A VIRTUAL REALITY 3D GAME: A COMPARISON BETWEEN AN IMMERSIVE VIRTUAL REALITY APPLICATION AND A DESKTOP EXPERIENCE

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ABSTRACT

The work aims to design and implement a 3D interactive and addictive object avoidance game using the Unity platform. The implementation of the immersive virtual reality application uses any smart mobile device as an input and output device, utilizing its accelerometer and compass to record the orientation and rotation data of the device in 3D space and capture the digital environment stereoscopically on the device screen. A comparative study between a virtual reality and a desktop real-time 3D game is performed to analyze the various attributes of the game and determine which medium is most effective.

Index Terms— Virtual reality, VR game, 3D game, Oculus Rift, Unity

1. INTRODUCTION

Systems that can be considered virtual reality (VR) systems have been around since the 1960s. Virtual reality is an alternate world filled with computer-generated images that respond to human movement. The simulation environment is accessed with the help of an accurate data set consisting of audio-visual headsets and fiber optic data gloves [1, 2].

Gamification is a method of digital engagement rather than personal engagement, meaning that players interact with computers, smartphones, mobile screens, or head-mounted displays devices (e.g., Oculus Rift, HTC Vive, or Google Cardboard) [3]. VR games are a medium of interactive entertainment that has gained widespread popularity in recent decades. Although they may be seen by some as simply a form of recreation or distraction, VR games can be understood as a complex and diverse medium that has the potential to engage and challenge players in different ways [4]. In this paper, we explore how VR games can be understood as both a medium and a system, and consider the implications of these perspectives for how we think about and interact with VR games.

Virtual reality games can be thought of as a system, as they are made up of interconnected elements that work together to create an overall experience for players [5]. These elements may include the software and hardware that run the game, the rules and mechanics that govern the game, and the goals that players are trying to achieve. Understanding video games as a system can help us better understand how they work and how they can be designed to achieve certain outcomes [6].

One way to understand the complexity of VR games as a medium and system is the various roles they can play in our lives [7]. For some gamers, VR games may be a way to pass the time or relax. For others, they can be a source of social connection, allowing players to interact with each other online or in person. Still, others may see VR games as a form of artistic expression, using them as a platform to create and share creative content with others.

The purpose of the work is the development of interactive and immersive applications in virtual reality environments through the Unity platform [8]. Unity is a high-level graphics engine (or game engine) that makes it easy to build an interactive 3D environment. It is a complete development environment, which includes and integrates a core operating mechanism that takes care of visual rendering of the scene, movement of objects, handling of user input, physics, and artificial intelligence mechanisms. The behavior of objects is defined at a higher level through the C# programming language. This research aims to determine and understand the factors that make a virtual reality game appealing to players, both on VR systems and smartphones.

2. RELATED WORK

Based on the hardware of the VR systems, we can distinguish the following categories: (a) desktop VR Systems, which are based on a PC and can work even without special equipment, and (b) immersion systems (i.e., immersion VR), which is defined as cutting off the user's vision from the real world [9]. In this work, we opt to provide a complete analysis of both the desktop 3D version of the application as well as the immersive VR version using a head-mounted display (HMD). Another category of VR games is adaptive mixed reality games [10, 11]. These are games whose view can be modified between a completely virtual traditional format and augmented reality, using parts of the environment as game content [12]. The technical limitations of the device, the user's physical environment, and the actions that the user interacts with directly adapt the game's content and presentation.

Lee *et. al.* [13] showed how desktop real-time VR games influence and enhance the learning process using several attributes such as usability, motivation, presence, cognitive benefits, and reflective thinking. This article provides guidelines for VR software developers for improving and strengthening the learning effectiveness of desktop 3D applications. Tuveri *et. al.* [14] examined the use of immersive technology to study the impact of gamification techniques to improve physical fitness using the Unity 3D game engine. To track users' movements and replicate them in the virtual environment, they used consumer-level equipment, such as an exercise bike, an Oculus Rift VR headset, and a Microsoft Kinect device.

Virtual reality games are designed to assist users with the conceptualization of scenarios of a specific activity, enhance participation in an online social community, and also to expand their knowledge. In this context, Tsoy *et. al.* [15] incorporated concepts such as prioritization in a multi-patient environment and resource stewardship in a serious board learning game designed to simulate a shift in the emergency department on how to treat and triage a patient.

Triberti *et. al.* [16] developed a virtual 3D environment where the user becomes part of a story using an HMD such as Oculus Rift, Samsung Gear VR, and Google Cardboard. As a result, these technologies offer richer learning experiences and use spatial depth on the screen. These studies debated that a VR game using a fully interactive GUI where the user may use gestures to interact with the virtual world is more realistic and acceptable by the users than one played in a 3D condition. Moreover, user testing showed that the immersive virtual environment allows the users to change their viewpoint by moving their heads, enhancing their enjoyment of physical activity.

In recent years, several researchers study the effects of VR on user perception such as proprioception, kinaesthesia, and brain activity in the effect of physiological and sociological factors [17]. Roettl and Terlutter [18] conducted a comparative study of 237 players to assess the participation and the cognitive load on different VR systems such as fully immersive VR and 3D desktop in 2D, stereoscopic 3D, and HMD scenarios. The study showed that fully immersive VR systems were preferred by users in most cases. Recent critical studies on the effects of 3D desktop and VR immersion technologies on physiological, behavioral, and sociological factors such as discomfort, eye fatigue, headache, and social isolation, when used for an extended period, showed that VR technology may negatively affect this direction [19, 20].

3. METHODS

In our work, we focus on the development of a virtual environment that presupposes the design and implementation of an interactive VR game in the form of environment simulation, produced in real-time by 3D computer graphics.

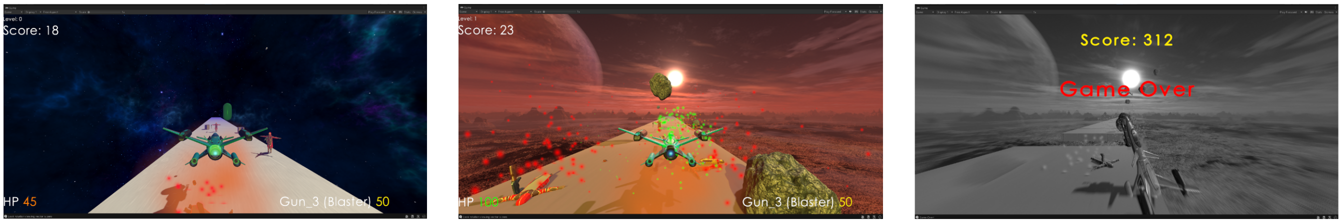
3.1. VR Game Scenario

The concept is based on an object avoidance VR game that includes basic game mechanics and real-time movements of the head, horizontal and vertical, to some obstacles/objects in the infinite runner game. The player can move freely in all directions but cannot go back, as the game world is gradually "collapsing" behind the user. The VR game features two tracks, which are dynamically generated. The first track is a simple straight line with static obstacles and enemies appearing at various points. The second track has additional gaps and moving obstacles over which the player must jump. The transition from the first to the second track takes place after the player achieves a certain predefined score, according to how many obstacles he/she may avoid.

Also, the player starts with a certain health point (HP). As the player's health decreases, so does accordingly the ability of the user to jump over the obstacles, meaning that if there is a large gap the player needs to jump, he/she may not make it. Note that the conditions for the players to lose ("Game Over") are: (a) either to have their life reduced to zero by collisions with obstacles or enemy fire or (b) to fall down the track. The player can also collect powerups (i.e., reward points), which appear randomly during the game route. Powerups provide either invisibility, where the player cannot be seen and attacked by enemies, or omnipotence, where various enemies and obstacles cannot harm the user. Also, powerups are used to replenish our health and ammunition. It is important to note that even if the player is in omnipotence mode, he/she may still lose if he/she falls down the track.

Enemies have weapons and react differently depending on their type. For example, the carabinieri characters get close to the player before shooting them, while the gunslinger characters try to open fire from a longer distance. Obstacles and enemies are destructible and during the battle, there is friendly fire, which means that enemies can destroy each other. Each weapon has different characteristics in fire rate, recoil, bullet damage, and reload time. Also, the ship has two weapons: (a) a laser (i.e., blaster), which is a reliable energy weapon that shoots straight with sufficient speed and firepower, and (b) a tracking missile launcher, which is activated automatically for a limited time by harvesting the user's omnipotence powerup, replacing the basic blaster.

Moreover, the player can eliminate the enemies either by shooting them, or by going over them by stomping on them with his/her boat. The player's score is proportional to the distance traveled. The degree of difficulty of the game also increases with the distance that the player has reached during the game. As the degree of difficulty increases the enemies' health point increases too and a lot more shots are needed to take them down. Finally, the powerups appear more and more



(a) (b) (c)

Fig. 1. The VR gameplay. (a) A random instance of the first track with static obstacles and enemies appearing at random positions. (b) A random instance of the second track with moving obstacles and enemies. (c) A game-over instance where the player loses.

rarely. Some random instances of the VR game are depicted in Fig. 1.

3.2. User Actions

The VR game is designed to run both on desktop devices (i.e., pc and smartphones) and on head-mounted displays (i.e., Oculus Rift VR headset) to take advantage of the fully immersive 3D VR environment. The application exploits passive device tracking that is it utilizes inertial device sensors such as compass, accelerometer, and gyroscope. The actions that a user can perform in the 3D virtual reality world are grouped according to their goal into:

- **Navigation Actions**: We implemented a camera navigation action as a form of interaction aimed at changing position within the virtual world in a horizontal plane (left-right) with some form of mobile device movement. Also, when the users move their head in the vertical axis this is translated as a jump action.
- **Object management actions**: This action refers to the destruction of objects located in the user's viewport. Only certain objects can be destroyed since we observe them for a certain period (depending on the object/obstacle).
- **System control actions**: The application is terminated by pressing the 'X' button on the top left of the device surface.

3.3. The Coordinate System

All graphics pipelines perceive the virtual world through a virtual observer (i.e., camera), also positioned in the 3D space. The virtual camera has its coordinate system, the eye coordinate system (ECS). Because the users move at their own will, it is important to convert the ECS to the world coordinate system (WCS). To this end, the WCS $\rightarrow$ ECS transformation expresses the 3D environment in the camera coordinate system. Thus, we define the ECS transformation as the inverted transformation applied to place the camera in a particular pose. Therefore, we have to coordinate the frame of the tracking system concerning the HMD.

Let us assume that we have an initial camera at the origin of the WCS. Then, we can translate and rotate the camera to any pose. Note that only rigid transformations are applied. Based on the WCS coordinates of shapes $\mathbf{v}_{WCS}$, one can easily obtain their eye space coordinates $\mathbf{v}_{ECS}$:

$$\mathbf{v}_{ECS} = M_c^{-1}\mathbf{v}_{WCS}\,, \tag{1}$$

where M_c^{-1} is a transformation matrix that includes rigid transformation parameters such as rotation angle and translation vector.

4. EXPERIMENTAL RESULTS

The VR game is developed for Oculus Rift VR headset but can also run on Google Cardboard using the Android operating system.

4.1. Implementation Details

We implemented our approach using Unity 2018.4.31f1 cross-platform game engine and C#. Also, we used Android Studio integrated development environment for developing the VR game on devices running the Android operating system. The minimum operating system package must be at least "Android 4.4 KitKat" and the "Minimum API Level" is set to "Kit Kat" (API level 19). We developed the VR game for Android mobile devices using the Android SDK, which is an open-source tool for detecting and tracking gestures and head movements, as well as interacting with animated and static 3D objects generated by libGDX. Finally, for the implementation of the 3D graphics, Blender 3.0 and the Unity 3D graphics assets were used.

4.2. Study Participants

To evaluate the VR application and test the studys objectives, a survey was conducted with a self-administered questionnaire. The questionnaire was delivered to M.Sc. students

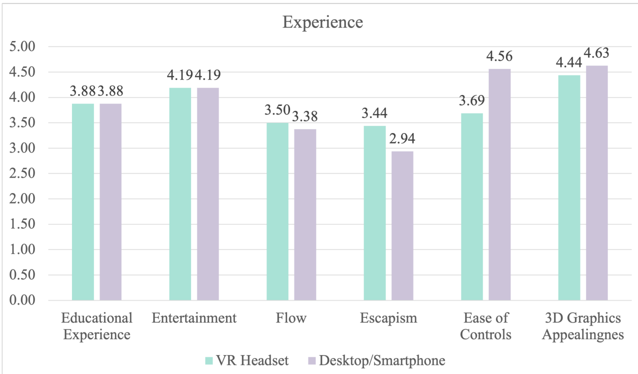


Fig. 2. Mean scores of experience factors with the VR game for both the VR headset and desktop versions.

Fig. 3. Mean scores of user satisfaction for the VR game for both the VR headset and desktop versions.

from the University of Western Macedonia. A total of 16 participants (11 men and 5 women) volunteered for this study. All participants played both the VR version of the game and the desktop version with an average time of gameplay of 17 minutes. The names of the participants were kept anonymous.

After the play-test, the participants were asked to fill out the questionnaire regarding their experience and thoughts about the VR game they played. The questionnaire was comprised of two sections and each question was rated on a five-point likert scale ranging from one that corresponds to strongly disagree to five that corresponds to strongly agree. More specifically, the first section contains six questions that measure the experience of the player with the VR game such as educational experience, entertainment, flow, escapism, ease of controls, and 3D graphics appealingness. The second group of questions comprises of four questions that measure the satisfaction, attitude, and re-usage intentions of the players such as level of immersion, and their satisfaction with the VR game and re-usage intentions concerning the application.

4.3. Results

To assess the experience of the users regarding the VR game for both the fully immersive and the desktop versions of the gameplay, we computed six factors showing the users' preferences and reactions to the VR game. Figure 2 depicts the mean scores for each experience dimension concerning the VR game for both the fully immersive and the desktop versions of the game. Dimensions such as educational experience and entertainment achieve the same score by the users for both versions of the game. It can also be seen that for factors such as flow and escapism the VR version is assigned with higher scores by the users but for the factors related to ease of controls and 3D graphics appealingness, the users rated the VR game to a lesser extent. This might be due to the movement in VR and the motion sickness.

Figure 3 represents the users' scores regarding their satisfaction with their experience with the immersive VR and the desktop version of the game. For three out of four factors, the immersive VR version of the 3D game was rated higher than its desktop counterpart. It is important to note that the Occulus users felt that the game environment was more interactive and more immersive than the desktop version of the game. In conjunction with the higher scores in factors such as ease of control for the desktop version of the game and the potential motion sickness from the use of the VR headset, re-usage intentions achieved higher scores than the immersive VR version of the game. However, moderate to high scores for the immersive VR version were also exhibited.

5. CONCLUSIONS

This study aimed to design a fully immersive VR game and examine the impact of the VR application on users concerning their perceptions and intentions about VR usage against the desktop counterpart of this application. Findings indicated that virtual reality may be considered to be preferable in some areas such as immersion and satisfaction while feelings of flow and escapism were triggered by the VR application. It is therefore possible to develop positive feelings and learn new things through fully immersive VR applications. The VR experience was also able to increase respondents satisfaction and in turn, enable them to form positive attitudes with the VR game.

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6. REFERENCES

[1] B. Xie, H. Liu, R. Alghofaili, Y. Zhang, Y. Jiang, F. D. Lobo, C. Li, W. Li, H. Huang, M. Akdere, C.Mousas, and L.-F. Craig Yu, "A review on virtual reality skill training applications," in *Frontiers in Virtual Reality*, 2021.

[2] C. Cruz-Neira and C. Fernndez, M.and Portals, "Virtual reality and games," *Multimodal Technologies and Interaction*, vol. 2, no. 1, 2018.

[3] S. S. Oyelere, N.Bouali, R. Kaliisa, G. Obaido, A. A. Yunusa, and E. R. Jimoh, "Exploring the trends of educational virtual reality games: A systematic review of empirical studies," *Smart Learning Environments*, vol. 7, pp. 1–22, 2020.

[4] A. Bile, "Development of intellectual and scientific abilities through game-programming in minecraft," *Education and Information Technologies*, vol. 27, no. 5, pp. 72417256, jun 2022.

[5] E. Martel, F.-Y. Su, J. Gerroir, A. Hassan, A. Girouard, and K.. Muldner, "Diving head-first into virtual reality: Evaluating HMD control schemes for VR games," in *International Conference on Foundations of Digital Games*, 2015.

[6] G. Tao, B. Garrett, T. Taverner, E. Cordingley, and C. Sun, "Immersive virtual reality health games: a narrative review of game design," *Journal of NeuroEngineering and Rehabilitation*, vol. 18, 2021.

[7] J. J. Allen and C. A. Anderson, "Satisfaction and frustration of basic psychological needs in the real world and in video games predict internet gaming disorder scores and well-being," *Computers in Human Behavior*, vol. 84, pp. 220–229, 2018.

[8] J.K. Haas, "A history of the unity game engine," 2014.

[9] S. Mills and J. Noyes, "Virtual reality: An overview of user-related design issues," *Interacting with Computers*, vol. 11, no. 4, pp. 375–386, 1999.

[10] M. Ma, M. McNeill, D. K. Charles, S. M. McDonough, J. Crosbie, L. M. Oliver, and C. McGoldrick, "Adaptive virtual reality games for rehabilitation of motor disorders," in *Interacción*, 2007.

[11] C. Reimann and V. Paelke, "Adaptive mixed reality games," in *Proc. ACM SIGCHI International Conference on Advances in Computer Entertainment Technology*, New York, NY, USA, 2005, ACE '05, p. 302305, Association for Computing Machinery.

[12] M. Vrigkas, A. Kleftodimos, and G. Lappas, "An augmented reality workflow for creating "live" wine labels," *International Journal of Entertainment Technology and Management*, vol. 1, no. 4, pp. 311–327, January 2022.

[13] E. Ai-Lim Lee, K. K. W. Wong, and L. C. Che Fung, "How does desktop virtual reality enhance learning outcomes? a structural equation modeling approach," *Computers and Education*, vol. 55, pp. 1424–1442, 2010.

[14] E. Tuveri, L. Macis, F. Sorrentino, L. Davide Spano, and R. Scateni, "Fitmersive games: Fitness gamification through immersive vr," in *Proc. International Working Conference on Advanced Visual Interfaces*, New York, NY, USA, 2016, AVI '16, p. 212215, Association for Computing Machinery.

[15] D. Tsoy, P. Sneath, J. Rempel, S. Huang, N. Bodnariuc, M. Mercuri, A. Pardhan, and T. M. Chan, "reating gridlocked: A serious game for teaching about multipatient environments," *Academic medicine: Journal of the Association of American Medical Colleges*, vol. 94, no. 1, pp. 66–70, 2019.

[16] S. Triberti, D. Villani, and G. Riva, "Unconscious goal pursuit primes attitudes towards technology usage: A virtual reality experiment," *Computers in Human Behavior*, vol. 64, pp. 163–172, 2016.

[17] N. Dllinger, E. Wolf, D. Mal, N. Erdmannsdrfer, M. Botsch, M. E. Latoschik, and C. Wienrich, "Virtual reality for mind and body: Does the sense of embodiment towards a virtual body affect physical body awareness?," in *Proc. Conference on Human Factors in Computing Systems Extended Abstracts*, New Orleans, LA, USA, April 2022.

[18] J. Roettl and R. Terlutter, "The same video game in 2D, 3D or virtual reality how does technology impact game evaluation and brand placements?," *PLOS ONE*, vol. 13, no. 7, pp. 1–24, 07 2018.

[19] B. Schne, J. Kisker, L. Lange, T. Gruber, S Sylvester, and R. Osinsky, "The reality of virtual reality," *Frontiers in Psychology*, vol. 14, 2023.

[20] Sokoowska B., "Impact of virtual reality cognitive and motor exercises on brain health," *International journal of environmental research and public health*, vol. 20, no. 5:4150, 2023.