A VIRTUAL REALITY-BASED SYSTEM FOR THE FIRE FIGHTING AND EMERGENCY RESPONSE

Aizhu Ren[1], Chi Chen[2], Liang Zou[3], and Fangqin Tang[4]

ABSTRACT

Fire is one of the urban disasters which lead to deaths and economic losses. Development of emergency response systems will shorten the response time and hence reduce the deaths and economic losses. The objective of the work presented in this paper is to develop a virtual reality-based system for the simulation of fire emergency response. The system is designed in an interactive mode, and can be used to facilitate fire fighting decision making, perform fire fighting drilling and emergency evacuation drilling. The spreading of the flames and smoke is based on fire numerical simulation, so that the evolution of the fire in the virtual environment is similar to that in real life. The simulation of fire scene, the development solutions for the realization of the immersion of the user in a virtual environment, the interaction between the users and the virtual environment are presented in details. The application of the system in an underground station is also given. The results showed that the VR-based system can enhance the effectiveness and efficiency of decision-making on fire fighting and emergency response.

KEY WORDS

virtual reality, emergency response, fire fighting, fire simulation, visualization

1 INTRODUCTION

Fire is one of the major disasters that often occur in urban areas. A fire should be controlled and suppressed in time. Otherwise significant casualties and economic losses will be caused. Therefore, a reasonable and efficient fire fighting plan should be worked out as soon as possible in the case of fire. An available method in common use to facilitate working out a reasonable and efficient fire-fighting plan in actual fire scene is to prepare a fire fighting project beforehand. From the prepared fire fighting documents, fire fighting commanders can collect the concerning information of the burning building so as to familiarize with some of the properties of the building, such as its position, inner structure, employing features, residents, exit and fire fighting facilities. Based on the collected information, commanders

[1] Professor, Department of Civil Engineering, Tsinghua University, Beijing 100084, the People's Republic of China, Phone 86-10-62782706, FAX 86-10-62771132, raz-dci@tsinghua.edu.cn
[2] Ph.D. Candidate, Department of Civil Engineering, Tsinghua University, Beijing 100084, the People's Republic of China, Phone 86-10-62782706, FAX 86-10-62771132, chenchi98@mails.tsinghua.edu.cn
[3] Ph.D. Candidate, Department of Civil Engineering, Tsinghua University, Beijing 100084, the People's Republic of China, Phone 86-10-62778987, FAX 86-10-62771132, zoul03@mails.tsinghua.edu.cn
[4] Ph.D. Candidate, Department of Civil Engineering, Tsinghua University, Beijing 100084, the People's Republic of China, Phone 86-10-6278987, FAX 86-10-62771132, tangfangqin00@mails.tsinghua.edu.cn

predict the possible evolution of the fire and work out corresponding fire fighting plan. However, most currently used fire fighting projects demonstrate the information of building structure and fire facilities distribution with simple words or 2D ichnography. Sometimes, such 2D projects fail not only to directly and efficiently show the structure features of some buildings with complicated inner space arrangement, but also to vividly describe the spreading of fire within the buildings.

Moreover, most traditional fire fighting projects are in short of sufficient analyzing functions, such as can not provide analysis and prediction of the possible evolution of fire to the commander; can not inquire, make statistics of and optimize the employing situations of the fire fighting equipments; and can not evaluate the influence of the flames and smoke on the evacuation of occupants.

Other measures usually taken to reduce the casualties and economic losses are to perform fire fighting drillings and emergency evacuation drillings. Such drillings can make the fire fighting soldiers and the occupants familiar with the building, the prepared fire fighting project, the evacuation routes, and so on. However, it should be noted that such drillings have prominent disadvantages: expensive, difficult to perform, difficult to repeat, and sometimes dangerous.

The rapid development of Virtual Reality (VR) technology makes it possible to overcome the disadvantages mentioned above (Freund et al. 2005, Li et al. 2005, Li et al. 2004a, Li et al. 2004b, Lo et al. 2004, Querrec et al. 2003, Xu et al. 2003, Shih et al. 2000). With VR, the commanders, the soldiers and the occupants can immerse themselves in the virtual building environment with virtual fire scenes. They can learn the inner 3D structure of the burning building easily and comprehensively, observe the vivid scene of flames and smoke, analyze and predict the possible evolution of the fire, make fire fighting decision, and also perform fire fighting drillings and emergency evacuation drillings without the disadvantages stated above.

Therefore, the objective of the work presented in this paper is to develop a virtual reality based system which can provide a better fire fighting project with above functions for the fire fighting commanders, the soldiers and the occupants. The technical details for implementing the presented system are introduced in this paper.

The paper is organized as follows: Section 2 introduces the overview of the system. Section 3 describes the approaches for the simulation and visualization of the spreading of fire and smoke. Section 4 depicts the simulation techniques for the fire fighting and the emergency evacuation. It is followed by section 5, an application instance of the system. Finally, the conclusions are drawn in Section 6 together with the recommendations for future research.

2 SYSTEM OVERVIEW

2.1 OBJECTIVE

This virtual reality-based system is developed for fire fighting commanders, soldiers, occupants, etc. With the system, the commanders can make fire fighting decision, the soldiers can perform fire fighting drillings, and the occupants can perform emergency evacuation drillings. Therefore, the users should be able to: (1) Acquire the information on building structures; (2) Navigate in the virtual building as if he was navigating in a real world; (3) Simulate and investigate the potential fire occurrence, fire and smoke spreading process; (4) Simulate and analyze the possible emergency response solutions in an immersive mode.

2.2 Development Environment

The tools for system development 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 fire and smoke. The visualization of fire 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.

2.3 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, Fire Fighting Simulation Module, Emergency Evacuation Module, and databases. The information of building, fire simulation, fire fighting equipments, emergency evacuation are stored and managed in different databases, but every module can access all the databases. The users control the system via Graphical User Interfaces (GUI), and they can alter the GUI for various use cases (e.g., the user can choose an interface without any menu and toolbar so as to immerse in the virtual environment by a Head Mounted Display when undertaking drill). Figure 2 shows an example of the user interface provided by the system.

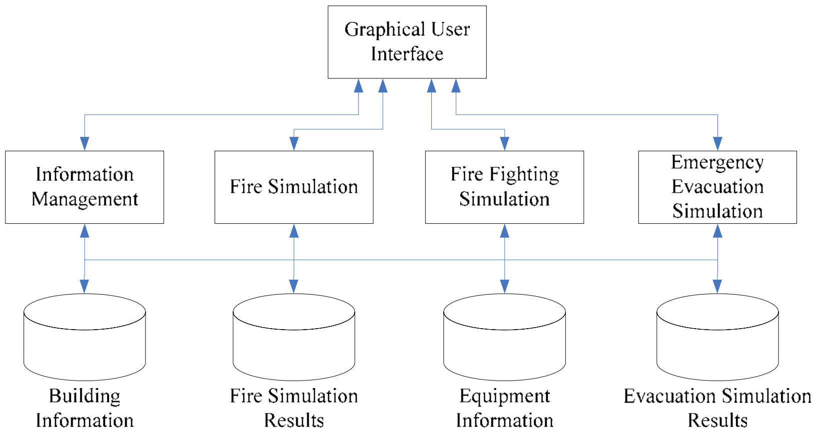

Figure 1: The Architecture of the System

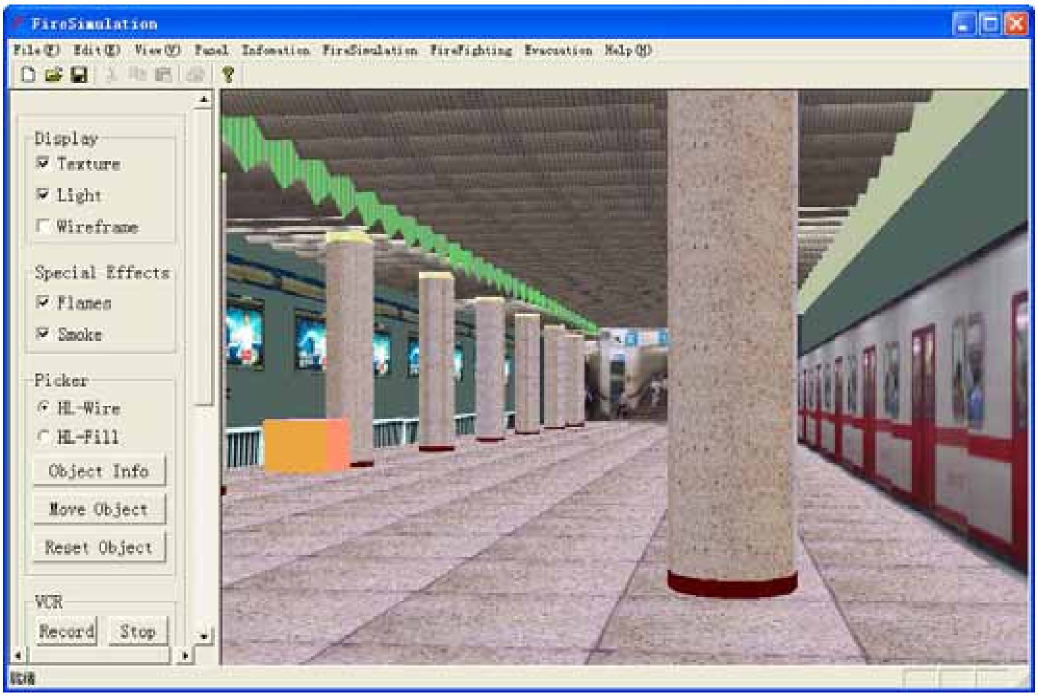

Figure 2: One of the Graphical User Interfaces (with the Interactive Virtual Environment of an Underground Station)

3 SIMULATION OF FIRE SCENE

Simulation of fire scene is the basis of this system. There are two significant issues to be solved to create a virtual building environment in fire condition: (1) how to realize the visualization of vivid flames and smoke; (2) how to make the evolution of the fire in the virtual environment consistent with the results of fire numerical simulation, which can provide most accurate prediction of fire development at present.

3.1 VISUALIZATION OF THE FLAMES AND SMOKE

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 type 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.

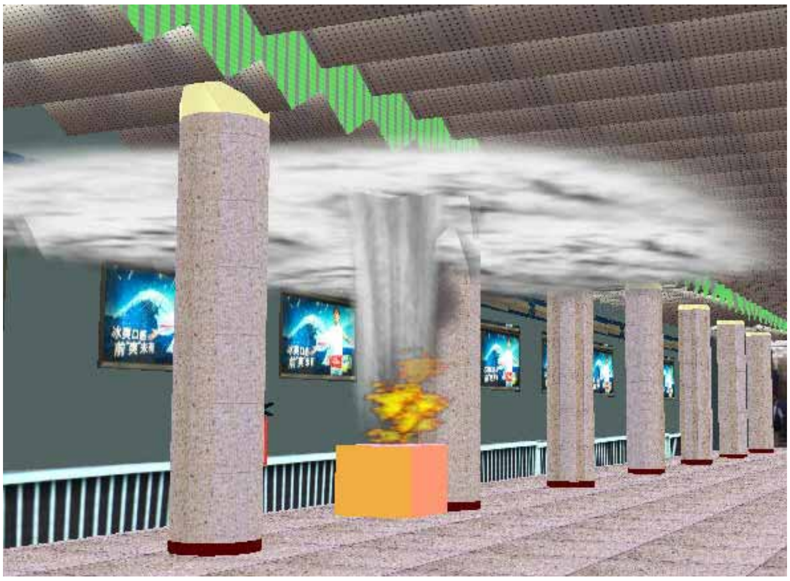

Figure 3: Visualization of Flames, Vertical Plume and Spreading Smoke in This System

3.2 SIMULATION OF THE SPREADING OF FLAMES AND SMOKE

It should be noticed that most fire fighting simulation, decision making and drilling work supported by GIS and VR is concentrated on forest fire disasters (Li et al. 2004b, Dimopoulou and Giannikos 2004). One available reason is that forest fire is comparatively easy to predict and simulate. In terms of building fire, the spreading process of the fire within the building is hard to predict. Therefore, the spreading process of flames and smoke is usually simplified in some of the researches concerning building fire (Freund et al. 2005).

In order to study the influence of the real fire on emergent evacuation process, it is not efficient to have the simple sketch to simulate the flames and smoke in virtual fire scene. It is quite necessary to make use of fire numerical simulation software to calculate and predict the developments of possible fires and visualize them in the virtual environment. 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 (Bukowski and Sequin 1997).

This system employs FDS, the fire numerical simulation 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 (Forney et al. 2003).

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 as following: 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 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.

4 FIRE FIGHTING DRILLING AND EMERGENCY EVACUATION DRILLING IN VIRTUAL ENVIRONMENT

The important issues taken into consideration in this system for simulating fire fighting and emergency evacuation in virtual environment include: immersion provided by the system, navigation and interaction in the virtual environment, interaction between fire fighting behavior and the evolution of fire.

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 vivid “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.

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 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 eyepoint 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. In this way, the users can perform emergency evacuation drillings in the virtual environment.

Apart from navigation, other interactions between the users and the virtual environment are also allowed in our system. Using the vgPicker class API, the authors implemented the functionality of picking objects within the virtual environment in the system. First, a vgPicker class’s API function vgPerformPickProcessing (vgPicker *pick, vgPosition *eyepoint) is called to perform a pick act. Then, the picked object can be obtained by another API function vgGetPickerPickedObject (vgPicker *pick). Thus, the picked object can be moved by the common Vega API function vgPos (vgCPos *handle, vgPosition *pos). 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. In this way, the users can perform fire fighting drillings in the virtual environment.

When the user “pick up” fire fighting equipments and turn on the switch to fight the fire, the fire simulation module will receive the user’s operation, and then reset the properties (such as number of particles, position, Scale and Life Cycle) of the particle systems used to represent the flames and smoke based on the user’s operation. Thus, the interaction between fire fighting behavior and the evolution of fire is accomplished. The flow of fire fighting drilling is shown in Figure 4.

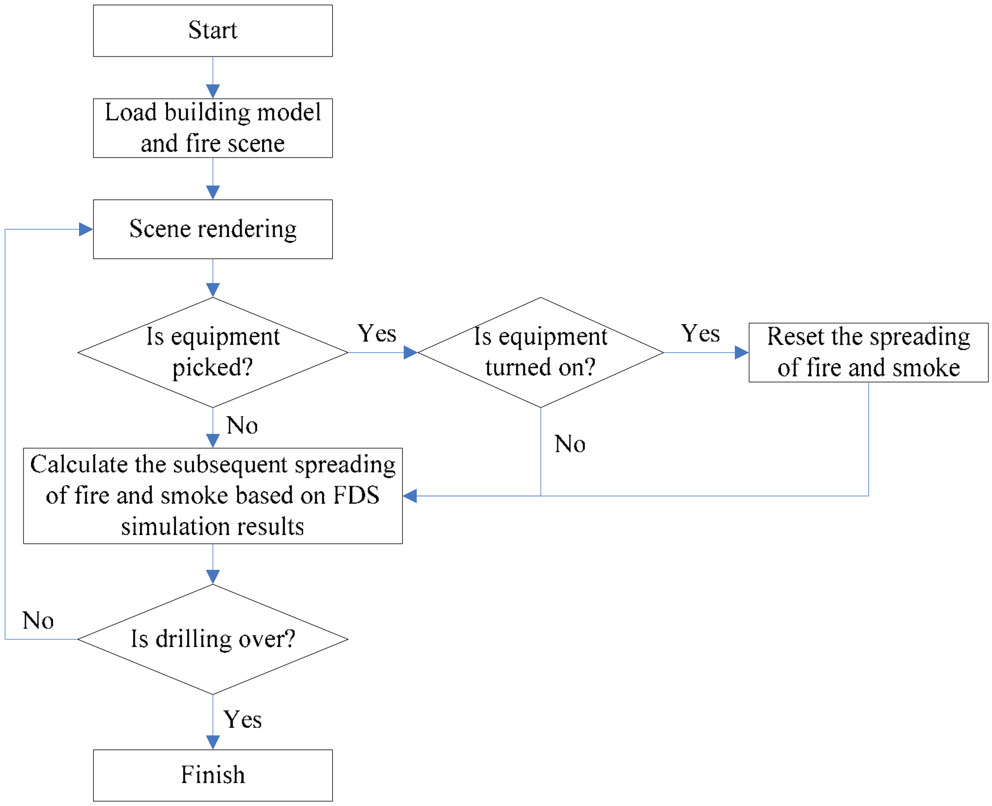

Figure 4: Flow of Fire Fighting drilling

The drillings in the virtual environment can be recorded for analysis. It is implemented with the support of vgVCR class provided by Vega. The vgVCR class is a lot like a computerized version of a video cassette recorder. First, an instance of vgVCR should be created by the API function vgNewVCR(void) or vgGetVCR (int idx). Then, the “VCR file” for recording and replaying emergency evacuation drillings can be specified by API functions vgVCROutFileName (vgVCR *vcr, char *fname) and vgVCRInFileName (vgVCR *vcr, char *fname). When a drilling begins, the API function vgVCRRecord (vgVCR *vcr) should be called to record the drilling. Similarly, the API function vgVCRPlay (vgVCR *vcr) is called to replay an existing drilling. To stop recording or replaying, the API function vgVCRStop (vgVCR *vcr) is called.

5 APPLICATION INSTANCE OF THE SYSTEM

The author chose an underground station as an application instance to test the practicality of the system. First, Multigen Creator was employed to create the 3D model of the underground station, FDS was used to numerically simulate the possible fire scenarios and then the simulation results were stored in the fire simulation results database.

Three types of users (fire fighters, passengers, and fire fighting commanders) made use of the system to perform drillings of fire fighting, emergency evacuation and fire fighting commanding respectively.

Figure 5 demonstrates the whole process how a fire was suppressed in the virtual environment. A box on the platform of the underground station suddenly caught fire. System users acting as fire fighters carried the foam extinguisher to the fire site, turned on the switch and put out the fire.

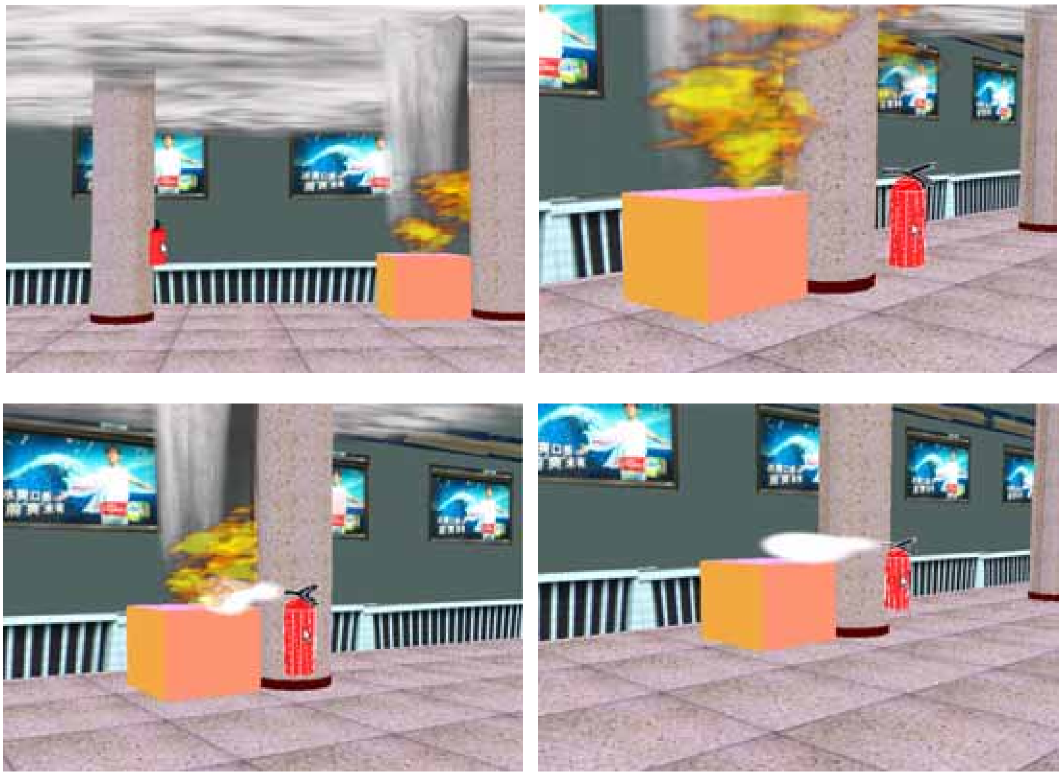

Figure 5: Fire Fighting Using a Foam Extinguisher

Users acting as passengers performed emergency evacuation drillings. At first they were "walking" in the virtual station. After noticing the burning box, they looked for the exit of the station and rushed to it. Through those drillings, the users became more familiar with the inner space structure of the underground station and acquired much experience of fire emergency evacuation. Meanwhile, the system recorded the process of the emergency evacuation, which can be used to evaluate the emergency evacuation performance of the underground station and to study the passengers' behaviors during emergency evacuation.

Users acting as fire fighting commanders collected the information of the station structure and the distribution of the fire fighting equipments soon after the train caught fire. They observed the fire scene in the virtual environment and then obtained the possible spreading of the flames and smoke (the development of the fire is predicted by FDS). By replaying the recorded emergency evacuation drillings, they studied the passengers' evacuation behaviors. Based on the information of the building, the equipments, the fire development, and the evacuation behaviors, they worked out the fire fighting plan. The practices showed that effectiveness and efficiency of fire fighting decision making is enhanced when using this system to support fire fighting commanding.

6 CONCLUSIONS

The VR system developed by the authors for fire fighting decision making, fire fighting drilling and emergency evacuation drilling was presented in this paper. The users, such as fire fighting commanders, soldiers and occupants, can immerse themselves in and interact with the virtual building environment. Texture mapping and particle systems are used to implement vivid visualization of flames and smoke. The spreading of the flames and smoke is based on fire numerical simulation, so that the evolution of the fire in the virtual environment is similar to that in real life. Navigation and "pick" interaction are allowed so that the user can perform emergency evacuation drillings and fire fighting drillings. The drilling processes can be recorded and replayed for further analysis. The user can obtain the concerned information of the building, the equipments, the fire development, and the evacuation behaviors, etc. during fire fighting.

The application instance showed that the system is powerful, and easy to use. It can enhance the effectiveness and efficiency of decision-making on fire fighting and emergency response.

Future research will be carried out to develop the DIS (Distributed Interactive Simulation) system that allows several users to take part in fire fighting operation simultaneously.

ACKNOWLEDGEMENTS

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).

REFERENCES

Bukowski, R. and Sequin, C. (1997). "Interactive Simulation of Fire in Virtual Building Environments." *Proceedings of the 1997 Conference on Computer Graphics, SIGGRAPH*, Los Angeles, CA, USA, 35-44.

Dimopoulou, M. and Giannikos, I. (2004). "Towards an Integrated Framework for Forest Fire Control." *European Journal of Operational Research*, 152 (2) 476-486.

Forney, G.P., Madrzykowski, D., McGrattan, K.B. and Sheppard, L. (2003). "Understanding Fire and Smoke Flow through Modeling and Visualization." *IEEE Computer Graphics and Applications*, 23 (4) 6-13.

Freund, E., Rossmann, J. and Bucken, A. (2005). "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, 388-394.

Li, H., Tang, W. And Simpson, D. (2004a). "Behaviour Based Motion Simulation for Fire Evacuation Procedures." *Proceedings - Theory and Practice of Computer Graphics 2004*, Bournemouth, United Kingdom, 112-118.

Li, L., Zhang, M., Xu, F. and Liu S. (2005). "ERT-VR: an Immersive Virtual Reality System for Emergency Rescue Training." *Virtual Reality*, 8 (3) 194-197.

Li, W., Jin, Y., Li, J., Guo, G., Peng, G. and Chen, C. (2004b). "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, 467-473.

Lo, S.M., Fang, Z., Lin, P. and Zhi, G.S. (2004). "An Evacuation Model: The SGEM Package." *Fire Safety Journal*, 39 (3) 169-190.

Querrec, R., Buche, C., Maffre, E. and Chevaillier, P. (2003). "Multiagents Systems for Virtual Environment for Training Application to Fire-Fighting." *Proceedings of the IASTED International Conference on Computers and Advanced Technology in Education*, Rhodes, Greece, 647-652.

Shih, N., Lin, C., and Yang, C. (2000). "Virtual-Reality-Based Feasibility Study of Evacuation Time Compared to the Traditional Calculation Method." *Fire Safety Journal*, 34 (4) 377-391.

Xu, Y., Ren, A.Z. and Pan, G.S. (2003). "Research on Fire Fighting Commanding System Based on GIS and VR." *China Civil Engineering Journal*, 36 (5) 92-96.