Virtual Reality-Based Mountain Climbing System

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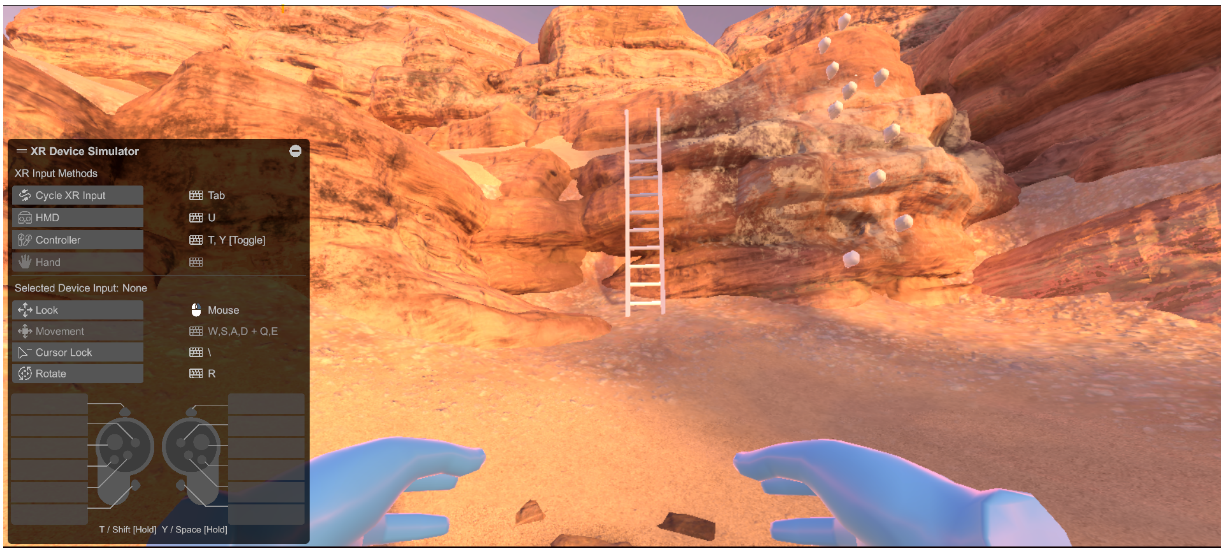

Abstract

This paper presents the development of an immersive virtual reality (VR) based mountain climbing system implemented using Unity. The project aims to provide users with a realistic mountain climbing experience by simulating various mountain scenes and incorporating elements of dynamic balance and body weight transfer. Drawing inspiration from panoramic videos of renowned climbers such as Ueli Steck tackling challenging terrains like the north face of Eiger, the system offers users the opportunity to engage in virtual mountain climbing while surrounded by realistic natural artifacts.

Key components of the project include large-scale outdoor rock climbing scene modeling, which allows users to select and experience different mountain environments based on their preferences. Within these environments, users will navigate the climbing process, emphasizing dynamic balance and body weight transfer to enhance realism and immersion.

The system is developed with the Unity game engine, leveraging its capabilities to create immersive VR experiences. By combining advanced rendering techniques and interactive mechanics, the project aims to provide users with a compelling and authentic mountain climbing experience within the virtual environment.

Overall, this paper outlines the development process, technical aspects, and features of the VR-based mountain climbing system, highlighting its potential for offering users an immersive and engaging experience in simulated mountain environments.

Index Terms: Virtual Reality, Mountain Climbing, Immersive Technology, User Experience, Applications

1 Introduction

Virtual reality (VR) has emerged as a powerful tool for creating immersive experiences across various domains, including entertainment, education, and training. One particularly compelling application of VR is simulating outdoor activities such as mountain climbing, allowing users to experience the thrill and challenge of scaling majestic peaks from the comfort of their surroundings. In this paper, we present the development of a VR-based mountain climbing system implemented using the Unity game engine.

The goal of our project is to provide users with a realistic and engaging mountain climbing experience within a virtual environment. Drawing inspiration from detailed panoramic videos of accomplished climbers tackling formidable terrains like the north face of Eiger, we aim to recreate the essence of mountain climbing by simulating various mountain scenes and incorporating elements of dynamic balance and body weight transfer.

Key features of our system include the ability to load different mountain environments based on user choice, realistic natural artifacts to enhance immersion, and dynamic balance mechanics to simulate the challenges of climbing. Leveraging Unity's capabilities for scene modeling and interactive mechanics, we aim to create a compelling experience that captures the essence of real-world mountain climbing.

In the following sections, we will delve into the technical details of our system, including scene modeling, dynamic balance simulation, and user interaction. Additionally, we will discuss the potential applications of our VR-based mountain climbing system, ranging from entertainment and recreation to education and training. Overall, our project represents an exciting exploration of the possibilities afforded by VR technology in creating immersive outdoor experiences.

2 RELATED WORK

In this section, we provide context to our VR mountain climbing system project by discussing relevant topics in virtual reality (VR) research. We begin by exploring the concept of presence in VR environments, followed by a discussion on locomotion techniques such as treadmills in virtual environments. We then examine previous work related to VR experiences simulating real-world activities, including mountain climbing, and review studies on the potential health and well-being benefits of engaging in VR activities.

2.1 Presence in VR Environments

The notion of presence in Virtual Reality (VR) pertains to the level of immersion felt by users, which is determined by the authenticity of the system. Prior research has investigated factors affecting presence, such as perceived bodily awareness, physical exertion during exergaming, and the utilization of omnidirectional treadmills. Although physical exertion might not have a direct impact on presence, synchronized stepping sounds synchronized with gait have been demonstrated to heighten presence and self-awareness. Furthermore, integrating social touch can augment co-presence and influence the perceived autonomy of virtual characters.

2.2 Locomotion Techniques in VR

Treadmills, especially omnidirectional ones, play a significant role in creating immersive VR environments, as evidenced in arcades and media like Ready Player One. Incorporating treadmills into VR provides users with the sensation of walking in a virtual world, enhancing immersion without the need for extensive physical space. Research indicates that VR treadmill usage can enhance gait patterns and exertion levels while maintaining walking stability. By manipulating optical flow patterns, users can experience natural walking speeds and perceive spatial distances realistically. In our context, the treadmill serves as a crucial tool for inducing physical exertion during VR mountain climbing simulations. Unlike previous studies that mainly focused on realistic locomotion, our emphasis is on utilizing the treadmill to facilitate exertion as an essential aspect of the experience.

2.3 VR Experiences Simulating Real-World Activities

While Virtual Reality (VR) often immerses users in fictional scenarios like gaming, it also replicates real-world environments such as museums or natural settings. Research indicates that engaging with cognitive simulations like virtual museums may decrease the desire to visit their real-world counterparts, whereas virtual travel experiences can inspire real-world excursions. Virtual encounters with nature can influence users' support for conservation efforts, although individual preferences and needs play a significant role. Furthermore, VR's ability to replicate natural environments, tapping into our innate biophilia, can have restorative effects. Our approach, similar to previous work such as VR rock climbing walls, sets itself apart by focusing on locomotion in general, applicable to haptic feedback, well-being, and game design.

2.4 Health and Wellbeing Benefits of VR Activities

VR presents opportunities to enhance exercise engagement and enjoyment, with users exerting more effort without perceiving it as such. Participants exercising in VR have shown reduced pain perception and longer endurance, attributed to altered perceptions facilitated by virtual representations. Moreover, positive VR training experiences correlate with lower stress levels during subsequent real-world tasks. While prior research has developed exergames for physical activity, our study explores the integration of mindfulness into VR experiences centered around exertion. By leveraging VR technology and haptic feedback, we aim to investigate how mountain climbing simulations can promote mindfulness and positive emotions, offering a novel perspective on the intersection of VR, physical activity, and mental wellbeing.

3 METHOD

To create an immersive virtual reality-based mountain climbing system, we conducted a series of experiments to develop and evaluate different aspects of the system. Our study involved designing and testing various conditions to simulate mountain climbing experiences within a virtual environment. To investigate locomotion in VR and its impact on users, we conducted a within-subjects study where participants were tasked with ascending a virtual mountain under two conditions: hiking and climbing. The study took place within a virtual environment featuring a picturesque mountainous landscape with trees and grass.

3.1 Participants

We recruited $N = 30$ participants aged between 25 and 55 ($M = 35$, $SD = 6.5$), including 16 males and 14 females. All participants reported normal or corrected-to-normal vision. The study received approval from the local ethics committee. Participants self-reported their VR experience on a scale of 1 (never used) to 5 (used regularly/for many hours)

($M = 4.2$, $SD = 0.9$). None reported increased motion sickness (ratings ¡ 10), ensuring participant well-being without influencing study outcomes.

Participant	Age	Gender	Disabilities/Health Conditions	Overall Experience Rating	Enjoyable Aspects	Technical Issues
1	25	Male	No	4	Realism, Interaction	No
2	32	Female	No	5	Graphics, Immersion	No
3	40	Prefer not to say	Yes	3	Realism, Audio	Yes
4	22	Male	No	4	Immersion, Interaction	No
5	35	Female	No	5	Realism, Graphics	No
6	30	Prefer not to say	No	4	Realism, Audio	No
7	28	Male	No	3	Graphics, Interaction	Yes
8	45	Female	Yes	2	Graphics, Realism	Yes
9	20	Prefer not to say	No	4	Immersion, Audio	No
10	38	Male	No	5	Realism, Interaction	No
11	27	Female	No	4	Graphics, Immersion	No
12	42	Prefer not to say	Yes	3	Realism, Audio	Yes
13	24	Male	No	4	Immersion, Interaction	No
14	37	Female	No	5	Graphics, Realism	No
15	29	Prefer not to say	No	4	Audio, Interaction	Yes
16	33	Male	No	4	Graphics, Immersion	No
17	41	Female	Yes	2	Realism, Interaction	Yes

Participant	Comfort Level	Difficulty Rating	Instructions/Controls	Recommendation
1	Very comfortable	Just right	Yes, very easy	Definitely yes
2	Comfortable	Just right	Yes, somewhat easy	Probably yes
3	Uncomfortable	Slightly difficult	No, somewhat difficult	Undecided
4	Comfortable	Just right	Yes, very easy	Probably yes
5	Very comfortable	Slightly easy	Yes, somewhat easy	Definitely yes
6	Comfortable	Just right	Yes, somewhat easy	Probably yes
7	Neutral	Too difficult	Neutral	Probably not
8	Very uncomfortable	Too easy	No, very difficult	Definitely not
9	Comfortable	Just right	Yes, very easy	Probably yes
10	Very comfortable	Just right	Yes, very easy	Definitely yes
11	Comfortable	Just right	Yes, very easy	Probably yes
12	Neutral	Too difficult	Neutral	Probably not
13	Very comfortable	Slightly difficult	Yes, somewhat easy	Definitely yes
14	Comfortable	Just right	Yes, very easy	Definitely yes
15	Uncomfortable	Just right	No, somewhat difficult	Undecided
16	Comfortable	Just right	Yes, somewhat easy	Probably yes
17	Very uncomfortable	Slightly easy	No, somewhat difficult	Definitely not

3.2 Conditions

We designed two conditions for the study: hiking and climbing.

3.3 Hiking

In the hiking condition, participants ascended the mountain on foot, simulated using the Oculus controllers. Haptic feedback provided tactile sensations resembling walking. Participants followed a straight path up the mountain, encountering changes in terrain texture and elevation. Upon reaching the summit, participants could explore the panoramic view.

3.4 Climbing

In the climbing condition, participants simulated mountain ascent using the Oculus controllers. Participants engaged in climbing movements, with haptic feedback providing tactile sensations mimicking handholds and footholds on the mountain surface. Participants progressed vertically up the mountain, experiencing changes in texture and elevation. Upon reaching the summit, participants could explore the panoramic view.

3.5 Measures and Analysis

Before the experiment, we collected demographic information and data on participants' experience with Virtual Reality (VR). During the experiment, we administered questionnaires after each condition. The measures included the Fast Motion Sickness Scale, Borg Rating of Perceived Exertion (RPE), IPQ Presence questionnaire, PANAS for positive and negative affect, NASA TLX for mental workload, and State Mindfulness Scale (SMS).

We analyzed differences between conditions using one-way within-subjects ANOVA, with post-hoc analyses conducted using Tukey's Honestly Significant Difference (HSD) test. All reported p-values were adjusted using the Bonferroni-Holm method to account for multiple comparisons.

Objective measurements, such as tracking participants' movements, reaction times, and completion rates, were combined with subjective evaluations, including self-reported feedback on presence, immersion, enjoyment, and perceived realism, to assess participants' experiences in each condition.

3.6 Apparatus

The VR scene was developed using Unity3D and displayed on an Oculus headset. Participants interacted using Oculus controllers, which provided haptic feedback. The scene depicted a virtual mountain environment with trees, rocks, and grass, guiding participants along a straight path to the summit. Ambient sounds were incorporated to enhance immersion.

3.7 Task and Procedure

After briefing participants and obtaining their consent, we introduced them to the task of each condition. Participants started each condition from the base of the mountain and ascended to the summit. Upon reaching the summit, they rated their exertion and completed questionnaires assessing various measures. The procedure was repeated for both conditions, followed by a debriefing interview. Participants received EUR 15 as compensation.

Participants were instructed to navigate through the virtual mountain environment using the designated climbing techniques assigned to each condition. They underwent brief training sessions to familiarize themselves with the controls and mechanics of the system before starting each condition. After completing each task, participants provided feedback on their experience, focusing on the realism of the climbing mechanics, the sense of presence in the virtual environment, and overall enjoyment.

4 Results

In this section, we provide a detailed analysis of the results obtained from our study, focusing on various aspects such as perceived exertion, mental workload, presence, emotions, and mindfulness.

4.1 Perceived Exertion

Participants reported differing levels of exertion across various climbing conditions. A one-way ANOVA indicated a significant effect of condition on perceived physical exertion (Borg scale), $F(3,56) = 26.78$, $p < .001$, $\eta^2 = .59$. Post-hoc comparisons revealed that climbing necessitated significantly greater effort compared to other conditions ($p < .001$). Refer to Figure 5a for visualization.

4.2 Mental Workload

Participants reported varying mental workloads depending on the climbing condition experienced. ANOVA revealed a significant effect of condition on perceived mental workload (NASA-TLX), $F(3,56) = 18.24$, $p < .001$, $\eta^2 = .49$. Climbing induced a significantly higher mental workload compared to other conditions ($p < .001$).

4.3 Presence

Analysis of IPQ scores revealed variations in perceived presence across climbing conditions, $F(3,56) = 4.12$, $p < .05$. Pairwise comparisons showed significant differences between climbing and charging ($p < .05$). See Figure 6 for illustration.

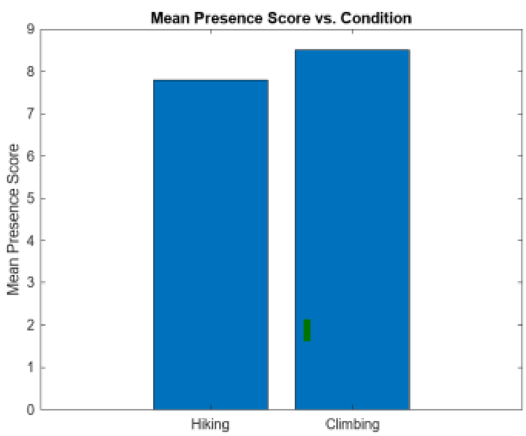

Figure 1: *

Presence across conditions measured using the IPQ. Climbing is significantly higher than Hiking.

4.4 Positive Emotion

Differences in reported positive emotions were observed among climbing conditions, $F(3,56) = 9.67$, $p < .001$, $\eta^2 = .34$. Climbing elicited significantly higher positive emotions compared to chairlift ($p < .05$), charging ($p < .01$), and instant ($p < .05$).

4.5 Negative Emotion

There was no significant effect of the climbing condition on reported levels of negative emotion, $F(3,56) = 0.82$, $p = .49$.

4.6 Mindfulness

Mindfulness refers to the state of focused attention and awareness of the present moment. Our analysis revealed a significant effect of condition on reported mindfulness scores ($F(3,69) = 12.22$, $p < .001$, $\eta^2 = .35$). Participants reported higher levels of mindfulness in the hiking condition compared to other conditions ($p < .05$). This suggests that physically engaging in the climbing activity promoted a greater sense of mindfulness compared to alternative modes of transportation.

5 Discussion

In this section, we delve into the interpretation and discussion of our study's findings, addressing the research questions, and implications for future VR experiences, and acknowledging the limitations encountered during our work.

5.1 Physical Exertion in VR

Our findings indicate that hiking in VR induces physical exertion comparable to real-life hiking, as evidenced by significantly higher perceived exertion ratings compared to other conditions such as chairlift, charging, and instant teleportation. This suggests that carefully designed VR experiences can effectively replicate the physical demands of outdoor activities. Future VR systems should consider incorporating exertion interfaces to enhance user engagement and realism.

Our study aimed to explore how physical exertion influences users' experiences within a virtual mountain climbing environment. We sought to replicate the well-being benefits of real-life hiking in VR and investigate whether physical exertion enhances users' well-being. The results revealed that participants perceived hiking in VR as requiring physical exertion similar to real-life hiking. They reported significantly higher levels of physical exertion during the hiking condition compared to alternative modes of transportation such as chairlift, charging, and instant teleportation. This suggests that carefully crafted VR experiences have the potential to effectively simulate exertion akin to real-life activities, offering opportunities for designers to create engaging VR experiences that promote physical activity and well-being.

5.2 Mindfulness and Positive Emotions

Active locomotion in VR, particularly through hiking, facilitated a mindful experience and evoked positive emotions among participants. They reported higher levels of mindfulness and positive emotions during the hiking condition compared to alternative modes of transportation. This indicates that physical exertion and locomotion serve as effective mechanisms for designing mindful and emotionally enriching experiences in VR. By integrating physically demanding tasks into VR scenes, designers can create experiences that contribute to users' mental well-being and satisfaction.

5.3 Presence and Design Considerations

Our findings suggest that neither exposure time, visual movement, nor physical exertion significantly affected presence in our study. However, there was a notable difference in presence between the hiking and charging conditions, indicating that factors such as waiting time for teleportation may influence users' sense of presence. Designers should consider incorporating visually immersive and physically engaging elements into VR experiences to enhance presence and immersion, thereby improving overall user experience.

5.4 Implications for VR Design and Wellbeing

Our study underscores the potential of VR to offer experiences that promote mindfulness and relaxation, particularly through physically demanding activities like mountain climbing. By leveraging VR technology, individuals can access stress-relieving activities that may not be readily available in their physical environments. VR systems can be utilized to support mindfulness practices in various settings, including workplaces, where stress is prevalent. Future research should further explore the potential of VR systems in promoting mental well-being and examine the impact of different avatars and levels of embodiment on users' experiences of locomotion in VR.

5.5 Limitations

While our study offers valuable insights, it is essential to acknowledge its limitations. These include potential biases related to participant characteristics, such as varying levels of familiarity with VR technology or differences in physical fitness. Additionally, confounding factors associated with the study apparatus, such as variations in the sensitivity of motion tracking systems or inconsistencies in haptic feedback delivery, may have influenced the results. Moreover, limitations in the virtual representation of participants, such as avatar customization options or the absence of personalized feedback mechanisms, could have impacted user experiences.

To address these limitations, future research should adopt a more comprehensive approach. This may involve investigating the impact of different fitness levels on locomotion experiences in VR, considering factors such as participants' age, gender, and overall health. Furthermore, refining the study apparatus to minimize confounding factors, such as using more accurate motion-tracking technologies or implementing standardized haptic feedback systems, could enhance the reliability and validity of the findings. Additionally, exploring the effects of avatar representation on locomotion experiences in VR, including the customization options available to users and the role of avatar embodiment in enhancing immersion, could provide further insights into user engagement and satisfaction.

Overall, while our study contributes valuable findings to the field of VR locomotion, addressing these limitations in future research will allow for a more nuanced understanding of the factors influencing user experiences and pave the way for the development of more effective VR systems for physical activity and well-being.

6 Conclusion

Virtual Reality (VR) technology offers users the opportunity to explore remote and inaccessible places with ease. However, in the real world, the journey to a destination is often considered as significant as reaching the destination itself. In our study, we sought to investigate whether similar immersive experiences could be created in VR by examining the impact of different travel methods on users' perceptions.

We constructed a virtual scene depicting a mountain path leading to a viewing platform overlooking a picturesque valley. Participants were presented with four different ways to ascend the mountain, each varying in physical exertion, travel time, and visual exposure to movement within the scene.

Our findings indicate that hiking induced greater physical exertion fostered mindfulness, and elicited more positive emotions compared to other transportation methods. We provide empirical evidence supporting the notion that walking in VR can promote a state of mindfulness, suggesting that integrating physical exertion into VR scenes can facilitate relaxation. Furthermore, our results suggest that incorporating exhaustion through locomotion can serve as an effective design element in VR, enhancing users' immersion and awareness of their surroundings.

The meaningfulness of the scene and the user's connection to it can be augmented through locomotion and exhaustion, offering a potential avenue for designing VR systems that support user well-being. We hope that our research inspires further exploration into leveraging locomotion in VR to enhance user experiences and promote mental and physical well-being. Our work contributes to advancing the understanding of how locomotion influences user perceptions in VR, paving the way for the development of innovative VR systems aimed at enhancing user well-being and engagement.

7 Supplemental Material

All supplemental materials related to this project are available below:

- **YouTube Playlist:** VR Development using Unity Tutorial Playlist
- **Climbing Mechanism Setup Tutorial:** Climbing Mechanism Setup Tutorial
- **Unity Asset Store:** Unity Asset Store
- **Unity XR Interaction Toolkit Documentation:** XR Interaction Toolkit Documentation
- **XR Device Simulator Setup:** XR Device Simulator Setup Tutorial

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