Application of Virtual Reality Technology to Evacuation Simulation in Fire Disaster

Aizhu Ren, Chi Chen, Jianyong Shi and Liang Zou
Department of Civil Engineering
Tsinghua University
Beijing 100084, the People's Republic of China

Abstract - *The correct and quick evacuation of occupants is very important for the save of lives in a public building when it is attacked by a fire. However, it is difficult to train the occupants for evacuation in a real environment since it is dangerous and expensive. This paper presents a virtual reality system developed by the authors for the simulation of occupant evacuation in an underground station. The simulation of fire scene, the simulation of evacuation process in a virtual environment, the development solutions for the realization of the immersion of the user in a virtual environment, and the interaction between the users and the virtual environment are presented in details. The results show that the system can be used for the evacuation simulation and safety evaluation of the building.*

Keywords: Virtual Reality, Emergency Evacuation, Fire Simulation, Visualization

1 Introduction

Emergency evacuation is very important in fire safety study. Surveys of fire accidents indicate that if occupants are successfully evacuated right after the fire, casualty can be greatly reduced even though the fire is not suppressed rapidly. There are two possible reasons for the failure of timely evacuation of the occupants from the burning building: one is that the emergent evacuation is delayed due to the improper layout of the inner structure of the building; the other one is that occupants take unreasonable evacuation measures because of panic or unfamiliarity with the burning building.

For the first issue, the solution is to simulate emergency evacuation in fire condition when a building is being designed. Hence, much concern has been concentrated on evacuation simulation, and many computer based evacuation models have been developed to address the needs [1,2,3]. In the present evacuation models, the space of the building is represented by a collection of tiles or nodes (fine network) or by arcs and nodes (coarse network), and the prediction of the evacuees' behavior is conducted by mathematical models [4,5,6,7]. However, it should be noted that the psychological responses and physical behaviors of human beings are usually quite complicated in fire conditions and very difficult to be predicted correctly. For example, the spreading of flames and smoke may create panic mental state and lead to abnormal behaviors, and sometimes, the decoration and lighting of the inner space of the building may mislead evacuees into choosing the wrong evacuation route. In other words, it is difficult for mathematical models to provide accurate prediction of human behavior in fire condition.

For the second issue, the solution is to conduct emergency evacuation training and drilling in real building. However, such on site drilling bears some disadvantages—high cost, poor repetitive capability and easy to cause accidents.

The rapid development of Virtual Reality (VR) technology makes it possible to overcome the disadvantages mentioned above [8,9,10,11]. With VR, the professionals and the occupants immerse themselves in the virtual building environment with virtual fire scenes. They can interact with the virtual environment, simulate emergent evacuation process, judge whether the inner layout and decoration of the building is reasonable or not and conduct evacuation trainings and drillings. Also, VR overcomes the disadvantages of high cost, poor repetition and danger stated above.

This paper introduces a VR system developed by the authors, which can be used in the simulation, drilling and training of fire emergency evacuation. The system can provide the users with a virtual building environment as that in the real world. The users are able to navigate in the virtual building environment with a "real" fire flaming around, and then obtain an insight into the spreading of fire. It should be mentioned that the spreading of flame and smoke in this system is simulated on the basis of fire numerical simulation, which makes the evolution of fire in the virtual environment similar to that in the real world.

The technical details are introduced in the following sections. The paper is organized as follows: Section 2 introduces the architecture of the system. Section 3 describes the approaches to the simulation and visualization of the spreading of fire and smoke. Section 4 depicts the simulation and interaction techniques for emergency evacuation. Finally, the conclusions are drawn in Section 5 together with the recommendations for future research.

2 System Architecture

The architecture of the system is shown in Figure 1. The system consists of Graphical User Interface, Information Management Module, Fire Simulation Module, Emergency Evacuation Module, Fire Fighting Simulation Module and databases. The Fire Simulation Module provides a vivid virtual building with "real" fire scene for the users. By the Emergency Evacuation Simulation Module, the users can perform emergency evacuation drillings and trainings, and evaluate the performance of emergency evacuation of the building. The Fire Fighting Simulation Module allows the users to perform some simple fire fighting tasks in the virtual environment such as using a virtual foam extinguisher to suppress a fire. In order to obtain immersion, a Head Mounted Displays is used to view the GUI when the user is performing emergency evacuation drillings and trainings.

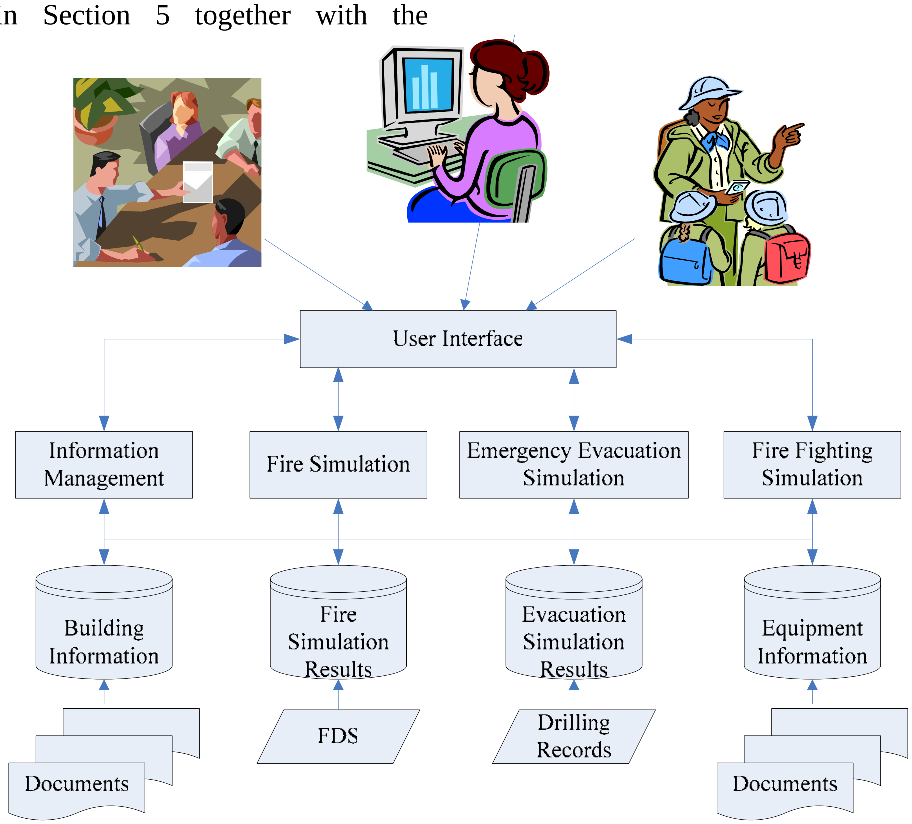


Figure 1: The Architecture of the System

The tools used for developing the system include: Vega, Multigen Creator, FDS and Visual C++ 6.0. Vega is a world famous real-time scene simulation platform for visual reality applications. Multigen Creator is employed to generate the 3D building model. Both Vega and Multigen Creator are produced by MultiGen-Paradigm Company, and can provide adequate support to each other. The fire numerical simulation model FDS (Fire Dynamics Simulator) is employed to predict the development of the fire, especially the spreading of the flames and smoke. The visualization of flames and smoke, and the interaction between the user and the virtual environment are accomplished by Vega APIs and development of C++ programs by means of Visual C++ 6.0.

3 Simulation of Fire Scene

The development of the fire in a building is very hard to predict accurately. Hence, in most of the previous emergency response systems, the spreading process of flames and smoke are usually simplified by simulation approaches such as cellular automata, random variables, etc. [11]. The emergency response under such simplified fire condition may be unreliable.

In order to accurately predict the evolution of fire in the virtual environment, this system employs FDS, the fire CFD model developed by The National Institute of Standards and Technology (NIST), USA, to obtain the potential evolution of a fire. FDS predicts smoke and/or hot air flow movement caused by fire, wind, ventilation systems, and other factors by solving numerically the fundamental equations governing fluid flow, commonly known as the Navier-Stokes equations. FDS can predict flow velocities and temperatures to an accuracy of 20 percent compared to experimental measurements [12].

The integration of fire numerical simulation and virtual reality can immerse the users in a computer-generated fire scenario which is too dangerous, difficult, or expensive to play out in real life [13]. However, it is very difficult to have instant numerical simulation of fire in the system when the users are navigating in the virtual environment, for the numerical simulation usually needs giant memory and CPU time. Thus the method adopted in this system is described in Figure 2: suppose every possible fire disaster case, use FDS to calculate the fire development in each case in advance, and then establish fire simulation results database for some concerned results, such as temperature, soot density, height of smoke layer, heat release rate. The system retrieves certain data in the fire simulation results database when it is running so as to achieve the visualization of the spreading of flame and smoke. The concerned results from fire numerical

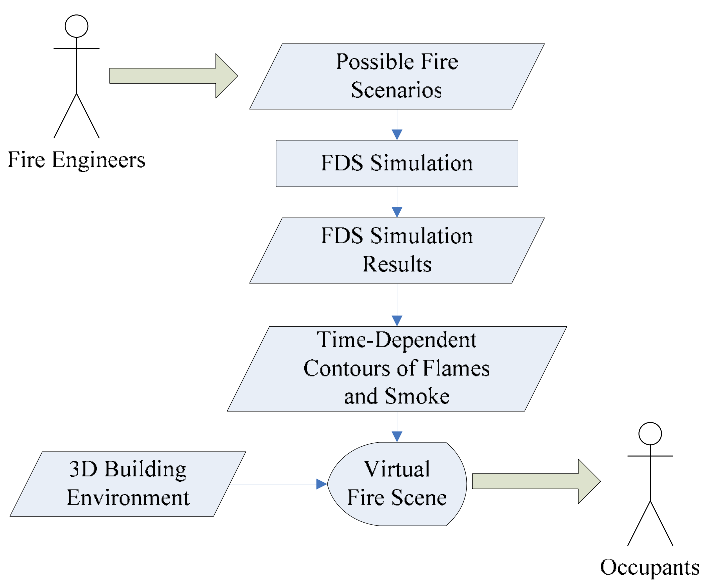


Figure 2: Integration of Fire Numerical Simulation and Virtual Reality

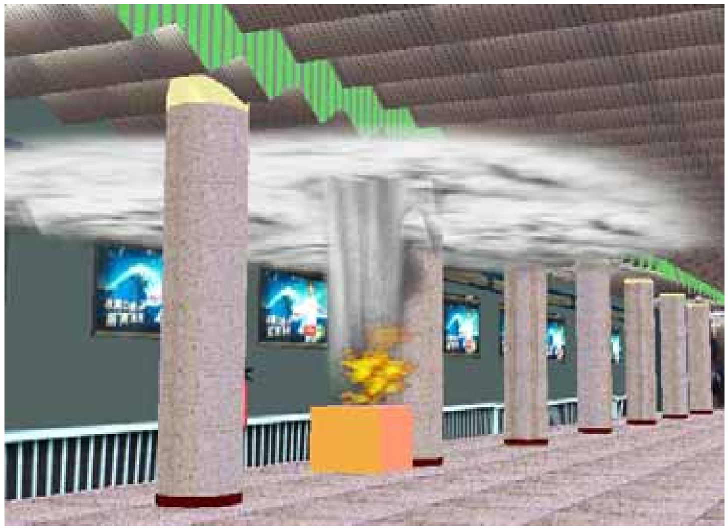


Figure 3: Visualization of Flames, Vertical Plume and Spreading Smoke in This System

simulation, such as temperature, soot density, etc., are processed to form contours. Based on the contours, the dynamic spreading of flames and smoke can be simulated by changing some properties (e.g. position, number of particles, Velocity and Life Cycle, etc.) of the particle systems. In this way the integration of fire numerical simulation and virtual reality are achieved.

In the virtual environment, texture images and particle systems are used to implement the vivid visualization and animation of flames and smoke. Vega provides the special effect module to set the properties of textures and particle systems. To obtain the images of flames and smoke which will be used as textures, one can play a fire video and get some static frames from it, and then use image processing tools to edit the static frames so as to make the part that is not fire transparent. Then, a sequence of such fire textures are mapped to particle systems and rendered circularly. In this way, flames animation and smoke animation with fast running speed and high accuracy are accomplished. Different types of flames and smokes can be simulated by setting various properties of the particle systems. Figure 3 demonstrates the visualization of flames, vertical plume and spreading smoke in this system.

4 Simulation of Occupant Evacuation in Virtual Environment

The important issues taken into consideration in this system for simulating occupant evacuation in virtual environment include: immersion provided by the system, navigation and interaction in the virtual environment, application of the system as an aid for evaluating the emergency evacuation performance.

4.1 Immersion in a Virtual Reality

Multigen Creator is employed to construct 3D building models. In the 3D building space created by Multigen Creator, the spreading of flames and smoke are visualized with the method mentioned above and subsequently a “virtual world” of fire is achieved. The users view the fire scene through a Head Mounted Displays, and navigate in the virtual environment using a mouse. In this way, the users are immersed in the burning building with no risk.

4.2 Interaction between the Users and the Virtual Environment

The user can navigate freely in the virtual environment as if he was walking in the real building. Nine different motion model types are provided by the Vega platform, including Fly, Drive, Walk, UFO, and so on. In our system, the

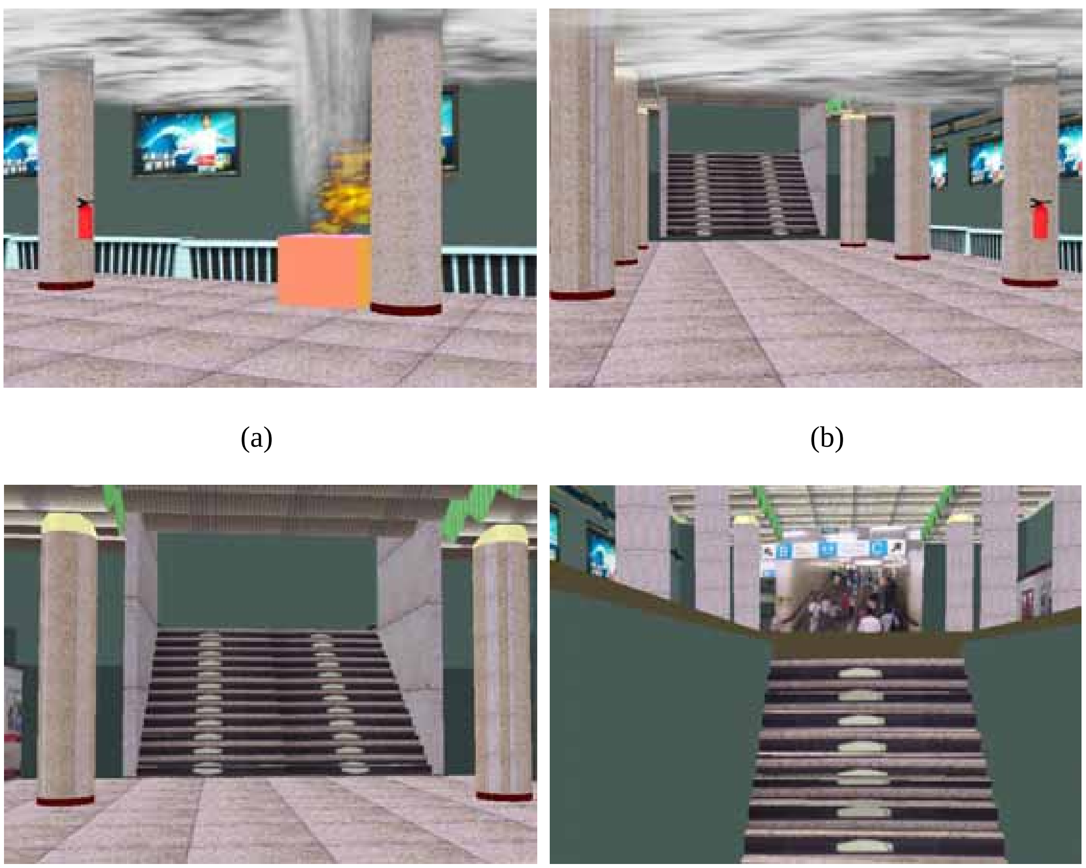
Walk type is chosen for emergency evacuation drilling and training. The navigation is controlled by a mouse. Moving the mouse left or right, while holding down the left button, will cause the user to move in that direction. Moving the mouse up and down will allow the user to look up and down. In our system, the height of the user's eye-point above the ground is changed by setting the value of Terrain Z Offset, which is one of the Walk motion model’s properties. This is useful when the building is of several floors. Figure 4 demonstrates an example of emergency evacuation drill: (a) and (b) shows when the user is navigating in the virtual underground station he notices that a box is burning. (c) and (d) shows the way upstairs to the exit.

In spite of the navigation function, other interactions between the users and the virtual environment are allowed in this system. Using the vgPicker class API, the authors implemented the functionality of picking objects within the virtual environment in the system. With the “pick” interaction provided in the system, the user who is navigating in the virtual fire scene can pick up fire fighting equipments (e.g. a foam extinguisher), carry them to the fire site, and suppress the fire. Thus, the users can perform fire fighting training in the virtual environment.

4.3 Evacuation of Emergency Evacuation Performance

The architects and the fire fighting company can evaluate the emergency evacuation performance of a building by two main means: the first is to conduct emergency evacuation drillings; the second is to predict the evacuation process by numerical simulation.

As discussed in Section 1, emergency evacuation drillings in the real building may be



(a) (b) (c) (d)

Figure 4: An Example of Emergency Evacuation to the Exit at Upper Floor

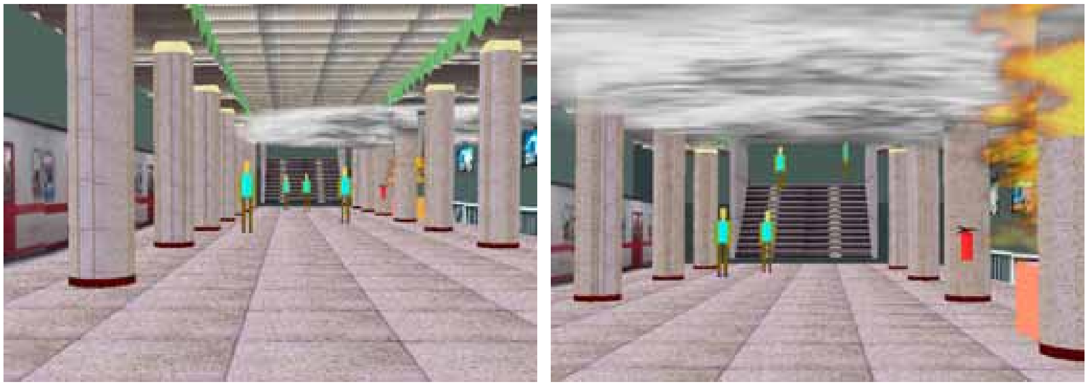


Figure 5: The Evacuation Processes of Four Virtual Human Models

expensive, difficult and dangerous. Employment of this system to perform evacuation drillings in a vivid virtual building environment is therefore a good solution. In order to evaluate the emergency evacuation performance, the drillings in the virtual environment should be recorded for analysis. Therefore, the functionality of recording and replaying the emergency evacuation drilling processes is provided in this system. It is implemented with the support of vgVCR class provided by Vega.

Another commonly used method for evaluating the emergency evacuation performance of a building is numerical simulation. The evacuation routes and evacuation time of evacuees are calculated and predicted for evaluation. To help the professionals to understand the evacuation processes of evacuees predicted by numerical simulation, this system can be employed to demonstrate the results of numerical evacuation simulation. It consists of three steps: to create paths in the virtual environment based on the simulation results by the Vega's Path Tool or the vgPath class API; to create a virtual human model with Multigen Creator; to make the human model travel along the designated path by vgSplineNavigator class API. Figure5 demonstrates the evacuation processes of 4 virtual human models.

5 Conclusions

The VR system developed by the authors for evaluation of emergency evacuation performance was presented in this paper. Using this system, the users can conduct fire emergency evacuation drillings and trainings in a virtual environment cheaply, easily and safely.

The technical details of the system were presented. Texture mapping and particle systems are used to implement vivid visualization of flames and smoke. Fire numerical simulation is employed to predict the development of fire, and the simulation results are processed and retrieved from database when the system is running. The immersive virtual building environment is realized with Multigen Creator and Vega. The interaction between the users and the virtual environment is accomplished by the Vega API and development of C++ programs.

With all the approaches introduced above, the system is successfully developed and works well. Future research will be carried out to develop the DIS (Distributed Interactive Simulation) system that allows several users to perform drillings simultaneously.

6 Acknowledgement

The research project presented in this paper is a part of the Project "Application of Computer Simulation and Information Technology for the Disaster Prevention and Mitigation", which was supported by the Chinese Education Ministry. The authors would like to acknowledge the support of the Chinese Education Ministry for this project (03010).

The authors also thanks the support from Tsinghua University — Hong Kong Polytechnic University, Center for Information Technology in Construction (CITEC) for the joint project Integration of GIS, CAD and Virtual Reality for Construction (Z062).

7 References

[1] S. Gwynne, E.R. Galea, M. Owen, P.J. Lawrence, and L. Filippidis, ”A review of the methodologies used in evacuation modeling,” *Fire and Materials*, Vol 23, pp. 383-388, 1999.

[2] L. Yang, W.F. Fang, and W.C. Fan, “Modeling occupant evacuation using cellular automata - Effect of human behavior and building characteristics on evacuation,” *Journal of Fire Sciences*, Vol 21, No. 3, pp. 227-240, 2003.

[3] S.M. Lo, Z. Fang, P. Lin, and G.S. Zhi, “An evacuation model: The SGEM package,” *Fire Safety Journal*, Vol 39, No. 3, pp. 169-190, 2004.

[4] T.S. Shen, ”ESM: a building evacuation simulation model,” *Building and Environment*, Vol 40, pp. 671-680, 2005.

[5] H. Li, W. Tang, and D. Simpson, ”Behaviour Based Motion Simulation for Fire Evacuation Procedures,” Proceedings - Theory and Practice of Computer Graphics 2004, Bournemouth, United Kingdom, pp. 112-118, 2004.

[6] S. Gwynne, E.R. Galea, P.J. Lawrence, and L. Filippidis, “Modelling occupant interaction with fire conditions using the buildingEXODUS evacuation model,” *Fire Safety Journal*, Vol 36, No. 4, pp. 327-357, 2001.

[7] P.A. Thompson, and E.W. Marchant, “Computer model for the evaluation of large building populations,” *Fire Safety Journal*, Vol 24, No. 2, pp. 131-148, 1995.

[8] N. Shih, C. Lin, and C. Yang, “Virtual-reality-based feasibility study of evacuation time compared to the traditional calculation method,” *Fire Safety Journal*, Vol 34, No. 4, pp. 377-391, 2000.

[9] W. Li, Y. Jin, J. Li, G. Guo, G. Peng, and C. Chen, “Collaborative forest fire fighting simulation,” Proceedings of SPIE - The International Society for Optical Engineering, v 5444, Fourth International Conference on Virtual Reality and Its Applications in Industry, Tianjin, China, pp. 467-473, 2004.

[10] E. Freund, J. Rossmann, and A. Bucken, “Enhancing a robot-centric virtual reality system towards the simulation of fire,” IEEE International Conference on Intelligent Robots and Systems, Las Vegas, United States, pp. 3732-3737, 2003.

[11] E. Freund, J. Rossmann, and A. Bucken, “Fire-training in a virtual-reality environment,” Proceedings of SPIE - The International Society for Optical Engineering, v 5664, Proceedings of SPIE-IS and T Electronic Imaging - Stereoscopic Displays and Virtual Reality Systems XII, San Jose, CA, United States, pp. 388-394, 2005.

[12] G.P. Forney, D. Madrzykowski, K.B. McGrattan, and L. Sheppard, “Understanding fire and smoke flow through modeling and visualization,” *IEEE Computer Graphics and Applications*, Vol 23, No. 4, pp. 6-13, 2003.

[13] R. Bukowski, and C. Sequin, “Interactive simulation of fire in virtual building environments,” Proceedings of the 1997 Conference on Computer Graphics, SIGGRAPH, Los Angeles, CA, USA, pp. 35-44, 1997.