Proceedings of the 5th International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/134/2025.LD21576

Research on Psychological Treatment of Depression Based on Virtual Reality Technology

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Abstract: Depression is one of the most diagnosed mental illnesses in modern society, with leading causes such as psycho-trauma concerning interpersonal relationships, primarily relationships and familial dynamics, and both physical and psychological disturbances resulting from protracted exposure to stressors. Former research explicitly proved that virtual reality technology is likely to succeed as a major treatment medium for psychological disorders, primarily due to the fact that it is immensely immersive, interactive, and private. However, very little research is available in the literature regarding the treatment through VR, and exposure-based therapies of real-life landscapes. This paper presents an effort in an such direction: using VR technology for the treatment of depression via virtual rehab landscapes and VR exposure desensitization training to reduce emotional stress and enhance the treatment effect. It found that the viewing of virtual natural scenes resulted in significantly improved moods of the subjects and reduced their stress, with increased interactivity being more effective. One study observed elevation among the patients, where the degree of anxiety also decreases gradually eventually leading to better tolerance of treatment and treatment effectiveness. All these findings confirm the claim that such virtual natural environments and exposure desensitization trainings would be effective for depression treatment because they allow for a new pathway of non-pharmacological interventions.

Keywords: Depression, Virtual Reality (VR), Exposure Therapy, Emotional Stress, Non-Pharmacological Interventions

1. Introduction

Depression is primarily caused by two key factors [1]. The first is trauma experienced early in life, particularly within partner or family relationships, which leads to physiological changes such as sensitization of the hypothalamic-pituitary-adrenal axis. This sensitization results in hypersecretion of adrenocorticotropic hormone, abnormal cortisol secretion, and impaired glucocorticoid feedback regulation. The second cause is prolonged exposure to stressors [2]. Extensive research has revealed that stress plays a major role in the pathogenesis of depression [3]. On exposure to stress, the rise of norepinephrine levels in the brain occurs rapidly. However, prolonged stress causes upregulation in tyrosine hydroxylase activity, which then reduces the levels of norepinephrine, and reduces the capability of the brain to cope with stress; hence mood disturbances and cognitive decline eventually set in. In view of these findings, there is a need to explore new treatment avenues for depression.

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Virtual reality (VR) is a technology that creates a computer-generated, three-dimensional environment, enabling users to engage interactively through multiple sensory modalities, including sight, hearing, and touch. This immersive experience can simulate a virtual world, providing users with a sense of presence within the environment. VR technology has been demonstrated to be effective in treating depression [4]. The application of VR in depression therapy has primarily focused on immersive psychotherapy [5], cognitive training [6], and VR-based social cognition and interactive training [7]. Yet, a gap exists in the literature about the use of VR for exposure training in a controlled, parameterized environment. Also, there are few studies using 3D modeling to replicate natural landscapes and show them in the virtual environment, even though such landscapes could be valuable for patients to connect with nature and thereby reduce stress. Natural landscapes have been long recognized for their positive input toward mental health, especially in the aspect of depression treatment [8]. But, it is not everyone who can access the resource or time that will enable them to visit these therapeutic landscapes. Therefore, the use of VR technology to create rehabilitation landscapes in the treatment of depression can be very therapeutic and, at the same time, commercially viable. In this study, by "virtual rehabilitation landscape," it is meant to be a nature-inspired environment designed through the use of VR technology with the purpose of restoration and enhancement of healthy mental conditions. The approach fuses landscape rehabilitation principles with VR technology to enhance physical and mental well-being.

This study aims to investigate how VR technology can be applied in the treatment of depression, with a focus on two key areas. The first area explores the use of virtual rehabilitation landscapes, investigating the characteristics and therapeutic functions of various natural landscapes in treating depression, and how these can be simulated and constructed for therapeutic purposes. The second area examines virtual exposure training, focusing on how to categorize exposure levels, develop treatment protocols, and assess treatment outcomes. This research seeks to address the limitations of conventional pharmacological treatments for depression, explore the potential of VR technology as an adjunctive therapy, and evaluate the commercialization prospects of VR mental health treatment. The findings of this study hold significant academic and practical implications.

2. Literature Review

2.1. Features of Virtual Reality Technology

The core features of virtual reality (VR) include immersion, interactivity, and constructivity [9]. Immersion indicates the feeling of getting completely absorbed in the artificial setting. It could be achieved through various perceptions such as viewing, hearing, and even feeling devices. The so-called sense of presence allows the users to devote full attention to the artificial world, thereby often leading them to forget where they are physically located. Interactivity refers to response to the user's action on virtual objects and scenes so that their actions have consequences on events happening within the scene; in return, the change in the scene affects the user. Constructivity means VR can offer a customizable, modifiable, and creative environment wherein users are not mere participants but also have the ability to design, alter, and create elements within the world. All these together increase patient engagement since it allows deep interaction with the virtual environment, therefore treatment acceptance, and thus therapeutic outcomes improve significantly.

2.2. The Application of Virtual Reality Technology in Various Fields

The successful application of virtual reality (VR) technology in the treatment of anxiety, phobias, and post-traumatic stress disorder (PTSD) provides a robust theoretical foundation for its potential use in depression intervention [10]. Furthermore, virtual reality has exhibited considerable efficacy across multiple domains, including education. Immersive virtual environments enable students to investigate

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simulated learning contexts—such as historical locations, outer space, or aquatic ecosystems—thereby augmenting engagement, enjoyment, and information retention [11]. In the medical field, VR facilitates the modeling of physiological and pharmacological characteristics of cells, tissues, and organs on a micro scale, as well as the geometric and physiological representation of human organs on a macro scale. These highly detailed virtual human models allow students and medical professionals to study anatomy, practice surgical techniques, and refine their clinical skills in highly simulated virtual environments. In contrast to traditional methods, such as autopsies or animal experiments, VR provides a visual and interactive learning environment that allows for repeated practice, thereby improving proficiency and skill retention [12]. These developments underscore the increasing sophistication and maturity of VR technology.

Furthermore, recent advancements in VR visualization technology have significantly enhanced its realism. One such advancement involves the visualization of complex volumetric images, achieved by converting data obtained from 3D scanning into three-dimensional grid models. These models are then subjected to geometric and topological error detection and correction, followed by user-defined slice generation and optimization of the grid for improved visualization. As a result, the processed 3D models exhibit enhanced clarity and more realistic textures in VR. In addition, the progress in VR device technology has further augmented the authenticity of the virtual experience. Notably, the development of micro-display technologies has led to the creation of Head-Mounted Displays (HMDs) that incorporate display technologies such as Micro-LED, Liquid Crystal on Silicon, and Digital Micromirror Devices. These advancements enable HMDs to deliver higher resolution images, thereby significantly enhancing the realism and immersion of the user experience.

3. Virtual Rehabilitation Landscape (Natural Landscape Based on Virtual Reality)

3.1. Fundamental concept

3.1.1. Definition of Virtual Rehabilitation Landscape

The natural rehabilitation landscape based on virtual reality technology is the virtual rehabilitation landscape. Through modeling the natural landscape, it is presented in a virtual environment, and people are immersed in these natural landscapes through HMD and other devices, to relieve stress and psychological anxiety and treat depression.

3.1.2. Natural Landscape

There are many types of natural landscapes with different characteristics and functions, as shown in Figure 1.

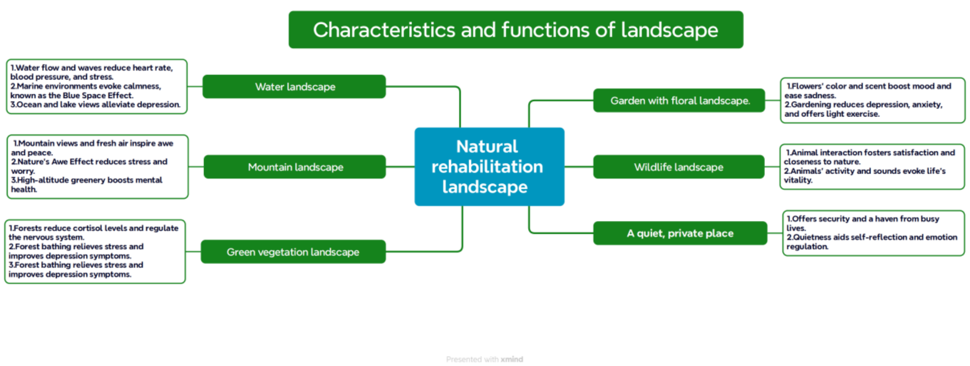

Figure 1: Characteristics and functions of landscape

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Generally, in contrast to urban landscapes, natural landscapes can alleviate stress and psychological distress, induce beneficial psychological and physiological effects, and facilitate recovery from worry or strain. [8]. The application of virtual reality technology to the treatment of various mental illnesses, especially in the treatment of depression has proved useful.

3.2. Modeling Method

There are three primary 3D modeling methods commonly used in the field. The first is the viewpoint synthesis modeling method based on multi-image input [13], which involves utilizing multiple image sets to synthesize new viewpoint maps and construct a 3D scene model. This approach enables the creation of virtual roaming experiences within the 3D scene. It is particularly suitable for the 3D reconstruction of natural landscapes and historical buildings [14]. The model's quality and fidelity are significantly influenced by the number and quality of input photos, together with the effectiveness of the automated algorithms and hardware employed for image processing. [14]. In general, achieving high fidelity often incurs significant time and financial costs, which may limit the level of immersion achievable for users.

The second method is 3D modeling using AutoCAD, a manual approach that employs modeling tools such as solid modeling and surface modeling features to enhance the flexibility and reusability of the design process [15, 16]. Additionally, AutoCAD's functionality has been extended through plug-ins and APIs to facilitate integration with 3DS MAX, thus broadening its range of applications [17, 18]. This technique is well-established and allows for the realistic reproduction of an object's geometric structure and surface texture. It is optimal for items necessitating elevated modelling precision and intricacy. However, this approach is not suitable for large-scale environments, such as natural landscapes, due to the extensive workload involved. Manual modeling with AutoCAD is time-consuming and labor-intensive, and the substantial computational resources required place high demands on hardware.

The third method, 3D laser scanning technology (also known as laser point-cloud modeling) [19], involves scanning objects with a 3D scanner to capture their spatial information. A schematic of 3D scanning data collection is shown in Figure 2. The spatial data is subsequently transmitted to a computer, where it is processed and transformed into a 3D model with graphics software [13]. Notable features of this method include geometric topological data, echo reflection intensity, and true/false color information [19]. As a result, it offers several advantages, including high model accuracy, efficiency in modeling, and high-density point clouds, which allow for a more detailed representation of the object [20, 21]. However, there are significant disadvantages: the need for high-end scanners to generate clear point clouds, as well as substantial demands for data processing and computing power. Consequently, the equipment required for this method tends to be expensive.

To enhance the authenticity of these models, techniques such as parallel rendering, occlusion culling, image-based rendering (e.g., combining top-down and upside-down images), Level of Detail (LOD) techniques, and texture mapping can be employed.

From a commercialization standpoint, 3D laser scanning technology is poised to become the most suitable method for modeling natural landscapes in the future. This will be explored in greater detail in the Discussion section.

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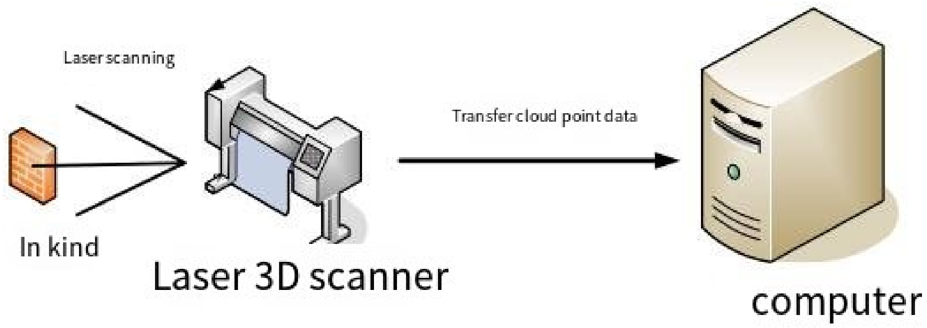

Figure 2: Schematic diagram of data acquisition of laser scanning[12]

3.3. Therapeutic Effect of Virtual Rehabilitation Landscape

3.3.1. Experimental Process

Li et al. conducted a study to explore whether a VR recovery environment (virtual rehabilitation landscape) could improve mood and alleviate stress, and whether it could play a beneficial role in the treatment of depression [23]. The research was divided into two phases. The first phase focused on validating the design and implementation of the virtual reality restoration environment, while the second phase assessed the impact of the intervention on emotional and cognitive recovery for individuals with mild to moderate anxiety and depression. The experimental virtual reality setting included a restorative garden and urban landscape, created with Unity. It consisted of four distinct areas (forest, lawn, gardening, and landscaped water) and various interactive activities (such as fishing and watering).

In the first phase, ten undergraduate students were recruited to view 30 2D images of the recovery environment. After each image, participants were asked to complete the Recovery Environment Scale (RES) following a 5-second viewing period. In the second phase, participants wore VR devices and were free to explore the restoration scene, navigating the different areas in a random order. The 3D modeled scene is shown in Figure 3. After a 10-minute experience, participants completed the RES questionnaire. In the third phase, 189 college students were categorised into five categories according to their VR scene experience: urban visual experience, restored environmental visual experience, interactive experience, fishing interaction, and watering interaction. Participants wore physiological monitoring devices, including EMG and EEG sensors, which provided data used as indicators of treatment effectiveness. Following the experiment, participants completed the PQ, PANAS, and GSES questionnaires.

3.3.2. Experimental Results

The experimental results [22] revealed that, in the first phase, the pictures displayed had a measurable restorative effect, particularly in the dimensions of "sense of distance" and "attraction compatibility." In the second phase, the VR recovery environment demonstrated a significantly higher restorative effect compared to the picture-based scene. In the third phase, no significant difference was found between the various VR scenes in the total score of the restored environment. However, the VR recovery environment outperformed the urban scenes in the "sense of distance" and "attraction compatibility" dimensions. Significant disparities in presence were observed among the different scene groups, with the participatory activity groups (fishing and watering) exhibiting a markedly stronger sensation of presence than the visual experience group.

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3.3.3. Experimental Conclusion

The VR recovery environment (virtual rehabilitation landscape) proved to be effective in improving mood and alleviating stress, with a stronger sense of immersion corresponding to better recovery outcomes. The results indicate that different landscape settings have varying restorative effects, and the more interactive the scene, the greater its potential for recovery.

3.4. Discussion

It is important to note that the VR restoration landscape used in the experiment by Li et al. [22] differs significantly from the virtual rehabilitation landscape discussed in this study. The primary distinction lies in the composition of the virtual scenes: in the former, the images were created through various methods, including hand-drawn graphics using Photoshop, AI-generated images, and images produced with CAD 2019 or SketchUp 2019, as shown in Figure 3 [22]. These images, while representing some aspects of reality, lack full immersion due to their distinct artistic style, which deviates from the real world. Consequently, they cannot provide the same level of immersion, which limits their therapeutic potential. Although this approach reduces both the complexity and cost of scene creation, it is less effective in fostering a realistic and immersive experience, which is crucial for therapeutic outcomes.

In contrast, the virtual scene in this study is designed to closely resemble the real world, offering a more immersive experience. Furthermore, it allows for the enhancement of natural landscapes by emphasizing elements that are known to improve mood and reduce stress. Despite the increased difficulty and expense of constructing highly realistic and immersive environments, the advantages for therapeutic effectiveness are significant.

To overcome the financial and technical barriers of creating high-quality virtual environments, a commercialization strategy based on the early-stage investment and late-stage compensation model [23] could be applied. This model allows for the allocation of substantial initial R&D investments with the potential for returns in the later stages through sales, ensuring sustainability and growth in the development of such immersive virtual environments.

Figure 3: 3D modeling of the restored scene[13]

4. Exposure Desensitization Training Based on Virtual Reality Technology

4.1. Concept

Exposure desensitization training based on virtual reality (VR) technology involves the systematic exposure of patients to stimuli that trigger symptoms, facilitated through VR. The underlying principle is to encourage patients to confront fear-inducing stimuli within a virtual environment, or to deliberately immerse themselves in a traumatic scenario, with the goal of gradually reducing anxiety through habituation and the eventual disappearance of the stimulus.

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4.2. Advantages

VR technology allows patients to undergo treatment remotely, from the comfort of their own homes. In comparison to traditional depression treatments, this mode of therapy is minimally invasive with respect to the patient's privacy. This high level of confidentiality enhances the therapeutic effectiveness for individuals suffering from depression [4][10]. Furthermore, this framework obviates the necessity for healthcare practitioners to sustain physical infrastructures, consequently lowering operational expenditures and enhancing the commercial feasibility of the treatment paradigm.[4]. Additionally, virtual exposure therapy offers significant safety advantages over real-world and imagined exposure scenarios. The virtual environment is customizable, allowing for easy adjustments to various parameters, thereby maximizing the potential benefits for patients [10].

4.3. Different treatment options

4.3.1. Treatment of Trauma

In this experiment, the psychotherapist worked closely with the patient, a victim of PTSD, to identify the root cause of the trauma: long-term verbal abuse and demeaning treatment by the patient's father during childhood and adolescence. Together with the psychologist, the patient compiled a list of instances in which they were reprimanded by their father, ranked according to the level of anxiety and distress these events caused. Table 1 presents a structured approach to systematically expose traumatic memories, arranged in a descending hierarchy of fear. Of the 5.6 items, the patient was exposed to immersive virtual environments for the most fear-inducing scenarios. Exposure to the next level of fear occurred only once the patient demonstrated relaxation and reduced anxiety at the current level.

Table 1: The level of fear of trauma

Behavior	Fear rating
Watch pictures of fathers reprimanding and belittling 10you	5
Talk to a friend about your father reprimanding and belittling you	10
Imagine your father reprimanding and belittling you	20
Watch a video of your father reprimanding and belittling you	35
Watch your father reprimand and belittle your old self 75in a virtual world	75
Experience your father reprimanding and belittling you 95in the virtual world	90
Experience your father reprimanding you in the real world	100

4.3.2. Treatment Options for Anxiety or Fear

The initial step involves utilizing VR technology to simulate various scenarios that may induce anxiety or fear. The second step, gradual exposure, allows patients to progressively encounter stimuli of varying intensity within the virtual environment. This method enables patients to gradually adapt and reduce their fear response.

4.4. Experimental process and evaluation

4.4.1. Experimental Process

Albert et al. [24] investigated the use of virtual reality exposure therapy for treating PTSD. In preparation, they developed a virtual reality system consisting of 14 scenarios, including battlefields, towns, villages, checkpoints, and hospitals, to replicate environments that may trigger trauma. Using

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the Clinician Control Panel (often referred to as the "Wizard of Oz"), the therapist was able to adjust the triggering stimuli in real time, such as explosions, shouting, or vehicles passing by. During the clinical sessions, patients wore a head-mounted display (HMD) and immersed themselves in the virtual environment, confronting their traumatic memories sequentially. Based on the patient's responses, the therapist gradually increased the intensity of exposure and provided emotional guidance to facilitate processing and reduce fear and anxiety.

4.4.2. Experimental Results

The experimental results demonstrated that 80% of the 20 patients treated showed statistically and clinically significant reductions in PTSD symptoms, as evidenced by improved scores on the PCL-M scale. Additionally, anxiety symptoms decreased by an average of 33%, while depression symptoms dropped by an average of 49% [24].

4.5. Measurement Index and Therapeutic Effect Evaluation

During each exposure session, patients wore biological monitoring sensors, including the Empatica E4 wristband and an upper arm blood pressure monitor, to measure physiological changes before and after the experiment. The sensors tracked parameters such as skin conductance, salivary cortisol levels, blood pressure, heart rate, and electroencephalography (EEG) [8], enabling a quantifiable assessment of the patients' anxiety levels and the degree of relaxation achieved during treatment.

5. Conclusion

This study looks into the use of VR technology for treating depression with two primary approaches: virtual natural rehabilitation landscapes and VR-based exposure desensitization training. From this, it can be shown that VR has a good promise as an effective and novel non-pharmacological intervention in reducing emotional distress and improving mental health. Advanced technologies used in this approach include multi-view image synthesis, AutoCAD manual modeling, and 3D laser scanning for the VR-based natural rehabilitation landscape. From the experimental results, it can be seen that the immersive VR nature scenes, such as forests, grasslands, gardens, and water bodies, offer good stress relief and positive emotional recovery. In the 3D scenes, interaction with such environments—for example, fishing and watering plants—showed much better improvement in mood than static or less interactive visuals. This proves the dual importance of both immersion and interactivity for optimizing VR-based therapeutic outcomes. Real images represented in VR are much more realistic than traditional flat images and, therefore, the impact is much stronger. The second method is by use of exposure desensitization enabled by VR, where a patient can confront trauma or rather anxiety-related stimuli in an environment that is controlled and can be customized. The process tailors the exposure to the specific fear level of the patient, noting steps to ensure gradual habituation and a decrease in anxiety indicators like heart rate, skin conductance, and even levels of cortisol. VR is private, cost-effective, and accessible, making it even more useful than traditional therapeutic modalities while overcoming some limitations. This study shows the hopeful chance of VR tech in helping depression by mixing immersive worlds with structured therapy plans. Virtual rehab places give a natural, healing getaway, while exposure desensitization offers a way to ease anxiety This dual method not only helps with reg therapies but also leads to new paths for selling things and wide use thus making paths for new and easier mental health answers

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