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Developing a VR-based Training Platform for Emergency Fire Handling Services Using Unity 3D

Muhammad Hasham Qazi
Electrical Engineering
Habib University
Karachi, Pakistan
mq05497@alumni.habib.edu.pk

Farhan Khan
Electrical and Computer Engineering
Habib University
Karachi, Pakistan
farhan.khan@sse.habib.edu.pk

Jeeeun Kim
Computer Science & Engineering
Texas A&M University
College Station, USA
jeeeun.kim@tamu.edu

Edgar J. Rojas-Munoz
Performance, Visualization & Fine Arts
Texas A&M University
College Station, USA
ed.rojas@tamu.edu

***Abstract*—The rising incidence of fires calls for advanced training methodologies that surpass the limitations of traditional firefighter training, both in scale and scope. Virtual Reality (VR) emerges as a potent solution, offering a wide range of realistic scenarios and cost-effective, safe training environments. This paper presents a novel VR-based training platform tailored for firefighters, which leverages Unity 3D and state-of-the-art fire simulation techniques to deliver high-fidelity experiences that closely mimic real-world dynamics. Trainees engage in an immersive VR setting where they experience full autonomy and multisensory feedback, heightening the educational impact through a procedural fire spreading mechanism that emulates actual fire behavior. Our system excels in providing a comprehensive framework, modular design for customizable scenarios, and integration of varied training modules to prepare trainees for an array of firefighting emergencies. Future work aims to enhance realism through advanced features such as Flashover and Backdraft simulation, real-time environmental controls for trainers, team-based exercises with human-agent interaction, etc. The paper concludes by emphasizing the platform's alignment with the set design standards for VR-based firefighter training and outlines prospective user testing with professional firefighters to further refine the VR experience.**

***Index Terms*—Virtual Reality, Human-Computer Interaction, Serious Games, Firefighting Training**

I. Introduction

Fire safety and emergency response services are critical for public safety, as they prevent countless deaths and injuries caused by disasters. Statistics from the National Fire Protection Association reveal the alarming number of fire incidents in the United States alone, with 1,388,500 fires reported in 2020, resulting in 3,500 civilian deaths and 15,200 injuries [1]. These numbers highlight the importance of well-prepared and properly trained firefighters in minimizing the loss of life and property. It is, however, challenging to gather a sufficient number of highly trained and skilled personnel. This presents significant difficulties because firefighting operations necessitate readily available, experienced firefighters who can swiftly respond to a range of fire emergencies. Traditional training methods involve reading through written reports of previous incidents and practicing for different settings and conditions in specialized training facilities. Nonetheless, setting up and maintaining these facilities is expensive, with spending reaching up to one million dollars each [2]–[4]. Concurrently, advances in Virtual Reality (VR) technology and real-time game engines offer promising solutions for simulating various fire scenarios and environments for firefighter training while also mitigating a lot of the risks involved with such training. While current VR technology has its limitations and may not fully replace real-life training for firefighters, it can certainly augment and support current training methods by training firefighters for specialized on-the-job situations that they may experience while performing their duties. Furthermore, utilizing VR may prove to be a cost-effective method to do so. This paper presents the design requirements and establishes user-informed baselines for developing experiential learning-based Virtual Reality simulations for firefighting training. It also includes implementation details for leveraging a real-time game engine known as Unity 3D. We contribute a modular base framework for designing such simulations, which is expandable, that is, more features may be added as needed thus allowing for more specialized scenarios to be developed. The paper also introduces technical methods for developing fire dynamics and utilizes a custom-designed fire-spreading model to simulate realistic fire propagation and its associated effects.

II. Literature Review

The development of training procedures for firefighters has taken on various innovative approaches. Beginning with the work of Kanat et al., which concentrates on the role of gamification in emergency response training, specifically within the public health domain [5]. This research offers valuable insights into how to prepare trainees for the vital tasks of communication and coordination during emergencies, leveraging the motivational affordances theory to foster a positive cycle of feedback and engagement. Brown and Poulton discuss how various attributes of gamification can be translated into effective training simulations [6]. Their work delves into the alignment of game design elements with educational themes, potentially leading to innovative approaches in workplace induction, situational awareness, and emergency response preparedness. Building on the theme of immersive training, the study by Suhail et al. explores the concept of passive haptics, which is a form of physical interaction enhancing the virtual experience [7]. This paper provides an examination of methods to integrate passive haptics and their significant impact on the user's sense of presence within a virtual environment, an essential factor for effective training simulations. The complexity of urban fire spreading is an aspect that cannot be overlooked in firefighter training. Charalampous, Besharat, and Stylios address this by presenting algorithms that can simulate fire spread in urban environments using Unity 3D, emphasizing the necessity for low-complexity models for real-time simulation [8]. Following this, Vichitvejpaisal, Yamee, and Marsertsri offer an in-depth technical perspective on implementing realistic fire and smoke simulations within virtual platforms [9]. They explore various computational techniques, such as fuel quantity calculations and voxel-based methods, which are pivotal in creating interactive and engaging training environments. From a systems perspective, Fuhrmann dives into the creation of a VR fire training system, elucidating the technical and user considerations that drive the development of immersive and interactive training tools [10]. In consideration of user experience, Ting et al. guide us through the intricacies of user flows within VR environments, illustrating how scoring systems and communication layers can be built into the Unity 3D platform to create a structured training progression [11]. Engelbrecht, Lindeman, and Hoermann's SWOT analysis presents a balanced view on the use of VR in firefighter training, highlighting the potential for enhanced multi-user scenarios alongside possible challenges like technological barriers and the risks of over-reliance on positive reinforcement [12]. Complementing these perspectives, Loh and Hicks provide a clear and concise examination of basic fire safety procedures, underlining the importance of understanding fire classes, the appropriate extinguishers, and standard extinguishing operations [13]. The challenges faced by first responders are given a human dimension in the work of Haskins et al., who employ thorough data collection and interviewing techniques to inform the design of VR scenarios that reflect common challenges encountered by firefighters [14]. Puel offers insight into the complexity of modeling different firefighting roles using AI, discussing the simulation of 3D environments and the potential for AI-driven interactions within these systems [15]. Finally, a series of studies by Cha et al., Moreno et al., Wheeler, Engelbrecht, Hoermann, Brown, and Poulton collectively provide a foundational framework for simulating real-time fire spread using algorithmic workflows, and they explore how these simulations can be enhanced with gamification elements to create robust training simulations [16]–[19]. These frameworks are crucial as they underpin the base architecture upon which customizable VR firefighting training simulations can be developed.

The cited works demonstrate a collective progress toward an integrated, multifaceted approach to firefighter training through VR. They each contribute to a growing understanding that combines technical innovation with user-centric design, aiming to create training environments that are informative and engaging. This integration of varying methodologies and insights lays the groundwork for developing VR simulations that can effectively prepare firefighters for the unpredictable and dynamic nature of real-world fire scenarios.

III. Methodology, System Design, and Results

A. Functional Requirements

Drawing from literature reviews and insights gathered from online firefighter communities, several fundamental features are deemed essential for an effective VR simulation tailored for firefighting training. First, it is critical for the environment to be immersive, responsive, and interactive; enabling users to engage with virtual objects for experiential learning. Second, maintaining high task fidelity is crucial to ensure a seamless transition of skills from the VR environment to the real world and to prevent the formation of detrimental habits. This means that tasks performed in the VR space should closely mimic their real-life counterparts. Third, full user autonomy is another fundamental feature, as it is not only required to give the user a sense of presence in the VR environment but it also facilitates a comprehensive evaluation of users' actions and movements within the simulation. The portrayal of fire behavior demands a high degree of accuracy; the simulation must reflect the intricate dynamics of fire in reality. Multifaceted haptic feedback — spanning visual, auditory, and physical (tactile) dimensions — enriches the user experience and greatly enhances the experiential learning process. For instance, generating tactile feedback upon contact with virtual fire may serve as a negative reinforcement mechanism, signaling that the user should avoid touching flames. Lastly, incorporating a full spectrum of firefighting tools and equipment, akin to those used regularly by professionals, is crucial to enrich the simulation's relevance and practical utility.

B. Software and Development Tools

The VR simulation was developed using Unity 3D which enables the proposed framework to leverage modern technologies for development and future scalability. Furthermore, as Unity 3D is a real-time game engine, it enables the simulation's parameters to be adjusted on the fly, which allows for customization of training scenarios as needed. The project leverages the Unity XR Interaction Toolkit to allow for VR interactions to be added to the simulation. To incorporate fire dynamics, the project makes use of the "Ignis - Interactive Fire System" which is available on the Unity Asset Store [20].

C. Flammable Objects and Fire Spreading Model

In developing a VR platform for firefighter training, a critical aspect is the accurate simulation of fire behavior and its spread. This is achieved using the Ignis Interactive Fire System, which provides a base for creating realistic visual

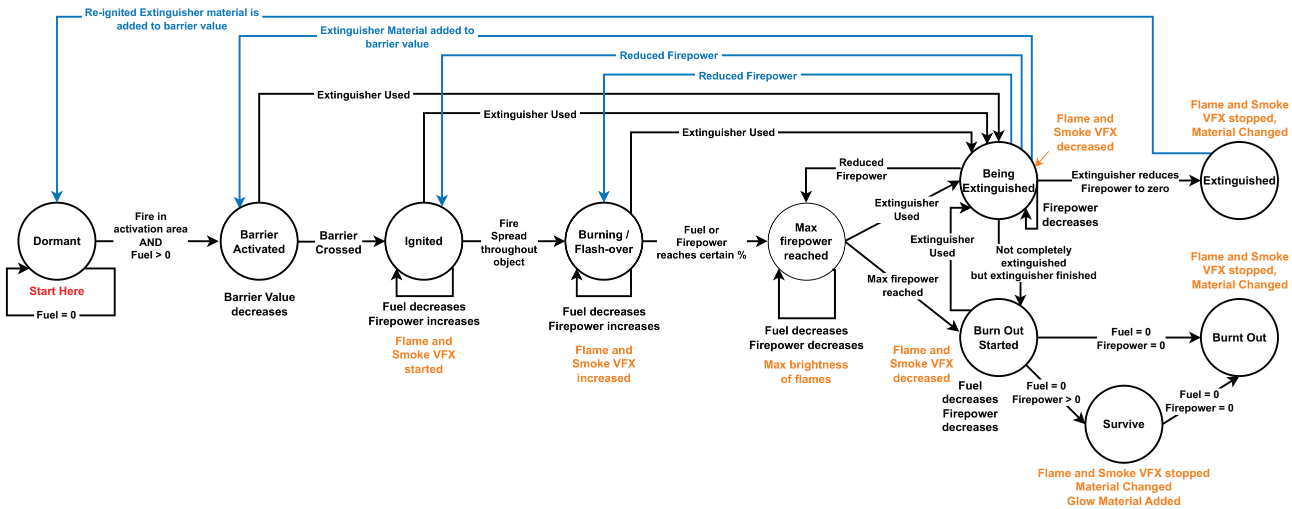

Fig. 1. State Management and Fire Spreading Model for Dynamic Fire Simulation in Real-Time 3D Environments

effects for fire and smoke. The platform incorporates a state management model inspired by the fire spread theory and the work of Moreno et al. [16]. The model allows objects within the virtual environment to exhibit flammable characteristics through a suite of customized scripts and event systems. These scripts, alongside other technical configurations, are crucial for dictating how objects ignite, sustain fire, and respond to firefighting efforts.

Figure 1 illustrates the comprehensive state management model designed for simulating dynamic fire spread in real-time 3D environments. The simulation tracks the lifecycle of a fire, starting from an inert 'Dormant' state. When ignited, the fire consumes the object's fuel, leading to various stages including 'Burning/Flash-over,' where a dramatic increase in fire activity occurs. The simulation allows for dynamic responses to fire extinguishing efforts, reflecting a decrease in firepower and potentially leading to a complete extinguish, or a 'Burnt Out' state if the fire naturally depletes its fuel. The system is sophisticated enough to simulate a relapse into active burning if the fire is not thoroughly extinguished and the extinguishing agent runs out. It is also to be noted that not all objects may burn. Inflammable objects do not go through these state transitions but may otherwise just increase their inherent temperature parameters (firepower) based on the properties of the materials they are made up of.

This immersive experience is enhanced through the use of haptic tacticle feedback. To employ this, the Unity tag system is used. Haptic feedback is provided to users when they interact with objects in the virtual environment, and a strong tactile sensation is provided when they come close to or interact with burning objects. This is used as a method of reinforcing the reality of the hazards present in the virtual training environment. The tags and event system are also used by the environment manager to execute events such as starting the fire alarm, managing data integration with backend servers, etc. The model is effective in delivering an educational experience that mirrors the unpredictability and behavior of real-world fires, ensuring that trainees can experience and react to fires as they would in actual scenarios. Through its detailed simulation of fire emergence and extinguishment, the VR tool equips firefighters with the knowledge and skills necessary for real-world encounters, granting them the opportunity to engage in extensive practice sessions to hone their response to fire-related emergencies.

D. Fire Visual Properties

Multiple factors contribute to the realistic representation of fire behavior in virtual simulated environments. These parameters are responsible for controlling various visual and atmospheric aspects of the fire, such as the liveliness of the flames, flame color, flame length, and the environment's impact on the flames such as wind zones, etc.
Additionally, the fire dynamics also govern the characteristics of the smoke, including its color, thickness (alpha value), and speed of dispersion. In the designed simulation, the color of fire and smoke dynamically changes based on the type of object that is burning. This feature aims to provide a realistic representation of fire behavior and the visual cues associated with different burning materials. By accurately simulating the color variations, trainees can develop a better understanding of the various fire dynamics associated with different objects, and learn to identify the type/material/properties of these objects based on their distinctive fire and smoke visuals (color, density, liveliness, etc.) and their propagation patterns. This helps enhance their situational awareness and enables them to make informed decisions regarding the firefighting strategies and appropriate response measures they may want to employ.
Incorporating embers and sound effects, the simulation intensifies immersion, guiding firefighters through a multisensory experience. By meticulously managing these fire dynamics. The virtual reality training application creates a highly dynamic

and authentic training environment for firefighters, enabling them to develop crucial skills and an understanding of fire behavior in a controlled and safe setting. Figure 2 showcases how the fire colors can be adjusted within the virtual reality training simulation. By manipulating the color of the flames, the simulation can represent various types of fires, such as a typical orange-yellow flame for a regular fire or a blue flame for a gas fire, etc. This visual differentiation aids firefighters in identifying material types and combustion stages during training.

Fig. 2. The sequence showcases varying flame colors and smoke densities, indicative of different burning materials. The first object shows a classic orange flame with thick smoke, typical of organic combustion. The middle object's intense red flame and lighter smoke suggest a distinct material and burn temperature. The third displays a unique pink flame with sparse smoke, while the last emits a bright yellow flame with almost clear smoke, representing a rapidly burning substance.

Similarly, the fire liveliness, smoke color, smoke density, amount of embers, etc. may also be altered. The ability to alter the flame and smoke properties adds to the realism of the fire scenarios in the simulated training environment.

In addition, burning objects may also change their materials to indicate the stage of the burning process they are in. This allows the firefighters to make decisions based on whether an object is about to burn out or reach its maximum flammability and prioritize their tasks and decisions based on the state of the flammable objects. These different stages of burning and material changing may be seen in Figure 3.

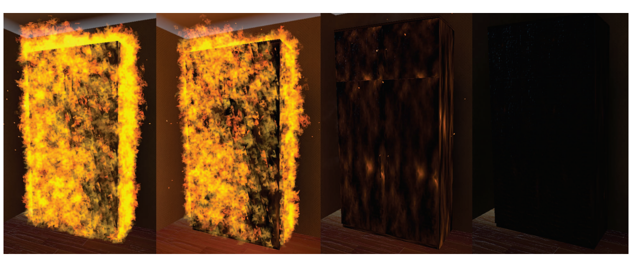

Fig. 3. The images sequentially depict the transition from ignition to burnout of a combustible object, showcasing the Ignition, Burn Out Started, Survive, Burnt Out states.

E. Fire Extinguishing Methods

The simulation features two types of extinguishing equipment: a water/foam-based extinguisher and an extinguisher cement ball, both designed to aid in fire suppression. To simulate the foam/water spray from the extinguisher, a particle system is utilized. The particle system emits particles that visually represent the extinguishing agent being discharged from the extinguisher. This creates a visual effect that mimics the behavior of foam or water being sprayed onto the fire. Complimenting this the extinguisher also incorporates a ray-cast extinguishing mechanism. When the user aims the extinguisher towards a fire and uses it, a raycast is projected from the position of the extinguisher's nozzle. The raycast detects the flammable object or fire source in its path and triggers an extinguishing action upon use of the extinguisher. This action may lead to reducing the fire's intensity, stopping the fire's spread, or completely extinguishing the fire depending on how the extinguisher is used. Furthermore, the extinguisher, on raycast check, also checks the object's fire type and only extinguishes it if the correct extinguisher type is being used.
To simulate the extinguisher cement ball effectively, a dust explosion particle system was utilized, generating realistic visual effects to mimic the explosion of the ball. Upon detonation, the extinguisher cement ball releases a sphere-cast extinguisher-a form of collision detection that projects a spherical shape outward. Figure 4 displays these extinguishing tools within the simulation.

Fig. 4. Left: Traditional fire extinguisher deploying chemical retardants, visualized by the blue particle stream. Right: Fire extinguisher balls, which upon activation, explode and release extinguishing agents to disrupt the fire's chemical reactions.

F. Haptic Feedback: Tactile and Auditory Haptics Integration

Haptic feedback is a crucial component of the VR firefighting training simulation as it provides a sense of immersion and presence to the trainees; enhancing the realism of the training experience. It allows trainees to receive visual, auditory, and tactile sensations that simulate real-world interactions. These occur when they touch objects, operate equipment, or feel burning objects. In the simulation, haptic feedback is delivered through the Unity XR Interaction Toolkit's built-in functionality. To deliver audio feedback, spatial audio is used. This allows the trainees to perceive sound sources in a three-dimensional space, just as they would in real life. Spatial audio helps accurately simulate the direction, distance, and movement of sound, creating a more immersive and lifelike environment. The use of spatial audio enables the trainees to identify the locations of critical auditory cues, such as the sound of crackling flames, collapsing structures, or distant cries for help. This information helps them make informed decisions and respond appropriately to the simulated firefighting scenarios. To enhance cognitive resilience and simulate real-world firefighting scenarios, a fire alarm system was meticulously designed and implemented within the virtual reality training application. This system incorporates custom scripts and flame events to effectively determine the activation and deactivation of the alarm. When any object within the simulated environment catches fire, a flame event is triggered and the environment manager subsequently triggers the fire alarm. As the number of burning objects increases, the fire alarm manager maintains a list to keep track of the ongoing fire incidents. Conversely, when objects cease burning, they are removed from the list. Once all objects have ceased burning and the list becomes empty, the fire alarm manager discontinues the alarm, terminating the auditory beeping. This interactive feature of the fire alarm system serves both as a source of auditory feedback and as a cognitive training mechanism for firefighters, replicating a source of constant annoyance that they may encounter during real-life firefighting situations.

G. 3D User Interface Design

The user interface (UI) design in the virtual reality firefighting training application allows the user to reset the scene, change and navigate between different scenarios, and toggle the type of rotation they prefer (continuous or snap-based) when using the controller's joysticks. The option to alter the turn type is a feature that is provided to ensure user comfort. Furthermore, the UI design serves as an information hub, displaying controller information and level objectives to the user. By providing clear instructions and objectives, the UI enhances user understanding and engagement, ensuring that trainees are well-informed about the training tasks and goals they need to accomplish.

Figure 5 showcases this 3D UI design, which provides an immersive and visually appealing interface for the virtual reality firefighting training application.

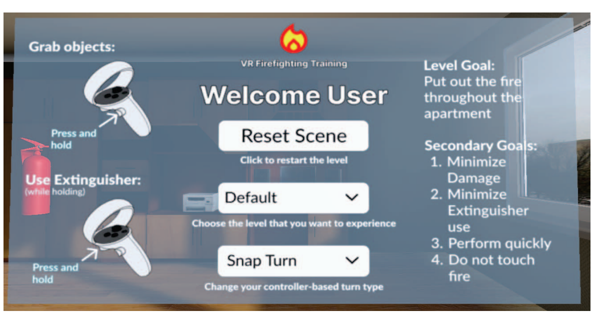

Fig. 5. 3D UI for the VR platform, depicting object interaction controls and a main menu outlining the mission objectives and performance goals.

IV. Expected User Experiences and Discussion

This paper discussed the implemented interactive VR simulation; utilizing existing literature for its theoretical foundations and Unity 3D for its development, with the purpose to enhance the training of firefighters. The simulation operates on a system equipped with a Ryzen 5 3600 CPU, Nvidia 1650 SUPER GPU, and 16 GB RAM, thereby ensuring smooth and responsive interaction for users. The Meta Quest 2 HMD was used to perform preliminary user testing. In the simulation, trainees are afforded complete body autonomy within this virtual space, enabling them to traverse and manipulate the environment. This freedom supports experiential learning, allowing for a spectrum of outcomes influenced by the trainees' decisions which directly impact the spread of fire, that is, the system affords the users to perform both good and bad actions. Feedback within the simulation is multisensory. Visual, auditory, and tactile cues combine to create an immersive learning experience. For instance, when a fire ignites, the accompanying alarm and the transformation of materials of burning objects provide immediate and informative cues. When flammable objects come into contact with other flammable objects they may also ignite, thus spreading the fire. During the burning process, the object changes its materials to showcase which state of the burning model it is currently in. This allows the trainees to make judgments and act accordingly. Such cues may also be seen in Figure. 6 which depicts a user trying to extinguish the fire that has spread throughout the room. This showcases that if the correct steps aren't taken in a timely manner, the fire may spread beyond control, thus showcasing a failure to manage and control the situation during training. Such design intricacies ensure that the simulation does not merely mimic reality, but also educates through interaction and consequence.

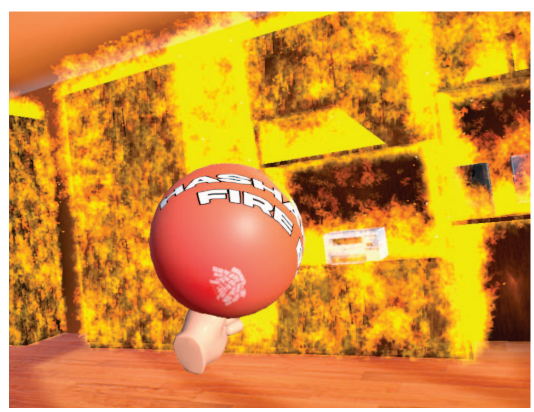

Fig. 6. A snapshot of the simulation, depicting a user poised to throw a fire extinguishing ball into a fully engulfed room fire scenario.

Our system stands out due to its procedural fire spreading mechanism, which operates in real-time within a three-dimensional space. This dynamic model offers a novel approach as it emulates the complexities of fluid dynamics-based simulations to approximate real fire behavior while eliminating the need for advanced computational resources by abstracting away some of these variable complexities. Furthermore, our system's modular design provides a base framework and opens avenues for expansion and refinement, allowing for the development of tailored simulations to cater to a variety of firefighting scenarios, surpassing the capabilities of many one-dimensional systems.

While other simulators may focus on specific aspects of firefighting training, our system provides a comprehensive framework and a holistic and engaging VR experience. The versatility of our system not only supports the creation of varied scenarios but also incorporates a broad range of firefighter training modules, such as fire spread method, visual and auditory cues, extinguishment support, etc. This integration is paramount, as it equips trainees with a robust skill set that is adaptable to numerous real-life situations, a quality that is not always present in other available simulators.

V. Limitations and Future Work

Future work includes developing implementations for Flashover, Backdraft, a UI panel for trainers to alter parameters in real-time alongside trainees, benchmarking the current fire spreading model to FDS-based systems to create even more accurate fire spreading, implementing randomness features into the environment, adding day and night cycles, providing human-agent interaction within the simulation for training team exercises, a backend server for data logging and analysis and improved haptics. This will allow the system to further increase the repeatability of the VR exercises, thus allowing for more varied situations and better experiential learning. In addition to the aforementioned features, the addition of human-agent interaction capabilities to the system would allow the trainees to carry out team exercises multiple times without wasted time and resources, thus allowing for increased repeatability of the training exercises. Future work will also include user testing of the system alongside firefighting trainers and trainees, to garner user feedback from both system users as well as trained professionals, so that the current features may be further iterated upon.

VI. Conclusion

In conclusion, this paper looked at the need for developing Virtual Reality-based firefighting training platforms, the rationale behind their necessity, potential applications, and design principles. Through a comprehensive literature review, the paper distills a suite of fundamental features integral to such simulations, which informed the development of a robust framework for VR-based firefighter training. Further, the paper outlines practical implementation techniques within the Unity 3D game engine, demonstrating how these features can be effectively developed. The importance of each feature is discussed, highlighting their contribution to the realism and educational value of the simulation. The exploration culminates in the presentation of future directions for this research, underscoring the potential enhancements that could elevate the system's performance and user engagement.

References

[1] I. NSC, ”Fire-related Deaths & Injuries - Injury Facts”, Injury Facts, 2020. [Online]. Available: https://injuryfacts.nsc.org/home-and-community/safety-topics/fire-related-fatalities-and-injuries/. [Accessed: 25- Sep- 2022].

[2] H. Engelbrecht, R. Lindeman and S. Hoermann, ”A SWOT Analysis of the Field of Virtual Reality for Firefighter Training”, Frontiers in Robotics and AI, vol. 6, 2019. Available: 10.3389/frobt.2019.00101 [Accessed 25 September 2022].

[3] S. Duffy, Basic Firefighter Training Reimbursement Program. Olympia: Washington State Patrol—Fire Protection Bureau, 2013.

[4] S. Loh and T. Hicks, Basic Fire Extinguisher Training Course, 1st ed. Princeton: The Department of Public Safety's Bureau of Fire Prevention, 2014.

[5] I. Kanat, S. Siloju, T. Raghu and A. Vinze, ”Gamification of emergency response training: A public health example”, 2013 IEEE International Conference on Intelligence and Security Informatics, 2013. Available: 10.1109/isi.2013.6578802 [Accessed 25 September 2022].

[6] L. Brown and M. Poulton, ”Improving Safety Training Through Gamification: An Analysis of Gaming Attributes and Design Prototypes”, Advances in Intelligent Systems and Computing, pp. 392-403, 2018. Available: 10.1007/978-3-319-94223-0_37 [Accessed 25 September 2022].

[7] M. Suhail et al., ”Simulating a Futuristic Fire Pump Panel in Virtual Reality,” 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), 2019, pp. 1415-1416, doi: 10.1109/VR.2019.8798280.

[8] V. Charalampous, J. Besharat and C. Stylios, ”Designing and Developing a VR Environment for Indoor Fire Simulation”, 24th Pan-Hellenic Conference on Informatics, 2020. Available: 10.1145/3437120.3437315 [Accessed 25 September 2022].

[9] P. Vichitvejpaisal, N. Yamee and P. Marsertsri, ”Firefighting simulation on virtual reality platform”, 2016 13th International Joint Conference on Computer Science and Software Engineering (JCSSE), 2016. Available: 10.1109/jcsse.2016.7748912 [Accessed 25 September 2022].

[10] A. L. Fuhrmann, “Building a Virtual Reality Fire Training with Unity and HTC Vive,” 2017.

[11] Y. Ting, C. Feng, W. Wenqiang and Y. Kai, ”Design and Realization of Ship Fire Simulation Training System Based on Unity3D”, IOP Conference Series: Earth and Environmental Science, vol. 108, p. 052101, 2018. Available: 10.1088/1755-1315/108/5/052101 [Accessed 2 October 2022].

[12] H. Engelbrecht, R. Lindeman and S. Hoermann, ”A SWOT Analysis of the Field of Virtual Reality for Firefighter Training”, Frontiers in Robotics and AI, vol. 6, 2019. Available: 10.3389/frobt.2019.00101 [Accessed 25 September 2022].

[13] S. Loh and T. Hicks, Basic Fire Extinguisher Training Course, 1st ed. Princeton: The Department of Public Safety's Bureau of Fire Prevention, 2014.

[14] J. Haskins et al., ”Exploring VR Training for First Responders”, 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), 2020. Available: 10.1109/vrw50115.2020.00018 [Accessed 25 September 2022].

[15] D. Puel, “An authoring system for VR-based firefighting commanders training,” Electronic Imaging, vol. 30, no. 3, 2018.

[16] A. Moreno, J. Posada, Á. Segura, A. Arbelaiz, and A. García-Alonso, “Interactive fire spread simulations with extinguishment support for virtual reality training tools,” Fire Safety Journal, vol. 64, pp. 48–60, 2014. doi:10.1016/j.firesaf.2014.01.005

[17] Cha, M., Han, S., Lee, J., & Choi, B. (2012). A virtual reality based fire training simulator integrated with fire dynamics data. Fire Safety Journal, 50, 12–24. doi:10.1016/j.firesaf.2012.01.004

[18] Wheeler, Steven & Engelbrecht, Hendrik & Hoermann, Simon. (2021). Human Factors Research in Immersive Virtual Reality Firefighter Training: A Systematic Review. Frontiers in Virtual Reality. 2. 671664. 10.3389/frvir.2021.671664.

[19] Brown, L.D. and Poulton, M.M., 2018, July. Improving safety training through gamification: An analysis of gaming attributes and design prototypes. In International Conference on Applied Human Factors and Ergonomics (pp. 392-403). Springer, Cham.

[20] Arctibyte, “Ignis - interactive fire - URP/HDRP: Particles/effects,” Unity Asset Store, https://assetstore.unity.com/packages/tools/particles-effects/ignis-interactive-fire-urp-hdrp-181079 (accessed Aug. 08, 2023).