Designing and Developing a VR Environment for Indoor Fire Simulation

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ABSTRACT

Serious games have been progressing for decades in both digital and non-digital forms. Using a game approach to train and educate people is steadily rising, mainly based on the market of virtual and augmented reality. Fire training is an important subject because of participants' safety, the required costs, the limitation of the scenarios' complexity, and the ecological concerns. Nowadays, the reduced prices of hardware and software expedited the rise of the VR/AR immersive training experiences. The development of a virtual environment for fire training purposes is a challenging project. In this work, we present a fire spread simulation environment for training employees, in indoor fire cases, which runs in a CAVE (Cave Automatic Virtual Environment). This immersive environment has been developed in the Unity 3D engine and fire spread modeling was performed with FDS (Fire Dynamics Simulator). The developed platform allows the user to observe the fire propagation, roam through the scene, and intervene with the proper extinguisher to blow out the fire.

CCS Concepts: • **Applied computing → Interactive learning environments**.

Additional Key Words and Phrases: Virtual Reality, Unity 3D Engine, Fire Training Simulation, Fire Propagation

ACM Reference Format:
Vlasis Charalampous, Jeries Besharat, and Chrysostomos Stylios. 2020. Designing and Developing a VR Environment for Indoor Fire Simulation. *J. ACM* 37, 4, Article 111 (October 2020), 6 pages. https://doi.org/10.1145/1122445.1122456

1 INTRODUCTION

Serious games have rapid growth in both the gaming industry and learning environments. Djaouti et al. [1], mention that the origins of this term go back to the age of Renaissance, where Neo-Platonists used light-hearted humor in the literature to deal with serious topics, which called "serio ludere". Abt in his book[2] in 1970, gave the first clear definition for Serious Games: "Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be

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0004-5411/2020/10-ART111 $15.00
https://doi.org/10.1145/1122445.1122456

played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining".

Computers are being used for years as an educative tool, by applying any available technology. Teachers and trainees combine the traditional oral method with educational videos and interactive presentations to strengthen the learning experience. Studies[3] mention that students learn more efficiently when a variety of teaching methods is being applied. Virtual technologies provide a very realistic experience where the trainee can deeply immerse, he has the illusion of being part of the simulation, and interact with it. The participating student is no more a passive observer but he is a part of an experience that provides deeper learning outcomes. These technologies create a new learning paradigm, where the teachers are the designers of the immersive educational environment rather than traditional lecturers[4].

Designing an educational scenario in a virtual environment comes with infinite capabilities, in contradiction with the real-life cases. E.g. if the case scenario is the representation of a room with certain dimensions and some furniture that is hard to find, in virtual training this barrier could be surpassed easily. Burning various objects to simulate a real-life scenario is something that could lead to potential fire burn injuries and also, and it is costly for the training organization and requires repeating training sessions for the newcomers. In addition to this by, applying immersive technologies in training could eliminate potential ecological concerns such as fire emissions.

Section 2 presents some notable related work in VR fire training simulations. Section 3 describes the implementation of the proposed training simulation and the system architecture, while in section 4 the main logic is explained in detail. Section 5 presents the fire extinguishing approach and section 6 concludes the paper and presents future work.

2 RELATED WORK

Fire training simulations or fire spread simulations, in general, had been widely investigated in recent years and it is a popular field of research. Moreno et. al[5], proposed fire spread algorithms for forest and urban environments that produced approximated but good results that firefighters and managers could use. They proposed algorithms with low complexity to run efficiently with standard computing power. They adapted the grid approach where each grid's cell hold the essential information, like the type, the state, the fuel, and others. The validation of the algorithms have been performed with the use of the FARSITE application, the output of Zhao's analysis scenario[6], and also by professional firefighters' consulting.

Fathima et al.[7] presented an immersive environment for fire safety training, where the core concept was Pull, Aim, Squeeze, Sweep for fire extinguishers. This VR teaches the trainees how to apply some fire safety drills that had been taught earlier, in a real-time physical situation. The entire training process applied gaming patterns to be friendlier for the trainees. The scene was an office room, where a fire breaks out and the user has a specific amount of time to save a person by taking him outside the office and rescue him.

Dechamplain et al.[8], presented Blaze, a serious game intended to educate users for house fire hazards. The scene starts with a small stove-top cooking fire and the user has to pick the appropriate tool or ingredient to extinguish the fire and he is able to decide according to the circumstances. For the fire propagation system, they used the block concept where each block has a material and temperature value. The fire spreads by heating adjacent blocks, which trigger the fire spread when they pass a limit. This limit depends on the material of each block.

Schlager[9], proposed a solution for training non-professionals using the HTC VIVE as an extinguishing agent. The virtual environment has been developed with the Unity 3D engine and a grid approach adapted for the fire spread model. A 3D grid of voxels was developed where and every voxel holds the object's information: temperature, state, and physical properties. Every voxel

Fig. 1. Room scene on fire

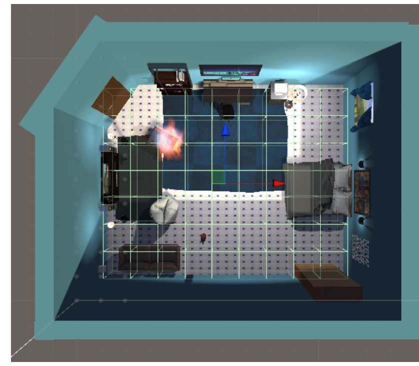

Fig. 2. Automatic grid generate

is responsible for starting or stopping the fire spread, according to the auto-ignition thresholds that were set for each object. Every object had six radiators -on each side- that received or emitted heat to the scene.

3 IMPLEMENTATION

Fire modeling can be categorized as empirical, semi-empirical, and physical[10]. Empirical modeling uses statistical relationships and physical modeling uses convection and heat transfer. The semi-empirical approach uses both empirical and physical to create hybrid modeling.

In this research, we used mathematical equations that are widely accepted in the fire-related bibliography. We took into consideration many aspects of an object's material, such as density, size, volume, geometry age, etc. and we investigated a novel algorithm that could calculate the mass reduction and the propagation of the fire but this was a complicated solution and with unreliable results. Thus, we turned into the FDS solution, which is an established software tested in numerous projects and used widely for the fire modeling. [11–15]

Fire Dynamics Simulator (FDS) is a powerful Computational Fluid Dynamics (CFD) model developed at the National Institute of Standards and Technology (NIST). It is written in FORTRAN 90, which has been used for modeling a variety of phenomena, such as pyrolysis, combustion products by fire, spread of fire and smoke. As its creators mention, "the model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flows with an emphasis on smoke and heat transport from fires"[16].

3.1 System Architecture

This research aims to investigate and model an indoor fire and then create an immersive environment with the evolution of fire as well as fire extinguishing. An appealing room scene has been designed (fig. 1) with Unity 3D engine and Blender.

The scene's objects have been tagged as flammable, automatically from the script. Respectively, the fire has its own tag to separate its behavior from the flammable objects' behavior. All the flammable objects' geometries were imported in the FDS to calculate the fire impact on them.

FDS is a FORTRAN software tool and thus, we had to create a script in FORTRAN language to describe each of these geometries. Before the simulation starts, we set a time step which is the rate that the simulation runs. After running the simulation, the FDS exported multiple files with the model results. These results describe the fire spread on the specific geometry based on several factors such as material, size, the volume of this geometry, and more. Based on this set of data we focus on the mass-loss rate values and the time it takes for the fire to burn the geometry, so we created methods to retrieve this data to use them in the algorithm.

To start the fire training, the scene needs to be set. The script sets automatically the simulation step, calculated from the dataset and the user has the option to alter it, to change the simulation speed. Furthermore, the trainer has to set the furniture's burning material, by a drop-down menu. This information is being used in the extinguishing logic - that will be described below - where the user will have to pick the right extinguisher to blow off a specific material.

4 THE METHODOLOGY

4.1 Retrieving data from FDS's datasets

Initially, we had to develop the methods for data preprocessing. Thus, we parsed the needed datasets and extracted the essential information into lists, in order to use them in the algorithm. The lists are the mass-loss rate and the time-stamps list which are essential for the mass reduction logic. From the first two lists we calculated the full burn index; the point that the object's mass zeroes out, and by this, we can calculate the total time that an object needs to lose its whole mass. In order to complete the second part, we need to calculate the total mass and we managed this by summing up all the subtracted mass quantities from the mass-loss rate list.

4.2 Fire propagation - Grid System

The succeeding part of our approach concerns the fire spread simulation process. According to the scenario, the fire starts in a room, on a specific object, and then it should start spreading in the room based on our methodology. In a real-world scenario, the fire that burns an object remains in it until it burns completely, while at the same time it spreads to the nearby objects that come in contact. To simulate the same process we created a method for generating an invisible grid in Unity's scene (fig. 2).

We developed a method that calculates the floor dimensions by using Unity's Mesh renderer bound size property, which gives us the length of the x-axis and the z-axis. We segmented the 1x1 cells and these cells have Unity colliders attached that informs us about the objects they touch. In conclusion, by this grid-cell approach we know, in every cell, which objects locate in and we can create lists for every cell that will hold this information. So, if a cell has two objects in it, we check the ignition temperature of every object and we generate fire clones, if the cell's temperature passes the ignition temperature limit, and gradually we transfer the fire into adjacent cells.

4.3 Reducing the mass

The main method of the simulation is the reduce-mass method. In this method we reduce the objects' mass by applying the following logic. When a fire clone is generated then the reduce-mass method, for the specific cell's object, starts running. This method - while the mass is greater than zero - iterates and subtracts the mass quantities from the mass-loss rate list and subsequently from the object that is burning. The rate of reduction is the same with the simulation step that we described in section 3.

5 EXTINGUISHING

A fire training simulation without an extinguishing system that provides user interaction, could not be considered a complete solution. We count on the trainee's interaction to add significance to the training sessions, so the trainee can acquire practical knowledge in handling fire hazards. Thus, we developed an extinguishing system with many options.

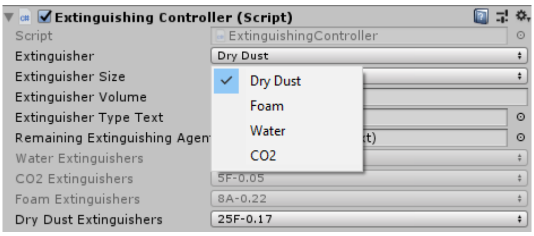

Fig. 3. Extinguisher main types (Unity Inspector)

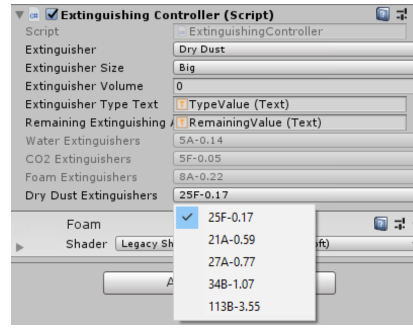

Fig. 4. Extinguishing subtypes

After thorough research [17], [18] we concluded on some specific types of extinguishers, and we created the necessitated algorithms where the trainee should pick the proper extinguisher to extinguish the fire. In the real world -during the simulation- the user has to pick a standard, empty, extinguisher with the proper device attached to it, in order to get connected with the immersive environment. To enhance the interactivity we let the user select, initially, the size of the extinguisher between medium and large, which applies in the duration that the user presses the extinguishing handle. To improve the learning outcomes and increase the benefits that the users can derive from this educated virtual reality project, we allow the trainee to select between different types of extinguisher such as water, CO2, foam and dry dust. Thus, depending on her choice, the fire will start to stand out or stay unaffected. e.g. using a CO2 extinguisher to stop a fire that blazes a piece of furniture with common material will not put out the fire. The ultimate choice for the trainee is the extinguisher sub-types, which denote the power of the extinguisher. Indicatively, when the user chooses the dry dust extinguisher, there are five available sub-types (fig.4) to choose from; 25F-0.17, 21A-0.59, 27A-0.77, 34B-1.07, 113B-3.55. he decimal number denotes the fire amount that will get subtracted every second the extinguishing material gets in contact with fire.

6 FUTURE WORK AND CONCLUSIONS

In future stages of this research, we plan to add or enhance some of this VR training's features. The simulation will be reviewed by professionals firefighters in order to give us feedback about the quality of the simulation, the virtual environment, and the realistic objects' burning and fire propagation. We consider implementing a solution for integrating this platform in mobile.

This research, whilst it has future work in progress, provided us some useful findings. FDS is a powerful tool for modeling fire but hides a lot of complexity. Considering the use of a GUI tool would help the ease of use from a trainer's perspective. Although after many experimenting simulations an optimal solution for our simulation was found. We utilized only the mass-loss rate and the time sequence of the simulation exported dataset, but the possibility of using more of FDS' features should not be kept out. Unity Engine, along with Blender, provided us a powerful software platform for creating an appealing virtual environment. Moreover, the main contribution of this research work, is that it can be adopted by firefighting organizations in order to support trainees during their learning period. Furthermore, this fire spread simulation work can educate civilians in order to learn how to react on fire hazards situations. Both contributions are really important for everyday life, taking into consideration common fire situations, that sometimes lead to casualties or injuries. Once the extinguishing agent integration is completed, then we will have a complete virtual fire training environment.

ACKNOWLEDGMENT

This research work is funded by the Operational Programme "Western Greece" 2014-2020, under the project "Virtual Reality Simulator for Training Against Fires, V-staf, Co-financed by the European Regional Development Fund (ERDF).

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