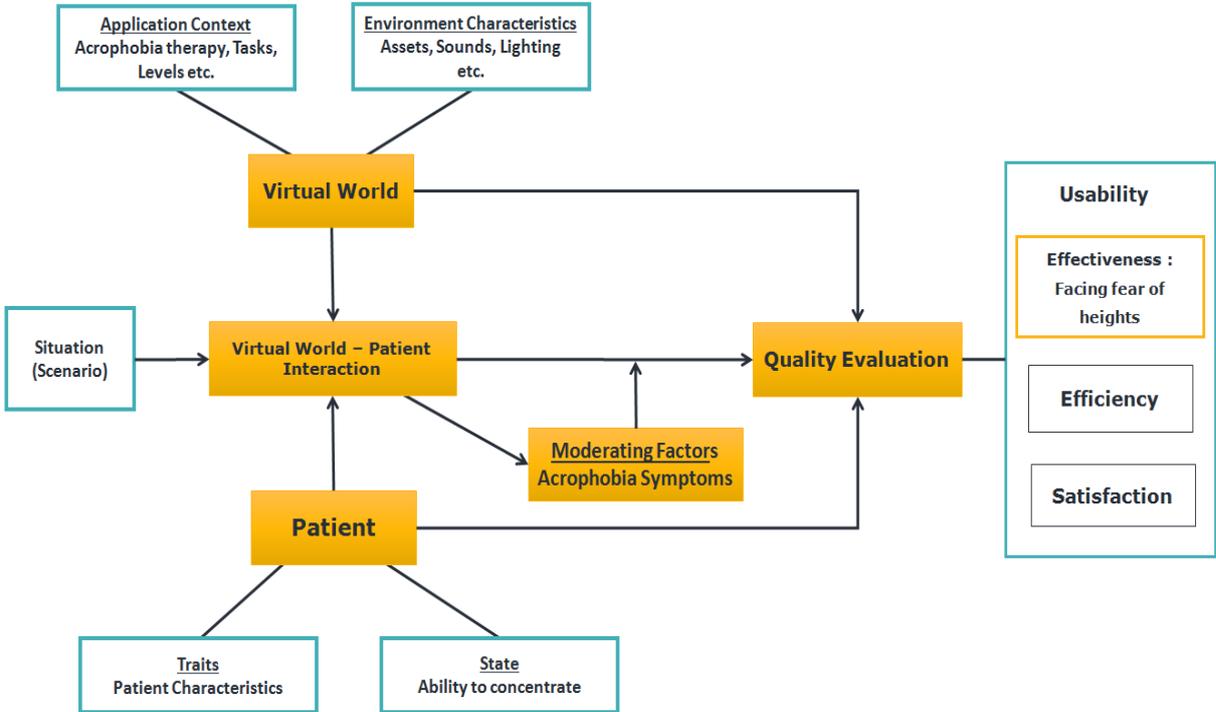


Figure 3-2: System Architecture

3.3.2.1 Virtual World

Our system is based on the true immersive virtual reality which means the patient entirely immerses into the computer-generated environment. Thus, and to break his connection with the outside world, we have chosen a number of features to be designed and manipulated according to the project's objectives.

- **Application context** : determines what the specific application serves for which is in our case reducing or treating the fear of heights. It also includes the specific tasks that have to be fulfilled by the patient as well as the task characteristics (e.g., several levels of difficulty) are deducted from the specific context.
- **The Environment Characteristics** : determines how the environment should be build to get ready for designing and rendering in the next phases. Since we aim to offer a convincing alternative therapy simulation that can trigger the same phobic responses as in reality, a suitable design is a necessary requirement for satisfactory use and outcomes of our system, for example, poor user interaction in VR can decrease performance. However, if the patient could experience a situation as lived through with a sufficient sense of presence, the treatment would be feasible. This requires a coherent environment with realistic objects.

3.3.2.2 Patient

The *patient component* covers biological, physical, psychological, and social characteristics of participants and is based on the human factors definitions by (Chapanis, 1991; Stramler, 1993) and. It includes human capabilities as well as human limitations that are relevant for safe, comfortable, effective design and use of our application. These factors can be further categorized as :

- **Traits** : the enduring personal qualities or attributes that influence behavior across situations. Relevant user traits are adaptability, prior experience with VR, susceptibility to immersion (Nash, Edwards, Thompson, & Barfield, 2000; Youngblut, 2003).

- **States** : the temporary internal characteristics. Several states have been researched in relation to VR applications: relevant are, for example, motivation to interact with VR, attention resources, and identification with an avatar. In our system, ability to concentrate on the task at hand in VR was chosen as a patient state (Nash, Edwards, Thompson, & Barfield, 2000; Youngblut, 2003).

3.3.2.3 Virtual World-Patient Interaction

The third component of our system architecture is the *virtual world-patient interaction*, representing the actual use of the system by a patient. Inside the virtual world, users navigate, interact with and experience different situations based on the chosen *scenarios*, as a result they display certain behavioral actions that are related to performance. Within the use situation, the interactions must be coherent to give the same psychological impact as in the real world.

3.3.2.4 Moderating Factors

The moderating factors directly result from the *virtual world-patient interaction* and they can influence the quality measures of a our VR application. This interaction can lead to intended effects (e.g., presence) or not (e.g., cyber-sickness). In our system, state fear of heights which involves the different acrophobia symptoms are the expected moderating factors to be triggered directly from the use situation as shown in the Figure 3-3.

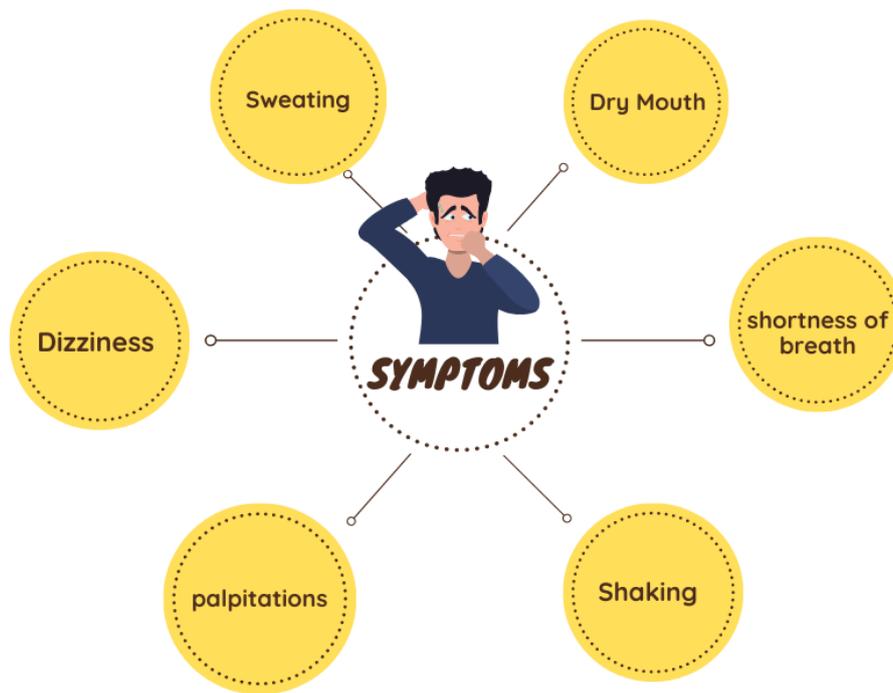


Figure 3-3: Expected responses when using AcroFree.

3.3.2.5 Quality

In our system, the *quality* represents the outcome of the VR application (see Figure 3-2). Quality is defined by the International Organization for Standardization (ISO) as the “degree to which a set of inherent characteristics fulfills requirements” (International Organization for Standardization 1998). The degree represents the level to which a product or service satisfies, which can be deemed, for example, as good or poor quality of a product. For VR applications, this can be broken down into further aspects of quality that are also known from a usability context (effectiveness, efficiency, and satisfaction; (International Organization for Standardization 1998)). An increase in these three quality characteristics is a measure of impact on usability, which can improve or degrade application usability. Each of the attributes are defined as follows :

- Effectiveness: degree to which the patient correctly and completely achieve the levels tasks.
- Efficiency: resources expended by the patient to correctly and completely achieve the game goals.

- Satisfaction: degree to which patient needs are satisfied by using the VR therapy application.

A VR therapy system shows high quality when the expected purpose of the application is fulfilled which means an increase in performance with as few resources as possible, and when system usage is satisfying for the users. In our project, the ability to overcome fear of heights virtually and then in reality is the measure of therapy effectiveness selected as outcome variable.

3.4 Phases of the methodology

We needed a methodology for creating the virtual reality therapy application consisting of scenario driven virtual environment. Therefore, we tried to develop a suitable approach for creating a stable and immersive virtual world with interactive objects based on our system architecture and the resources. The methodology is divided into 5 phases, see Figure 3-4.

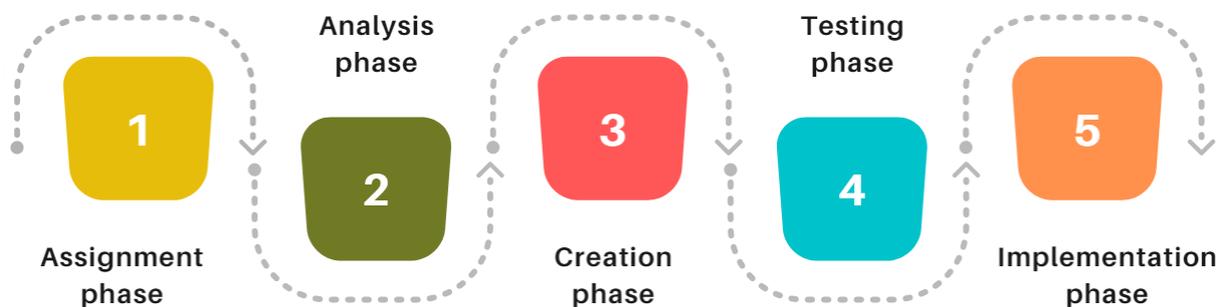


Figure 3-4: Phases of the methodology

3.4.1 Application Assignment phase

This phase was performed as carefully as possible and all the details were taken into account, as it's the foundation for further work. We started by developing an idea of the overall concept of the serious game application in order to describe the requirements and wishes that needed to be achieved. Clarifying the goal of the VR application, which is in our case overcoming fear of heights, was the most important part and the first task to be completed. Defining the target group is the second thing to be done. The virtual environment is very

different, depending on whether it's for children, adults or whether the target group is students, customers or workers etc. Patients with acrophobia are the target group of the project. Then we described how exactly should the environment look like including the objects, the sounds and the lighting etc, also what should happen after inputs from the users of the application, so we can set a detailed list of requirements for the development phase. The final step was to make the scenario draft that determines the plot, tasks, levels, setting of the virtual world and all the interactions between the patient and the fear-provoking stimulus in the environment.

3.4.2 Analysis phase

Here, we analyzed carefully the output of the assignment phase to shape the foundation of the whole application. List of objects and list of actions and activities are derived from the environment description and the detailed scenario. The objects were classified based on their appearance and functions. Defining the objects that would be animated within the use situation and their states was the next step. For example, the elevator can be ascending or descending with a closed door, but when it stops the door can be opened or closed depending on the situation and the user interactions. This means that there can be different layers of such states thereby we also decided the states that should be combined with others. After that, we assigned actions that leads the state changes to the objects. This gave us the ability to know which types of objects share the same actions and whether the action for two different kinds of object can be driven by the same script or not. All of this is summarized in different diagrams and flow charts.

Figure 3-5 illustrates the user's interaction with the VR system. When the user is ready, he/she select the scenario from the main menu and start a new level. Once already inside the scenario, the user can move freely around the environment and interact with it and he/she must fulfill a series of tasks to pass to a new level, restart the scenario or exit the game.

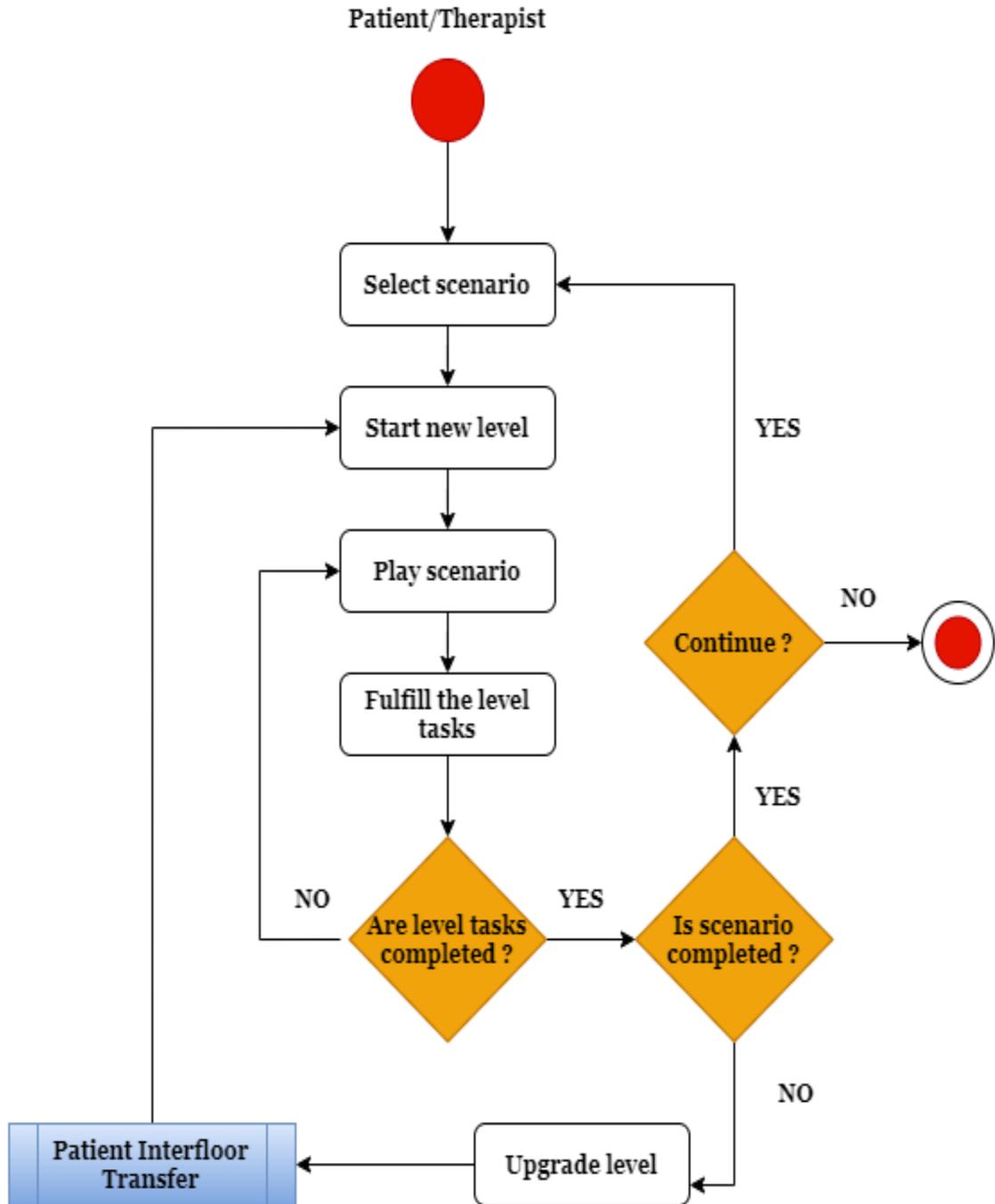


Figure 3-5: Activity diagram of the user/VR system interactions.

An algorithm flow chart of patient behavior with the elevator derived from the scenario draft is shown in Figure 3-6. If the patient has completed all the level tasks he/she can call the elevator and waits until the doors open. Then, he/she makes an inside request to pass to the next level and waits again until the door opens on the desired floor.

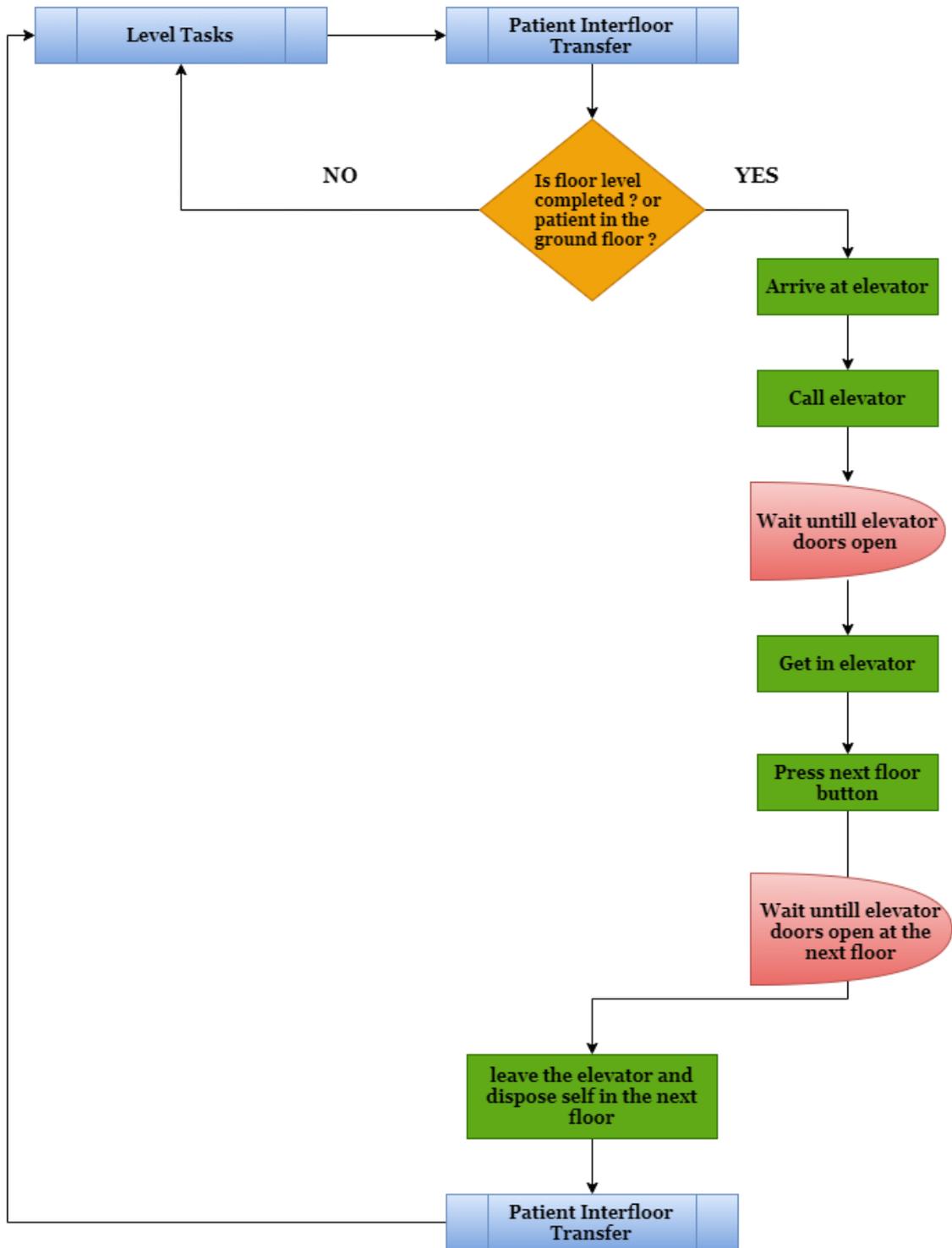


Figure 3-6: Algorithm of the patient/elevator behavior.

3.4.3 Creation phase

This is an extreme programming-like approach that consists of creating the assets of the virtual environment based on the list of objects and the scenario draft from the earlier phases, which means creating the small bricks that build the whole virtual world. There was many kinds of assets, scripts, texts, graphics, animations and sounds that needed to be created to end up with a realistic environment for overcoming the fear of heights. By graphics we mean the 2D graphics such as the graphical user interfaces GUI and the 3D models representing the different objects used in the environment architecture like the high building, the elevators etc. Animations are the basis for the interactions between the patient and those graphics in the virtual world. Almost all state changes are accompanied by corresponding animations which can accompany the state itself like a running escalator, or are based on the very nature of the objects, like the elevator door opening animation. Then we backed all the actions by various kinds of scripts that drives the virtual world. There are scripts to hold the state of the objects, scripts that change the states, scripts that leads the patient in his/experience and others. The main foundation for the scripts is the state diagrams made according to the detailed scenarios.

3.4.4 Testing phase

After creating our virtual world we started the testing phase as soon as possible. This included testing all the assets together, the scripts, the interactions and the overall feel of the environment in order to confirm that the work is progressing in accordance with the application requirements. We made sure that within the use situation, the patient with acrophobia can really be triggered by our simulated fear-provoking scenarios and buildings. Also we tested the understandability of the virtual environment and the controls.

3.4.5 Implementation phase

This phase consisted primarily of deploying the software application with the hardware and calibrating it for light and acoustic conditions. Calibration is very important for stereoscopic projection and haptic interaction because the patient must see the touch in the actual position so he/she doesn't lose the feel of presence. Final testing was of course conducted after deployment.

3.5 Conclusion

Virtual reality exposure therapy (VRET) has been used in the psychological treatment of acrophobia since 1995, and has come to dominate the treatment of numerous anxiety disorders. We explained in this chapter how creating height-related experiences where the acrophobic can face their fear in a simulated safe environment has proven its efficiency. We then presented our proposed approach that aims to offer patients and therapists an efficient exposure VR therapy application in the form of a serious game and we introduced the architecture design description of the whole system, including how it works and the detailed phases of the system development.

Chapter 4

Implementation, Results and Evaluation

4.1 Introduction

The creation of VR applications is quite different from the creation of a desktop application or a Web page. Moreover, virtual reality therapy application development for overcoming acrophobia in which the human factor is extremely important, is a complex process that requires strong skills in a variety of tools and techniques to reach the quality levels necessary for treatment success. Thus, the key principle is to develop it with a high-performance and low-power architecture. This includes software/hardware design which involves the use of prototyping tools, development environments, libraries and frameworks that are beneficial for creating a realistic height-related VR experience with all the interfaces, computer-human interactions and the logic behind them.

4.2 Technical Description

Before starting the creation phase of our VR therapy application, we first wrote a clear description of what the serious game should be and what it should be able to offer to the patient, we then extracted from that all the application objects, actions and requirements, as a foundation of the design process. In that regard, we decided that the game should be used by the patient in conjunction with the therapist and should run on personal computers. For an efficient experience, different 3D models and graphics should be created to achieve a high degree of fidelity and realism. Spatial sounds are also needed to add atmosphere, emotion and fantasy to the overall environment, including background music, sound effects from objects and actions, a therapist voice that guides the patient through the game, and motivational effects when completing the scenario tasks, like applause and cheers. Within the use situation, the patient should be able to view, navigate and interact with the virtual world, such as activating elevators and grabbing objects. This requires realistic animations and interactions that respect the laws of physics, such as gravity and collisions, to maintain the feeling of presence and enhance the patient immersion. As a form of a self-therapy application, the patient can also control the experience by interacting with the graphical user interface to start the scenario, pause the game flow if he/ she is getting too agitated, or quit the game entirely at any time.

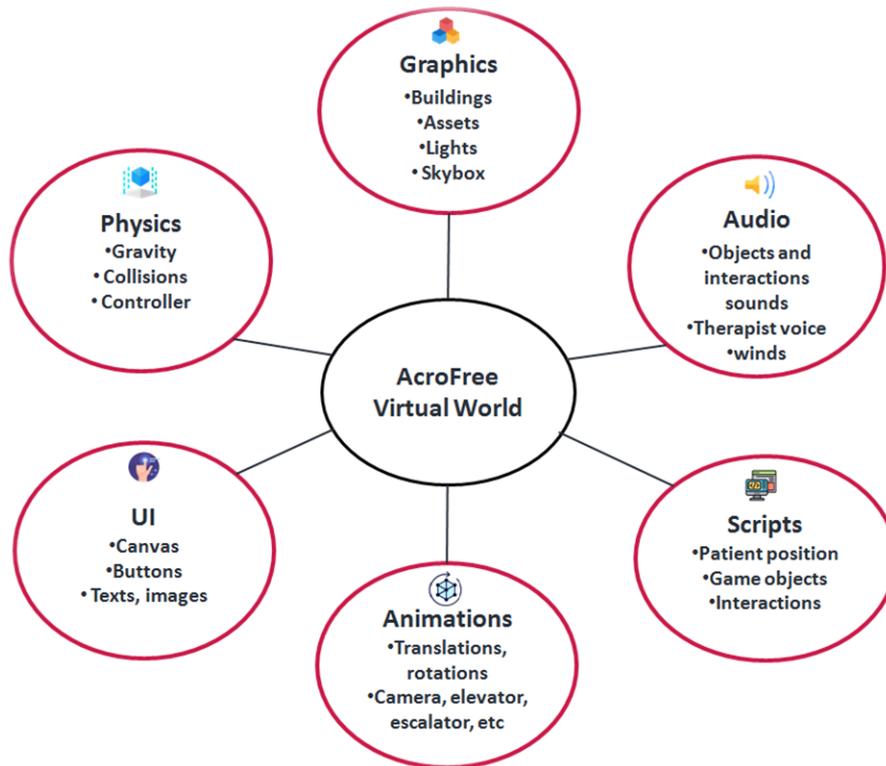


Figure 4-1: Technical description of the application requirements.

4.3 Development Environment

4.3.1 Hardware

For the hardware we are using a high-powered PC with the HTC Vive virtual reality headset developed by HTC and Valve and released in April 2016. It includes a headset with a front-facing camera, two handheld motion controllers that offers realistic HD haptic feedback, two base stations for a 360-degree play area tracking coverage, a small box to bridge the headset with the machine, and the necessary peripheral cables. The headset uses "room scale" tracking technology, allowing the user to move in 3D space and use the controllers to interact with the environment. The base stations must be placed at opposite corners of the room with a clear view with each other, shooting fields of lasers for motion tracking. Moreover, the room-scale setup, that sets the virtual boundaries of VIVE, needs a minimum play area of 2 m x 1.5 m (6 ft 6 in x 5 ft).

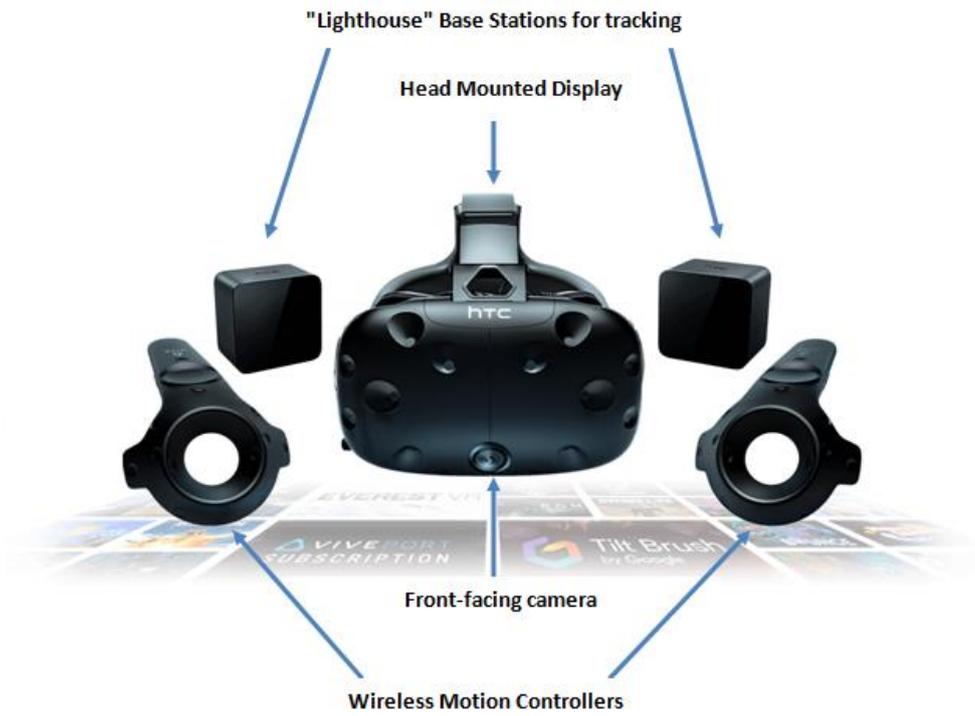


Figure 4-2: Components of the VR system HTC Vive.

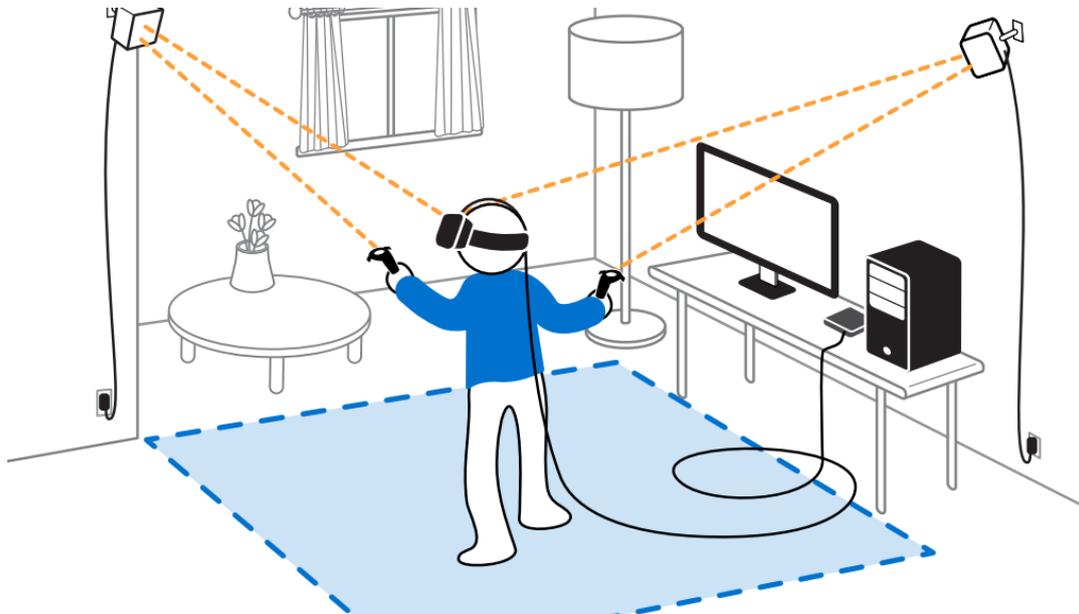


Figure 4-3: Schematic setup of the VR system HTC Vive with interaction area (blue) (Michael & Chris, 2018).

4.3.2 Software

4.3.2.1 Steam VR

The Vive requires the use of Steam and SteamVR which is the ultimate tool for powering and controlling the VR experience through a number of features including the room setup that defines the play area, and the device management that gives the user the hand to update firmware, pair new devices, change audio settings, mirroring, and customize features like motion smoothing. Setting up the VIVE with SteamVR is a simple process. The application is really well designed and guides the user through each step from calibrating the floor to tracing out the play area, to testing that everything is connected properly. Once the SteamVR setup is completed, the Vive does an excellent job of providing a simultaneously navigation in virtual and physical reality.

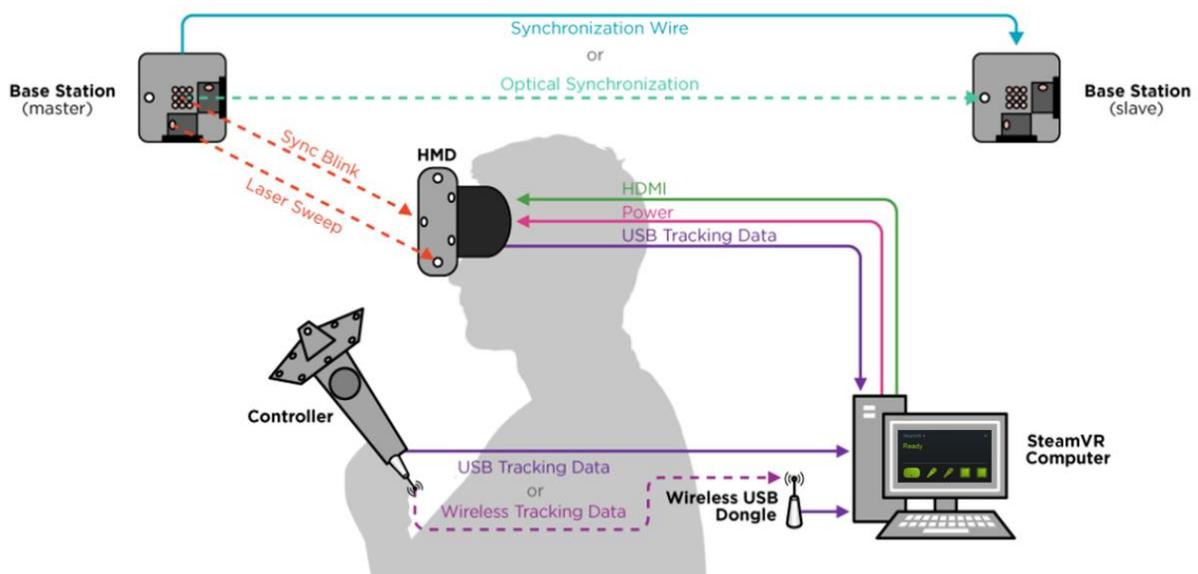


Figure 4-4: SteamVR Tracking System Overview (Morgan, 2017).

4.3.2.2 Unity3D

To satisfy the VR therapy requirements and the above criteria, we have chosen Unity3D game engine to develop our application. Unity3D is a powerful cross-platform 3D engine that gives the users the ability to create 2D and 3D games and applications for mobile, desktop, the web,

and consoles. It is the world's largest and number one game development platform that supports all main VR devices and file formats used by different 3D building applications including Cinema4D, 3D Max, Maya, and more with all the rigging, materials and textures intact. Unity also supports all common image file formats, including PNG, JPEG, TIFF and even layered PSD files directly from Photoshop. When it comes to audio, Unity supports WAV and AIF, ideal for sound effects, and MP3 and OGG for music. The primary programming language used to write commands for game objects, the animations and the overall logic of the virtual world is C# "object-oriented scripting language". The usage of this tool was suitable for realizing creative and realistic height-related environments, laying out the application levels, creating graphical user interfaces, controlling animation, writing the scripts and organizing the project.

Unity Plugins

Since one of Unity's biggest pros is the huge community-based asset store for free and paid 3D objects, materials, textures, and audio files, we used it to access more features of Unity3d game engine efficiently.

- The SteamVR plugin is an indispensable Unity asset for building the VR environment and connect it with the Vive. It provides a library of VR prefabs, a standard application programming interface (API) and an Interaction System that offers concrete examples of interacting with the virtual world and the related APIs. This helps managing three main things: loading 3d models for VR controllers, handling input from those controllers, and estimating what the hand looks like while using those controllers.
- Another asset that took a central role for developing our therapy application is the VRTK toolkit. It is a collection of useful scripts and prefabs that provides a high-level interface for the creation and manipulation of virtual objects. It helps the users to rapidly setup the VR controls in Unity and allows them to add common VR functionalities and actions like touching and grabbing with the controllers, interacting with Unity3D UI elements through pointers, navigating the scene by means of teleportation etc.

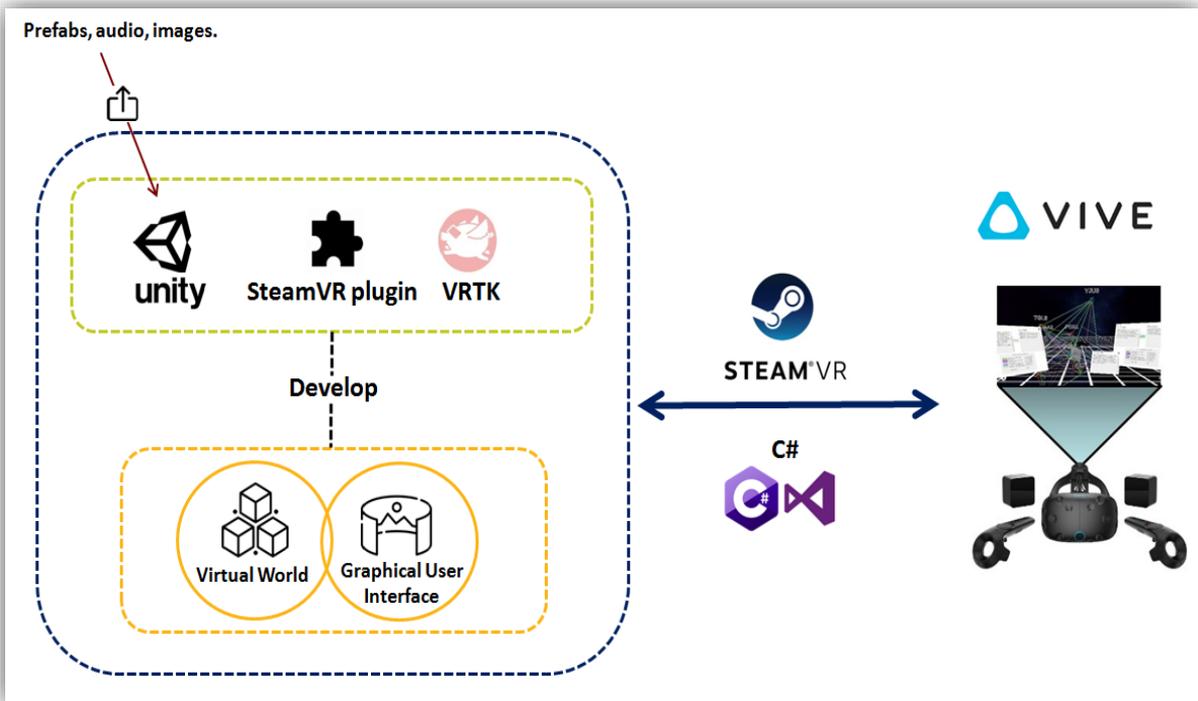


Figure 4-5: Diagram of Software and Hardware work flow.

4.4 Development Process

Within the use situation of the serious game, the HTC Vive device captures its own movement through its Sensors, which transfer them to the system. These input are then caught by the system's Input Event Listener, which recognizes them and passes the appropriate events to the Event Handler. After that, the Event Handler sends functions both towards the GUI system and the Scene Manager that contains everything that is visible to the patient. The GUI functions are then used to navigate and interact with the interface. Additionally, the GUI system notifies the Scene Manager for the visibility status of all parts of the VR interface. The system functions interacting with the Scene describe animations and game object behaviors which can be for example opening a door or activating an escalator. Once everything has processed the information given, any updates are passed to the renderer, so the updated scene can be represented visually. This visual result is then returned to HTC Vive headset device so it can be displayed to the patient. A Data Flow diagram illustrate the whole process in Figure4-6.

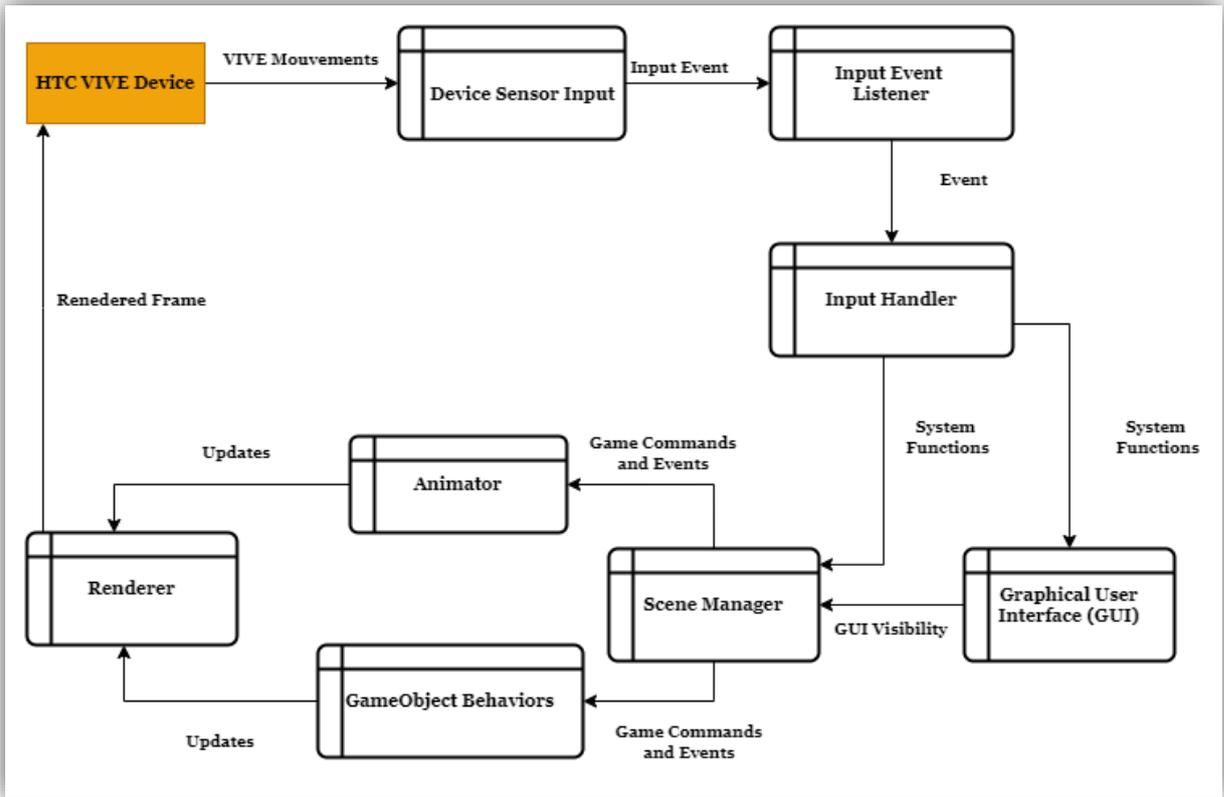


Figure 4-6: Data flow level 1 Diagram.

4.5 Prototype Content

4.5.1 Graphical User Interface

The initial action that the user can take upon starting the game is navigating the Main Menu, of the Graphical User Interface. This curved canvas is located inside the scene and it consists of two panels as shown in Figure 4-7. Inside the virtual environment the patient can also pause the scenario upon pressing the menu button of the controller which enables the In-Game user interface. This canvas allows the patient to restart the whole scenario, check the help panel, or exit the game entirely.



Figure 4-7: Main Menu User Interface.

The patient can choose to learn more about the controllers gestures by selecting the help panel, or he/she can choose directly to go into the scenarios (see Figure 4-8).

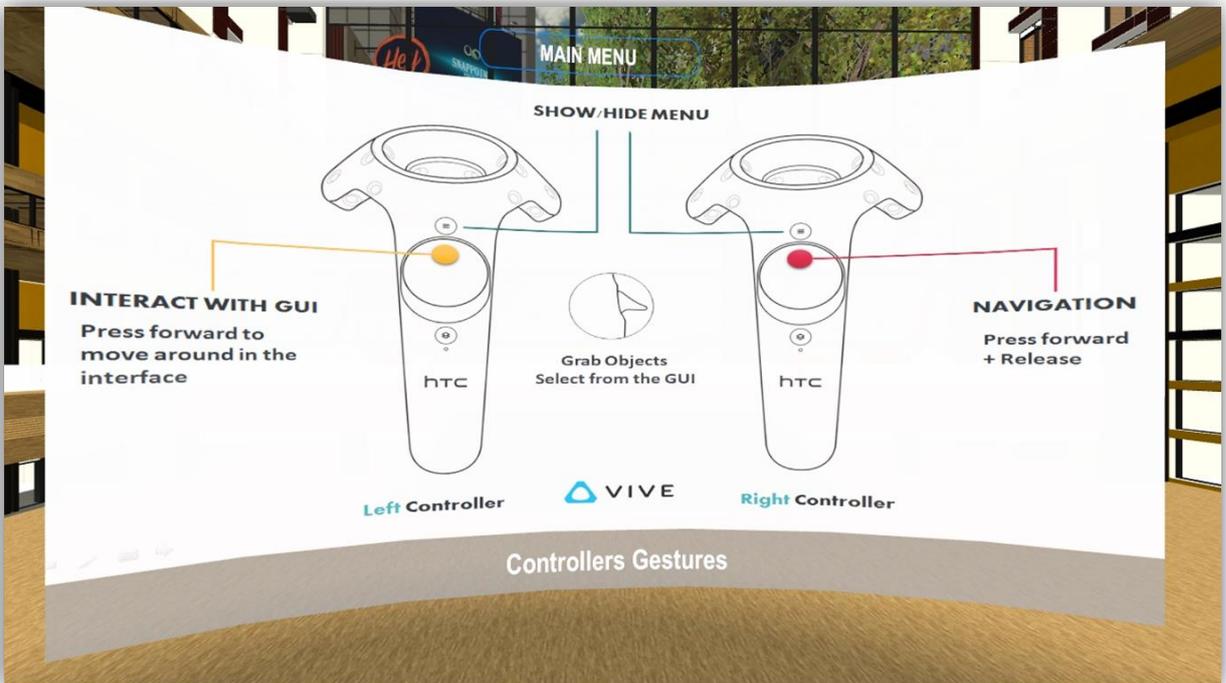


Figure 4-8: Controller Gestures.

For the selection, the patient has to press the touchpad and move the pointer around the interface then press the trigger button to confirm the action. A sequence of steps are required to implement this:

1. Inside our Unity project, we first created a VRTK Setup as a template to use for the interactions between the controllers and the objects. Then, we parented it with the SteamVR prefabs needed, which are the [*CameraRig*] and [*SteamVR*].
2. We set up the *Scale Render Viewport* of the Play Area to adjust the render resolution, and the *VRTK_Height Adjust Teleport* as the base teleport method for the whole scene.
3. The controllers setting up necessitates a series of scripts that manages all the basic interactions events with the virtual environment. We also added a Straight Pointer Renderer to the left controller that emits a straight line to the interfaces panels for the GUI navigation with the touchpad press as the activator in the parameters.
4. Once the Play Area and the Controllers are all ready, we set up the objects participating in the game scenarios and the GUI panels as interactable objects and we added a specific tag, a *BoxCollider*, and a *RegidBody* to each one of them to activate, test and validate the interactions with the controllers. For the grab event we chose the trigger button which snaps the object to the controller and releases it when the button is released.

Every GUI interactable panel is attached with a script that is activated with the trigger button to provide functionality, such as the "Interface Navigation" script, that manages the interactions between the controller and the panels of the interface, the "Show Menu" script, that handles enabling and disabling the user interfaces and the "Start Scenario" script, that covers all the actions needed to initialize the scene.

4.5.2 Designed Environment

Since the main goal of the serious game 'AcroFree' is helping people who suffer from acrophobia to overcome their fear, the most important part of the project was mainly focused on creating different situations with a realistic sense of height in which the patient learn in a safe context how to control their phobic responses when facing the feared situation in the real world. A 3D environment was designed along with an assortment of other assets and models, such as roads and textures, to be used for an attractive and interactive scene. Various of sounds are also used in the project to enhance the feeling of realism and immersion, such as the relaxing music during the graphical user interfaces, the elevator sound, the winds, the trees etc. Inside the environments the patient is guided gradually by a therapist voice in Arabic to face the simulated height-related scenarios.

A joyful interior of a tall office building with a lot of floors and a panoramic glass elevator was designed as the first virtual environment of the serious game. In order to challenge and motivate the acrophobic patient, we developed 3 levels in which he/she must complete a series of entertaining tasks that gets harder progressively depending on the floors height.

4.5.2.1 Navigation inside the building

When the scene of the first environment is loaded, the patient will be asked to move inside the building and observe what is around from the ground floor as a mental preparation before starting the height-related scenarios. Therefore, we added a *Bezier Pointer Renderer* to the right controller that emits a curved line to a point on the ground surface for the navigation inside the building and we added the touchpad press as the activator in the parameters. In the *PolicyList* script attached to the *Bezier Pointer* we created a tag named "floor" that determines the navigation area allowed inside the environment.

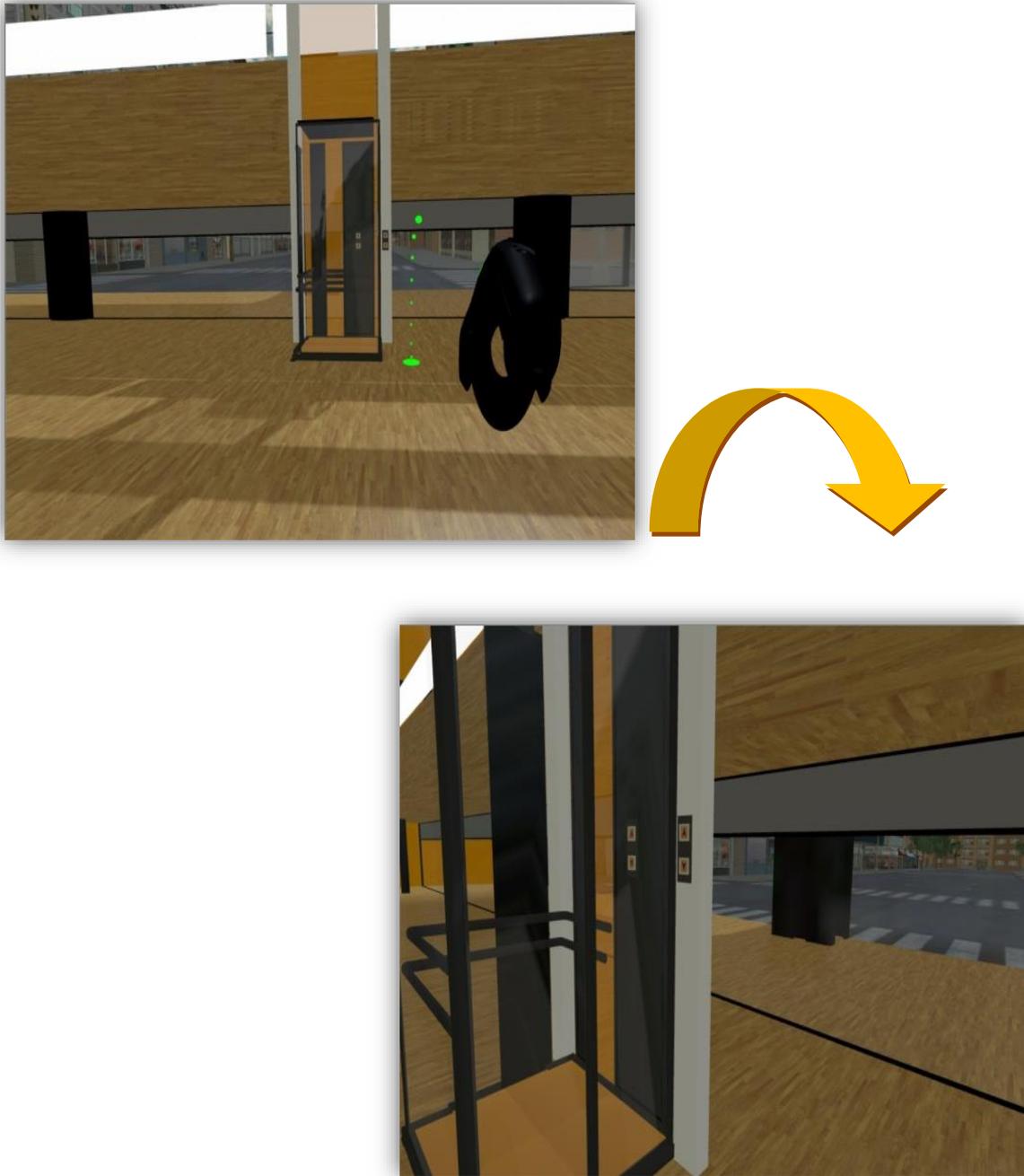


Figure 4-9: Patient navigation inside the building (Teleportation using the touchpad).

4.5.2.2 Elevator Animation

For the elevator scenario, we started by creating the elevator animations: ascending/descending and doors opening/closing, using Unity Mecanim's state machines and scripting to manage all the sequences of the animation clips. The State Machine flow is dependent on external variables, for example, a Boolean “isActivated”, a float “speed”, and

the animations' exit time. The elevator buttons were then set up as interactable objects and the controller trigger button was chosen for the interactions.

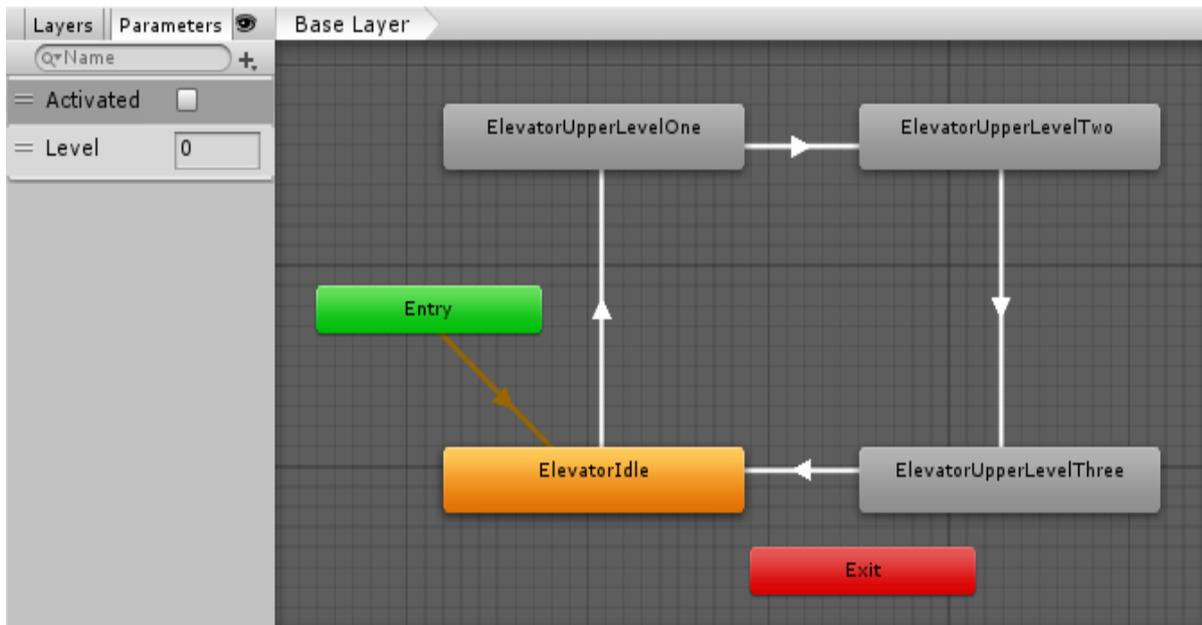


Figure 4-10: Elevator State Machine (Ascending/descending).

When the patient activates the elevator, the *[CameraRig]* becomes a child to the elevator *GameObject* until arriving to the next level. Then, it returns back to its *VRTK* old parent.

4.5.2.3 Interactions Mechanism

Since the goal is not only to simulate the sense of height but also to expose the patient to life-like situations to teach him/her how to adapt with them in their daily activities, we chose familiar tasks that are about returning specific objects to their places when faced with height views.

In order to create the zones where the objects are supposed to be dropped, we used the *SnapDropZone* *VRTK* prefab for each object and we provided it with the model highlight to generate the outline which determines its final position, rotation and scale. We chose to leave the highlight object always active with a red color to guide the patient. Once the valid object enters the *Snap Drop Zone* trigger collider, the highlight color changes to green to notify the patient and when he/she releases it, it will be snapped into place.

4.5.2.4 Application Levels

- **Level 1**

The first level starts by calling the elevator that takes the patient to the 4th floor. When he/she arrives and the elevator doors are open, he/she will be asked to enter an office room designed with a panoramic glass walls overlooking other rooms, floors and buildings from the city as a height reminder.



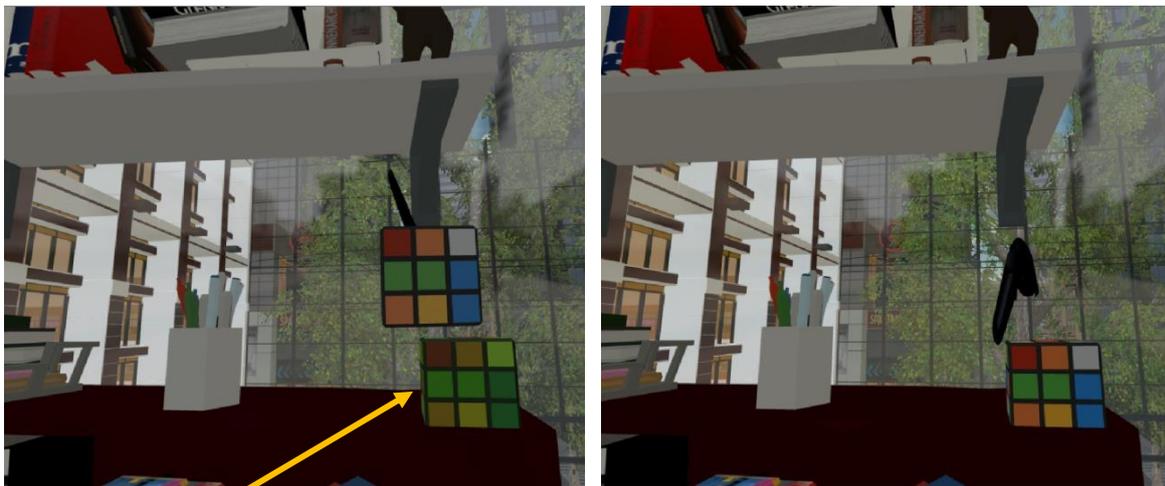
Figure 4-11: The exterior of the office room.

In order to trigger fear-related responses, the task of this level is walking around the room to return back three interactable objects to their places that are attached to the glass wall, the books and the Rubik's cube to the small library and the doll to the shelf. After completing the task, the elevator will be ready to take the patient to the next level.



Figure 4-12: The office room before completing the tasks (The circles illustrate the interactable objects).

The patient approaches to the glass wall to return the objects back which is a challenging step for someone with an intense fear of heights.



The highlight color changes to green

(a) Returning back the Rubik's cube to the library attached to the glass wall

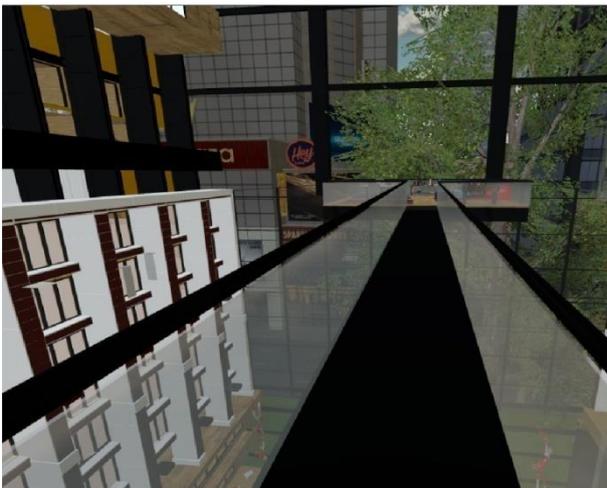


(b) Returning back the doll to the shelf attached to the glass wall

Figure 4-13: Patient view while doing the level 1 tasks.

- **Level 2**

When the elevator arrives at the 7th floor, the first task of the second level is asking the patient to take an automatic flat escalator with a medium speed that will allow him/her to observe the whole environment with a sense of height to cross from the walkway to an open breakout space which has no walls but only glass edges.



(a) The flat escalator



(b) the breakout space

Figure 4-14: The level two patient view.

Like the first level, the patient will be asked to return specific objects to their places, but this time he/she must move to the edges which will trigger higher level of anxiety. The Figure 4-15 illustrates different interactions between the patient and the level 2 objects when doing the tasks.



(a) Returning back the Rubik's cube to the library attached to the glass wall



(b) Returning back the books to the library attached to the glass wall

Figure 4-15: Patient view while doing the level 2 tasks.

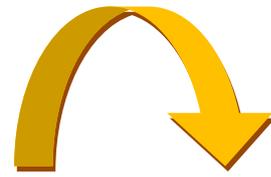
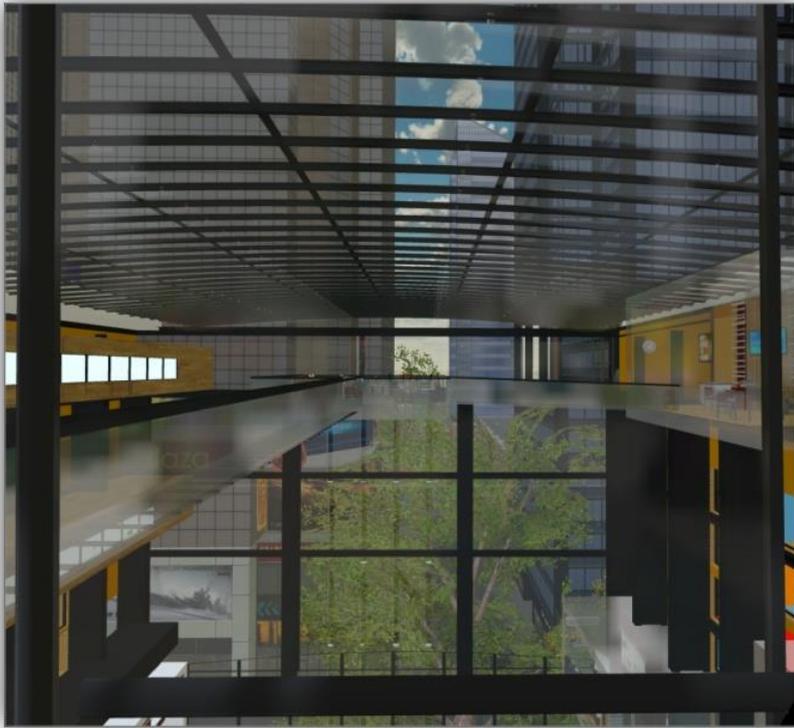
Once the tasks are completed, the escalator will be activated to take him/her back to the elevator. the Figure 4-16 illustrates the breakout space with all the objects in their places.



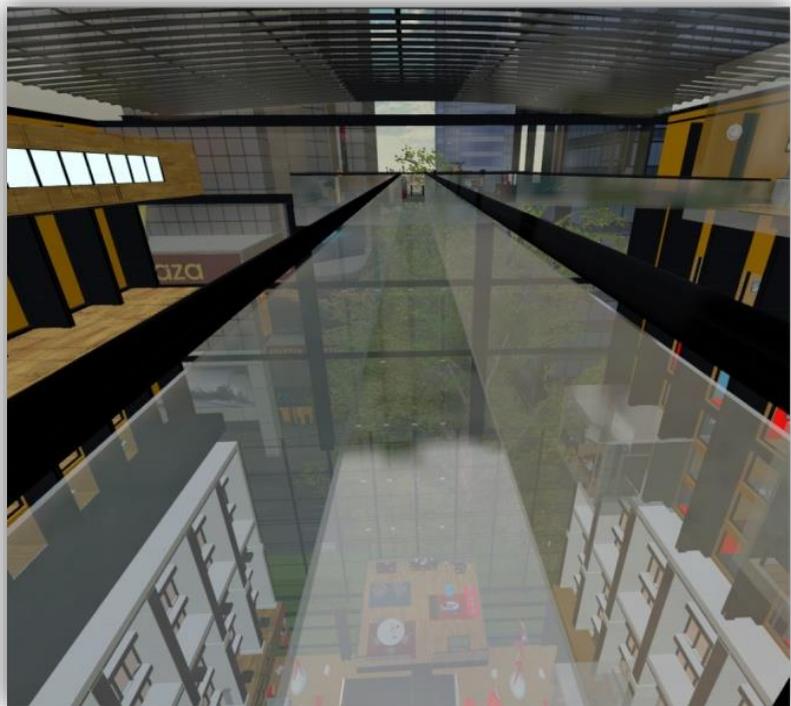
Figure 4-16: Breakout space after completing the level 2 tasks.

Level 3

The final level of this environment takes place in the 10th floor and it starts by asking the patient to cross a panoramic glass bridge from the walkway to a panoramic breakout space with glass floor and edges. To cross it, the patient has to focus on the path which will increase the anxiety responses and push him/her to face the fear step by step.



(a) The elevator view



(b) The path to the breakout space

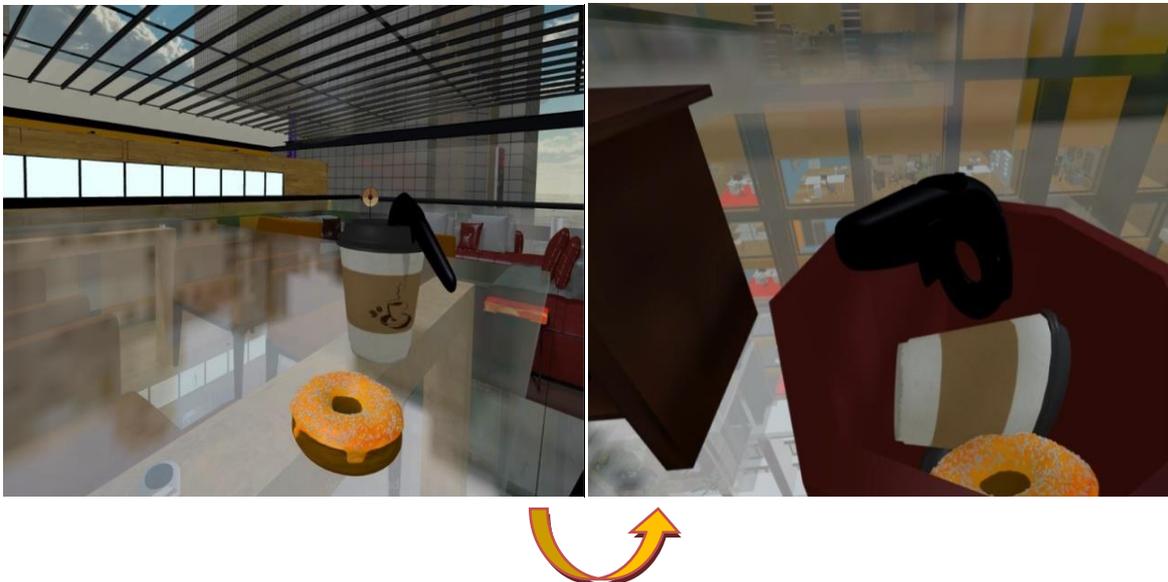
Figure 4-17: Patient view of the glass bridge of level 3.

Then, he/she will have to return the books that are all around the space and the Rubik's cube to the small libraries that are attached to the edges, throw the coffee cup and the donut in the mini trash can, and finally cross another glass bridge holding the coffee mug to the office kitchen in order to

put it in the sink. When doing the tasks, the patient needs to look closely to the objects which will expose him/her to different height views as shown in the Figure 4-18.



(a) Taking back the book from the glass floor to the side table



(b) Throwing the coffee cup to the garbage can attached to the glass edges

Figure 4-18: The level 3 tasks in the breakout space.



Figure 4-19: Crossing through the glass bridge to the office kitchen.

Once all the tasks are successfully completed the patient can go back using the elevator to the ground floor and the In-Game interface appears so he/she can choose to restart the environment scenario, load the next environment, or exit the game.

4.6 Application Usability by the therapist

Using AcroFree, the therapists exposes the acrophobic patients to the height-related environments while observing their experiences and fear responses in the virtual world in order to provide judicious cognitive feedback. The behavioral and affective observations determines the highest anxiety provoking situations for a particular patient and it includes :

- The time that the patient takes to complete each task.
- Fear questionnaires before, during and after the VR sessions to measure the levels of behavioral avoidance and distress.
- Using heart rate sensors and observing the patient symptoms and interactions during the exposure therapy.

Meanwhile, the scenarios can be repeated as much time as needed until the patient is comfortable with their response and the level of anxiety decreases

4.7 Conclusion

The primary goal of this chapter was to present the implementation mechanism and results of our proposed VR therapy application. We started by explaining the technical description of our system. The development environment that encounters the hardware and software integration was then introduced. The next section clarified the development process and data flow. Finally, we presented the prototype design and content which involves the final virtual environments, the graphical user interfaces and the interactions during the therapy scenarios.

Conclusion and Perspectives

5.1 Summary

Over the past decade, virtual reality technology has emerged in the mental health sector and proved its efficiency as a powerful exposure therapy for several types of disorders including acrophobia which is one of the most common anxiety disorders. Worryingly, the intensive fear of heights results in significant interference with the activities of daily life and may increase the risk of developing other mental health problems and major depression. Immersing the acrophobic patients in safe simulated fear-provoking environments can fortunately motivate them to seek treatment and overcome their phobia.

In the light of above mentioned optimistic potential of virtual reality exposure therapy for treating acrophobia, and regarding the limited access to traditional psychological treatment, a VR serious game application that takes advantage of the new technologies was devised in this project as a tool that can be used by patients and their therapists for treating this disorder. Height-related situations were created with different challenging tasks that provoke gradually phobic responses and motivate the patient to face their fear repeatedly in a safe context.

The prototype that supports the HTC Vive headset was developed in Unity Game Engine along with different libraries and plugins. In the development process, and after doing more research on the traditional exposure therapy, we wrote a series of entertaining scenarios that are familiar to the patients daily activities. We then focused on the design of a 3D life-like virtual environment where the patient can feel the sense of height. In order to implement the scenario draft, we moved to the Virtual World-User Interaction phase where we linked the environment with the headset and the controllers in a coherent way to maintain the feeling of presence during the whole experience. Moreover, we added a therapist voice that guides the patient through the game levels, along with a variety of other sounds to reinforce the sense of immersion. Finally, an interactable Graphical User Interface was developed to control the application.

Unfortunately, due to the Covid-19 pandemic and the social distancing, the psychological evaluation of the application outcomes on real acrophobic patients was postponed.

5.2 Future Work

During the writing of this dissertation , we have been able to observe that with the growth of VR technologies, immersive 3D simulations are now ready to move from specialist laboratories into clinics to increase access to the best psychological interventions for mental health disorders. Therefore, we believe that our application can provide rich and effective clinical assessments in the near future. The first step towards this goal would be to test and validate the usability and efficiency of the whole system with a therapist. To be more precise, we have determined to evaluate the effect of "*AcroFree*" on a group of acrophobic patients and write a comparative study before and after the VR sessions as a verification of our results in the therapeutic practice.

In addition, we would like to enhance the virtual world realism in order to simulate similar phobic situations as the real life experiences. This includes improving the visual realism in the static and dynamic aspect which has two components : the geometric part that consists of the virtual objects and the illumination that refers to the fidelity of the lighting model. Moreover, there is a number of hardware technologies that could be used to further improve the immersion of the patient, such as the 3dRudder feet motion controller, the Leap Motion tracking device, and the Vive tracker.

Apart from that, the application can be expanded to a software platform for the treatment of various other anxiety disorders with more levels and scenarios. A database will be added in which all the patients profiles and sessions results will be stored to be evaluated later by the therapist. After collecting enough data, the database can be used to train an AI virtual therapist that have its own avatar to communicate inside the virtual world with the patients, guide them and track their progress.

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