The Effectiveness of Virtual Reality for Studying Human Behavior in Fire

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Abstract. In this study, a virtual environment of fire condition was designed and implemented to support the research of the human behavior under anxiety states. The results gathered from this experimental platform were compared to the data from real fire condition to verification the effectiveness of the information provided from this virtual platform. The Correlation coefficient is 0.9958, which indicate that the simulation system is highly practical in research of human behavior under pressure condition. Conclusion could be made that virtual environment based on cave virtual display system is suitable for simulation of fire condition.

Keywords: Fire condition · Virtual reality · Environmental stress

1 Introduction

Environmental stress is initially raised as a technical term in the field of psychology. But this word appeared frequently in human factors engineering in recent years, since the behavior of human being under anxiety condition is much more different from the normal condition. And the stressors of environmental stress can be divided into disaster stress and background stress.

There are mainly two types of environmental stress, one is the disaster stress, and the other is the background stress. Fire condition is a typical circumstance which can arouse disaster stress [1]. The study of human behavior under fire condition is very important in fire rescue and evacuation.

There are many ways to simulate a fire circumstance; the most common one is the fire drill. But it is usually difficult to call a fire drill for its costs and other difficulties. And for safe sake, the fire drill usually cannot arouse enough stress for the subjects since the hazard of real smoke and fire is hard to control. Alternative ways of fire drill is very necessary in studying disaster stress. Full size entities simulation can be the substituted of real scene, but due to the difficulty and the costs of it, this methods can only be set up for specific purpose and special place. Virtual reality is an alternative method of fire drill. Since the virtual 3 dimension environment is easy to implement than the real stage, the danger and the costs in fire research can reduce a lot. Also there are not so much limits for the site of fire disaster in virtual environment.

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2 Virtual Reality in Fire Condition Simulation

2.1 The Theory of Stress

The word stress was first appeared in the field of psychology, means a set of non-specific body adaptation responses to the stimulation from both internal and external environment factors, called stress reaction also. Those internal and external environment factors went by the general name of stress source, or stressor. Stress is generated by unexpected urgent and dangerous situations that can cause a highly stressful state. Environment stress refers to the external factors. There are two kinds of external stress, one is the nature stressor such as extreme cold, hot, light, damp and so on; the other is artificial stressor such as stroboflash, radial, noise and so on. When subjects exposed to the environment stress, their instinct responses is to relief them from these stress.

Fire condition is a typical environment stress. The features of high temperature, smoke, light, and the threat of death are all obvious characteristic of environment stress [2]. It is a very good way to test and verify the applicability of the virtual reality in human reactor researching by constructing a virtual fire disaster situation and collecting people's behavior in it. And there is also important realistic meaning in studying the fire condition, such as how to design the eye-catching safety warning marks in public place, Evacuation route settings, researching of crowd behavior and so on.

2.2 The Research of Virtual Reality in Environmental Stress

Virtual reality is a technology that combines computer since, digital graphics, three dimensional displays and other new techniques both in software and hardware. It can give people a virtual 3 dimensional world based on computer simulation which provides salutations of visual, auditory, tactile and other sensory. These set of experiences combine together to create a highly immersive environment to make people feel that they are in the real scene. Immersive, unlimited and randomness are the characters of virtual reality, and these are highly compatible to the fire condition simulation which needs a lot of randomness and immersive [3].

Research in this field can be traced back to 1993 in Britain; a simulation system called VEGAS is developed to simulate the escaping behavior under the fire condition using 3 dimension simulation technologies. In China, there is also some research of virtual reality using in fire escaping or other disaster. Liu kun and Wang guan sheng of Beijing university of technology designed a training system for the fire condition using the 3 dimension real time rendering [2]. Shen yi li put virtual reality technology into the reach of earthquakes [2]. These researches mostly focused on the evocation and crowd activity, but ignored the consistency of experimental condition to the real situation, in another word, the realness of the simulation.

More and more new technology of virtual reality is put forward in recent years, such as CAVE, RAVE system. CAVE is a projection system with 3 to 5 sides of rare projection as the sides of a cube to construct a space like a cave. In this space, people can observe a virtual scene with stereo glasses. Since the closure of the viewing environment, it can provide a highly realistic feeling of the virtual scene. RAVE can be

interpreted as an extensible CAVE, which can open the sides of the cube into 180 degrees, 135 degrees and 90 degrees (as a CAVE). Based on this physical structure, work in with high resolution graphics and the active stereos projection together, a highly immersive and authentic experiment system can be built much more real than before.

Subjects in this experiment system will be put into the CAVE space, surrounded with light, color and sound. All these features will give subjects feeling of nervous especially in simulating a condition of fire. The compliance of the virtual experiment and the real scene is the focus of this research. By compare the data gathered in both virtual environment and real scene can estimate the effectiveness of the experiment system.

All these new technology makes the virtual reality more and more real. By using virtual scene, some research that cant or hard to realize in real world can carry on in the virtual world. Research of human factors engineering in dangerous or rare situation, such as nuclear reactor, large construction site and so on, can be put forward easily. But the realness of the simulation and the availability of the data gathered in the virtual scene are still not quantitative evaluated.

2.3 The Software Development Environment

A virtual experiment system of fire simulation has the following conditions: high reality sensation, flexible interaction and living fire and smoke effect. There are several software that aimed at fire simulation such as FDS (Fire Dynamics Simulator) CFAST (The Consolidated Model of Fire And Smoke Transport) ALOFT-FTTM (A Large Outdoor Fire plume Trajectory model - Flat Terrain). FDS is a well-known fire simulator tool for the fire protection engineering field, which can accurately calculate the temporal and spatial distribution of physical quantity, to simulate fire exactly. CFAST is used to calculate the temperature, smoke concentration within up to 30 rooms. ALOFT-FTTM is focused on the outdoor fire disaster. These software are all with very specific focus. They focus more on the physical quantity of the fire, but not the feeling of subjects in a fire disaster. So a new experiment system that aimed at built a highly immersive environment and collecting the data of subjects is needed in this case.

A high rise building fire is simulated in this subject. To meet the need of immersive, Unity 3D was choose as the virtual reality engine. Although there are several virtual reality engines to choose, but the following characters make Unity 3D the best choice. First, an outstanding rendering result can enhance the realness of the virtual scene; second, the programing part can base on the C# language which means a wide range of compatibility; third, the physical engine is a pre-programed modular that can simulate the physical aspect of the real world such as gravity, collision and interference; fourth, a powerful partition system is very suitable for simulation of fire and smoke. The application framework of unity3D makes it very flexible to create more complex interaction and more random situation. To enlarge the range of subjects, two versions are needed for the experiment. One is based on the CAVE application for local user, the other is based on web for long-range user. Unity 3D can satisfy this need just with one program since the virtual scene built with unity 3D can be released to a wide range of application.

3 Developing Structure of the Experimental Platform

Any virtual scene is based on the 3D modeling. There are mainly two way to complete the modeling, one is based on the parametric; the other is based on the polygon. Usually parametric modeling is used in mechanical design, and focused in the topological relations of the different machine parts; polygon modeling is used in figure and scene modeling mostly appeared in game development, 3D max is a typical representative. In this case, Inventor is used for the modeling, then export to 3D max to change from parametric mode to polygon mode and reduce the facet. Only format of .fbx is acceptable for Unity 3D, so the model must export as .fbx by 3D max. The framework for developing program is as Fig. 1.

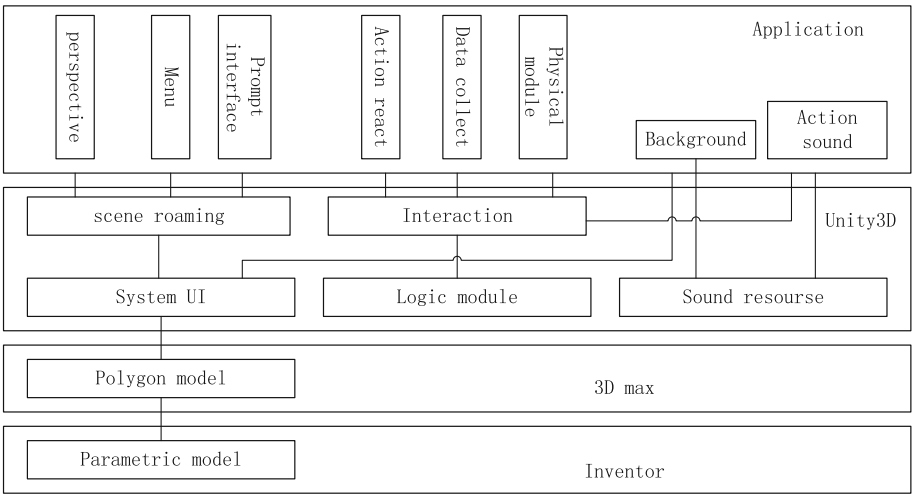

Fig. 1. Developing structure

The Fig. 1 just shows the developing structure of the program, but under web condition, communication with client is also needed. The 3D scene created was finally put into a JSP framework; subject's behavior will communicate with JSP and recorded directly into the server's database through net. All the recording and analyzing are done by the server.

There are 2 problems in the programing. First, time demand is quite strict under web application. Virtual reality usually consumes a lot of system resources and may cause the pause of Execution which will influence the experiment result a lot. To avoid this, a caching mechanism was used in this system. All the scene data will download into the client machine. During the test, there's no data upload. When test ending, all the data gathered will send to the server as one data structure. Second, the sense of reality is important during the interacting. Full application of the physical engine of Unity 3D can add lot of realness to the scene. Gravity is added to any non-stationary object, and collision test is added to the door or window. Thus, any movement in this space is just like real.

4 Design of the Scene

As the research objectives, there are several features of fire in high rise building. First, Fire can spread easily in more ways in high rise building, air conditioning systems, electrical systems and chimney effect can all increase the speed of fire spread; Second, evacuation difficulties, usually the speed of evacuation is much slower than the speed of smoke spreading for the long vertical evacuation distance and high population density; Third, in most cases the only escaping way is the stairs cause the elevator shaft is usually the thoroughfare of smoke [1, 5, 6]. These features of high rise building make the escaping ways as following. Residents can take advantage of the facilities in the building, such as fire elevator, stairwell, balcony, refuge floors and so on; or they can follow the instruction of the fire radio, if the building has this facility; Or Self-help and mutual aid escape will carry on, like sheets, curtains and the pipes to escape. Facilities in the virtual room should be set Compliant for these conditions to make the experiment can meet the real situation.

In this virtual experiment platform, a typical indoor scene of an apartment is the most important virtual scene. The first 10 min in the fire disaster is usually the most important even decided whether the escaping can achieve or not. So the experiment focus on the choice that people made in the first 10 min [3]. We have set some daily necessities in this scene. Cell phone, television, phone, curtain, sheet, rope, floor maps of the building and so on were putting in the room, to provide clue of escaping. People for escaping can choose waiting for the instruction, or self-help, or get information from the TV or radio. The sight of the door and the window also provide clues like smoke, fire or light. So the modeling and the programing are mostly focused on these things.

The typical indoor scene of the high rise building was modeling as Fig. 2.

Fig. 2. Inside room structure

The fire and smoke is finished with the partition system of unity 3D. The basic theory of the partition system is redrawing 1 to 2 materials again and again to create chaotic effects. Particle systems typically include a particle emitter in an object, a particle animator player and a particle renderer, if interaction with other objects is needed, a particle collider should be added to objects. In this case, to simulate the real fire effect, the particle collider is most important. All the walls was added with particle colliders, when the smoke or fire collide with the wall, barrier and reflection will occur, thus the real smoke and fire effect can be simulated.

5 Simulation and Analysis

5.1 Simulation

200 subjects were randomly selected to the experiment in this virtual experiment platform. Their behavior were recorded into the database. Also a questionnaire is asked to fill after experiment. In these 200 results, effective experimental number is 176, the total completion rate is 88 %. There are 16 people unfinished the experiment due to the stress or other questions, and another 8 people just give up the experiment.

The experiment gives 10 min to the subject; the first objects choose by the subjects will indicate the escaping mean of them. Such as, if they choose to open the television, maybe they want to get information about the situation thus they tent to wait for farther information; if they choose the cell phone, maybe they also want information about the fire, but have more motivation to escaping; if they choose the rope, maybe they want to save themselves immediately; if they choose the door or window, they want to call for help.

The results of first choose object is shown in Table 1.

Table 1. First choice of the subjects

Choice	Number of subjects
door	63
cellphone	20
laptop	7
towel	25
rope	11
extinguisher	19
basin	17
Wallet	10
No action	4

The praetor diagram of the first choice is as Fig. 3.

To find out the difference from the real fire to the simulation, these data is compared with the data collected in real fire disaster. The result is as Table 2.

The correlation coefficient r was introduced to resolve the relation of these two set of data [7]. Quantitative analysis of the data was reviewed by this r. It is a number between -1 to 1; when it is positive, the relevant two sides are proportional; when it is negative, the relevant two sides are inversely proportional; when it close to 0, there are almost no relationship with the relevant two sides. The formula to calculate r is

$$r = \frac{\sum_i a_i b_i}{\sqrt{\sum_i a_i^2}\sqrt{\sum_i b_i^2}}.$$

The coefficient a_i and b_i are the data from virtual scene and real fire condition. The final result r is 0.9958, which means that these two data is highly proportional.

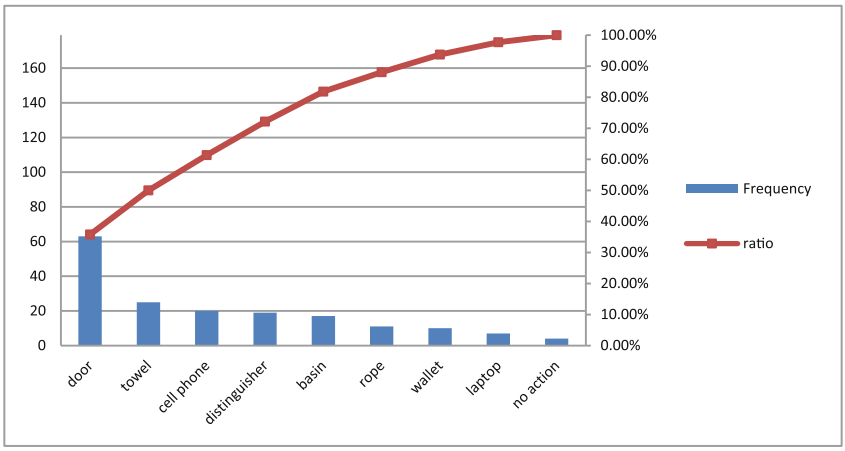

Fig. 3. Praetor diagram of the first choice

Table 2. Difference from the real fire to the simulation

Item / scene	Escaping directly	Contact with outside		Choose items		distinguish		Pack up	No action
	door	Cell phone	laptop	Towel	rope	distin-guisher	basin	wallet	
virtual (%)	35.80	11.36	3.98	14.20	6.25	10.80	9.66	5.68	2.27
		15.34		20.45		20.46			
Real (%)	38.1	16.82		17.04		20.9		4.44	2.7

In another word, the experiment data gathered from the virtual scene is greatly degree with the real fire disaster. This indicates that in research of people's action in fire condition, virtual experiment can take place of the real data.

5.2 Analysis of Interview

Only the data gathered in the experiment is not enough to determine whether the virtual reality can represent the real condition, the subjective feelings of the subjects are also very important in evaluating the usability of the system. Interview was put to the 176 subjects who has finished the experiment completely focused on their subjective feeling, opinions and suggestions of the system. The results gathered in Table 3.

Using fuzzy comprehensive evaluation method, the data was analyzed and calculated by the formulas as [8]:

$$\text{Gradation} = \frac{\text{evaluation}}{\text{totalnumber}}.$$

$$\text{General Gradation} = \sum \text{Gradation} * \text{weight}.$$

$$\text{Overall result} = \sum \text{General Gradation} * \text{Score}.$$

Table 3. Interview results table

Result / level / Project and weight	Very good	Good	general	poor
Fire effct （0.2）	112	48	12	4
Optional items set（0.2）	78	38	40	20
Operating Performance（0.25）	107	40	20	9
Room effect（0.15）	121	36	8	11
Scene authenticity（0.2）	106	46	16	8

Thus comes to the Table 4.

Table 4. Overall result

Result / level / Project and weight	Very good	Good	general	poor
Fire effct （0.2）	0. 64	0. 27	0. 07	0. 02
Optional items set（0.2）	0. 44	0. 22	0. 23	0. 11
Operating Performance（0.25）	0. 61	0. 23	0. 11	0. 05
Room effect（0.15）	0. 60	0. 26	0. 09	0. 05
Scene authenticity（0.2）	0. 61	0. 26	0. 09	0. 04
General Gradation	0.59	0.24	0.12	0.06
Overall score	90.28			

The Overall score of the experiment is 90.28, which shows that the subjects are satisfied with the virtual scene. This result indicates that using virtual reality technique in research of environment stress is a very effective way. But there are still some problems in this experiment system. Since the subjects know the purpose of the experiment before, they will not be panic as the real fire, so the items they choose are more rational. The other problem is the movement of the fire and smoke can only preset before experiment and cannot happen randomly, which is not as the real situation.

With virtual equipment providing more immersive feeling, people can get better experience in the virtual scene. Algorithms about movement of smoke and fire can make the fire circumstance more vivid.

6 Conclusion

By introducing virtual reality technique into the research of people's reaction in fire condition, a new method of studying environment stress is tested. The result shows that it is quite close to the actual situation. Unity 3D is quite adapt to establish the virtual scene for researching in human factors engineering, as a substitute of those experiments that is hard or even impossible to carry on.

More research should be taken on the following aspect: the sense of reality, location tracking and interactive equipment, which can promote the effect a lot.

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