Virtual Emergency Rehearse System for Dangerous Gas Diffusion in Chemical Industry Park

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Abstract

Efficient emergency rehearse system provides both commanders and evacuation crowds with better preparation for dangerous gas diffusion accidents, which definitely causes serious social panic and huge property loss. This paper focuses on four key issues raised by such accidents in the chemical industry parks. These issues include modeling, simulation, rendering and decision making. Virtual Reality and GIS are exploited to enhance intuitive and comprehensive visual information. Google SketchUp is worked as large model resource library and used to efficiently assemble the targeted virtual environments. Simulation of dangerous gas diffusion is built based on Pasquill-Gifford model and gas properties. Puff model combined with plume model is used to generate the gas diffusion animation. And evacuation route of crowds is display through scene-GIS map. Large scale virtual environment is rendered using OSG engine. All the simulation processes are recorded in a video with time tag embedded, which enable the commanders review history scene and hence make reasonable decision instantly. The gas emergency rehearse system enable all the people involved in this system having useful information and immersive experience. The system is now integrated into a common public safety platform and running well.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality;

Keywords: Emergency rehearse, dangerous gas diffusion, diffusion model, simulation record, OSG

1 Introduction

With the fast development of modern industries, the leak accidents of dangerous chemical materials were reported frequently during the stages of production, operation, storage and transportation. Such accidents are not only causing serious social problems including urban panic and property loss, but also causing long-term potential pollution problems to human living environment. These accidents have become one important kind of public emergency. Among all the leaking accidents of dangerous chemical materials, gas diffusion has more influence than other two states, liquid and solid. One reason comes from that it is uneasy to know the source of diffusion. Moreover, gas diffusion has larger range of scatter in stereo-space, especially under the effect of temperature and wind.

When considering the solution for the dangerous gas diffusion, there are many challenges existed. For example, there are inadequate precursory, severe destruction, many secondary and derived damages, and so on. One cannot gain experience to response such accident through expecting the same accident happening once more. So it is necessary to build an emergency rehearse system which has such functionalities as scientific prediction, orderly coordination and rapid response.

Reddick examines the impact of information technology (IT) on emergency preparedness and planning by analyzing a survey of US state government departments of emergency management[Reddick 2011]. The research results show that there has been a significant impact of IT on emergency planning, especially at the response phase. Actually, according to an available emergency rehearse system, a lifelike training scenario, position awareness and accurate situational evaluation are the three key factors. Technologies of Virtual Reality (VR)[Tang et al. 2009], GIS[Rifaat Abdalla and Li 2007] and Visualization[Intorelli et al. 2009] are exploited to create such rehearse system, which enable the emergency response involved persons to do better preparation for the real-life situation through advanced training in operational environment beforehand.

This paper is organized as follows. Section 2 reviews the prior researches in the field of emergency simulation and gas diffusion. Section 3 introduces the framework of Virtual Emergency Rehearse System. Section 4 shows the optimized Pasquill-Gifford model to generate the dynamic gas diffusion animation. The experiments results of the system and the conclusion of this paper are presented in Section 5 and Section 6, respectively.

2 Related Work

There are various researches about the field of emergency response. These researches focus on different targets using specific technologies. VR and GIS are the two frequently used technologies. VR provides users with scene immersion, multiple interaction channels and visual imagination. While GIS is used to capture, store, integrate, analyze and display data related to positions on the Earth's

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surface.

Son presents a novel methodology involving a VR based Belief, Desire, and Intention (BDI) software agent to construct crowd simulation, and demonstrates the use for crowd evacuation management under terrorist bomb attacks in public areas. The human behaviors are modeled with a high degree of fidelity[Son et al. 2008]. Aiming at astronauts, one experiment examined the influence of relative body orientation and individual spatial skills during VR training on a simulated emergency egress task[Aoki et al. 2007]. Police emergency response system and decision-making model are presented using GIS under the guideline of emergency theory[Li and Fu 2010]. Abdalla highlights application challenges for GIS interoperability upon emergency management[Rifaat Abdalla and Li 2007]. He presents a scenario-based case study, which aims to provide a demonstration of the utility of GIS interoperability for disaster management.

Dangerous gas diffusion model has its inherent links with material characteristic, climate condition and environment layout, and so on. SLAB, ALOHA and PASQUILL-GIFFORD are the typical gas diffusion models in emergency management. Sklavounos has simulated a large scale of cryogenic natural gas releases based on the SLAB model[Sklavounos and Rigas 2006]. Alhajraf predicts the atmospheric transaction of hazardous materials based on the ALOHA model[Alhajraf et al. 2005]. The SLAB model is applied to predict to the boundary under the selected wind direction, but it takes no account of the surrounding terrains and the destiny changes in different height[Liu et al. 2005]. Although ALOHA is taken as a widely used research tool for the emergency response, it has lots of limited conditions. Taking some as examples, the wind speed should be greater than 1m/s, and the atmospheric conditions should be very stable.

The Pasquill-Gifford model is studied fairly earlier[Sorensen 1998]. The concentration in the vertical is the sum of the concentrations from individual puffs, so unequal concentrations would be in different height. There are no special requirements against the wind parameters, even the speed of zero is acceptable. Pasquill-Gifford model is popular to researchers for its less calculated quantities and the high spatial accuracy compared to the other models[Wei et al. 2008].

3 Framework of Virtual Emergency Rehearse System

In the virtual emergency rehearse system for dangerous gas diffusion in chemical industry park, there are at least three human roles should be considered. That is, emergency commander, rescuers and evacuation crowds.

Emergency commander need to obtain the information of overall situation for the current damage, and can forecast the situation progress accurately. Thus right instructions will be sent out correspondingly to both rescuers and evacuation crowds.

The responsibilities of rescuers are to help evacuation crowds to reach the safety zone as soon as possible with the aid of rescue tools. The rescuers start their work under the guidance of the commanders, and vice versa, they supply the instant data for the situation updating of the commander.

Actually evacuation crowds are not simply taking action for running off the on-the-spot of diffusion disaster. Their psychological state in emergency are significant different with the common status. They even do not follow the rules from the commander and make their own choice, especially in the case that the commander instruction did not reach them.

According to the above analysis of emergency management, a comprehensive emergency rehearse framework is proposed, as shown in Figure 1. The overall framework is composed of four levels, i.e.,

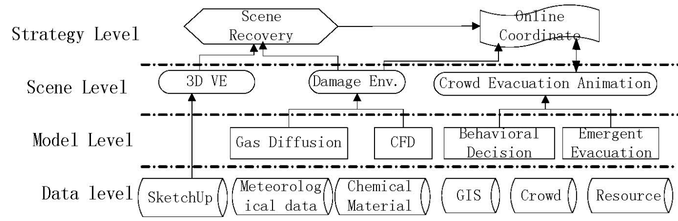

Figure 1: *The framework of the virtual emergency rehearse system.*

data level, model level, scene level and strategy level. The detail purpose and functionalities of the four levels are explained as the following.

Data level contains the required data for emergency rehearse. SketchUp is the model library for constructing the 3D virtual environment. The meteorological data include wind direction, temperature, stability class and so on, which can be exported from online weather stations. Chemical material describes the attribute of diffused materials and the emission rate. GIS is one pre-stored data for the chemical industry park and a map of GIS data amd models is built. The distribution of crowd and the rescue resource will be used in subsequent emergency decision.

In model level, gas diffusion and CFD are used to simulate the occurrent disaster based on meteorological and chemical material data. Behavioral decision model depicts the various behavior features of evacuation crowds. And the emergency evacuation model presents how to evacuate the crowds under the emergency situation.

In scene level, 3D virtual environment is rapid constructed through large model library, SketchUp. And dynamic configure of 3D virtual environment can be carried out due to specific chemical industry parks. Crowd evacuation animation displays the route, transformation tool and crowd animation when large scale of evacuation.

In strategy level, commander can recovery the history scene to aid the subsequent decision made. Online coordinate is working as the control center for the emergency rehearses system, collecting information and making the final decision.

4 Optimized Pasquill-Gifford gas diffusion model and simulation recording

Damage situation is formed using the gas diffusion model based on the meteorological and chemical material data. When the damage situation is bound with 3D virtual environment considering GIS data, the gas diffusion simulation will have both sufficient visual information and precise location coordinate.

The Pasquill-Gifford model, which is originally used to simulate toxic gas diffusion, is divided into Pasquill-Gifford plume model and Pasquill-Gifford puff model. The former is used to simulate the neutral continuous situation while the latter is used to simulate the neutral instantaneous gas diffusion. We adopt the puff model to describe the dynamic diffusion of the continuous toxic gas leakage.

The consistency of the position (x, y, z) in the instantaneous leakage is calculated by (1).

$$C(x,y,z) = \frac{Q}{(2\pi)^{\frac{3}{2}}\sigma_x\sigma_y\sigma_z} e^{\frac{-y^2}{2\sigma_y^2}} \left(e^{\frac{-(z-He)^2}{2\sigma_z^2}} + e^{\frac{-(z+He)^2}{2\sigma_z^2}} \right) \tag{1}$$

where the parameter Q is the emission rate of the tracer gas. The quantities σ_y and σ_z are the horizontal and vertical standard deviations of the spatial distribution of concentration,respectively. The He means the maximum height of the gas.The coordinate about equation (1) is based on the puff. The speed of the flume equals the wind u[R.Hanna and J.Drivas 1983]. So the equation is changed to new form of formula (2).

$$C(x,y,z,t) = \frac{Q}{(2\pi)^{\frac{3}{2}}\sigma_x\sigma_y\sigma_z} e^{\frac{-y^2}{2\sigma_y^2}} \left(e^{\frac{-(z-He)^2}{2\sigma_z^2}} + e^{\frac{-(z+He)^2}{2\sigma_z^2}} \right) e^{\frac{-(x-ut)^2}{\sigma_x^2}} \tag{2}$$

But we need an description of continuous gas diffusion with the time t. Generally, the Pasquill-Gifford puff model is obtained by equation (3) which can not be calculated from a series of simple functions.

As Pasquill says the puff model can be regarded as a combination of some plumes, we use the integration of the equation (2) to implement a dynamic diffusion animation, as (3) shows.

$$D(x,y,z,t) = \int_0^t C(x,y,z,w)dw \tag{3}$$

Actually, the value of the concentration at every position (x, y, z) is not required by the evacuation crowds. We usually concern about the areas where the concentration is higher than the dangerous levels. In this paper, we calculate the 3D boundary of the dangerous area and use this boundary to generate a dynamic animation. Because the integration result of (3) can not be expressed by simple functions,we assume that a puff is made up of a series of flumes. When the time is 0, there are two flumes. One is the original gas diffusion and the other is added by us according to the "worst principle" by Pasquill.

When $t \to \infty$, the toxic gas would become steady and the $D(x, y, z, t)$ is the equation (4).

$$C(x,y,z,He) = \frac{Q}{2\pi u\sigma_y\sigma_z} e^{\frac{-y^2}{2\sigma_y^2}} \left(e^{\frac{-(z-He)^2}{2\sigma_z^2}} + e^{\frac{-(z+He)^2}{2\sigma_z^2}} \right) \tag{4}$$

$$He = H + \Delta H \tag{5}$$

The parameter H in (5) is the height of the source of the leak. There are many methods to calculate the ΔH which is the rise gas height such as Holland Equation, Briggs Equation and the recommended formula in Chinese National Standards [Wei et al. 2008]. In this paper, we take advantage the Chinese National Standards to work out it. The equation varies from different conditions about the wind and atmospheric stability. The detailed cases are as followed.

The terrain and gas condition n_0, heat release rate index n_1 and gas height index n_2 can be found in table 1. The gas temperature T_s and air temperature T_a are used to calculate the heat release rate Q_h. The parameter ΔH_1 could get using the gas velocity V_s and the diameter of the leak source D. If the atmospheric is stable and the wind exits, there are three cases to compute ΔH.

Table 1: *value of the parameters n_0, n_1, n_2*

Q_h	Terrain	n_0	n_1	n_2
$Q_h = 2100$	Countryside	1.427	$\frac{1}{3}$	$\frac{2}{3}$
	City	1.303	$\frac{1}{3}$	$\frac{2}{3}$
$Q_h <= 2100$	Countryside	0.332	$\frac{3}{5}$	$\frac{2}{5}$
	City	0.292	$\frac{3}{5}$	$\frac{2}{5}$

- calculated by (6) and (7) when $Q_h >= 2100$ and $T_s - T_a >= 35$;

$$Q_h = \frac{0.35 P_a Q_v (T_s - T_a)}{T_s} \tag{6}$$

$$\Delta H = \frac{n_o {Q_h}^{n_1} H^{n_2}}{u} \tag{7}$$

- calculated by (8) and (9) when $1700 =< Q < 2100_h$ and $T_s - T_a >= 35$ and the ΔH_2 could be calculated by (6) and (7);

$$\Delta H_1 = \frac{2(1.5 V_s D + 0.01 Q_h)}{u} - \frac{0.048(Q_h - 1700)}{u} \tag{8}$$

$$\Delta H = \Delta H_1 + \frac{(\Delta H_2 - \Delta H_1) \times (Q_h - 1700)}{u} \tag{9}$$

- Otherwise the ΔH would be computed by(10).

$$\Delta H = \frac{2(1.5 V_s D + 0.01 Q_h)}{u} \tag{10}$$

When the air is very stable and wind speed is slower than 10 m/s, the equation (11) works, otherwise, (12) is to calculate the rise height.

$$\Delta H = \frac{Q_h^{\frac{1}{3}}}{[(\frac{dT_a}{dz} + 0.0098)u]^{\frac{1}{3}}} \tag{11}$$

$$\Delta H = \frac{5.50 Q_h^{\frac{1}{4}}}{(\frac{dT_a}{dz} + 0.0098)^{\frac{3}{8}}} \tag{12}$$

Other parameters should be computed are σ_y and σ_z. Several methods have proposed to get them like Sarton model, Pasquill model [Chitumalla and Harris 2008] and so on. In this paper, the method from the Chinese National Standard is adopted to acquire them. The concentration of points could be derived by Pasquill-Gifford model. The area of the gas diffusion should be acquired with the time varying to generate the dynamic gas dispersion animation. We use a series of plumes to generate the puff in this paper. To resolve the problem that integration can't be expressed by simple functions, a sum of discrete plume is taken as the approximation of intergration(the $C(x, y, z, t)$ means the concentration as showed in equation (2)) to computer the 3D boundary.

$$D(x,y,z,t) = \sum_{i=1}^{n} C(x,y,z,i) \tag{13}$$

By this way the complexity of the calculation could be decreased. Not only the occurrent disaster situation, but also the history scene is important for the right evacuation strategy to be made. Function of scene recovery is carried out in the system for the commanders to review. Video is employed to record the simulation process through grabbing the active window of the system. Especially, when a message event happens, the description of the event and the time are recorded in XML file. This file will be embedded in the captured video as event mark for accurate review.

5 Results and Analysis

The Scene is showed by Figure 2 before gas diffusion and the four tanks in the scene are the reactant equipment and the source of leak is beside them. The red lines in this figure represents the path to get away from gas contaminated regions. Figure 3 shows the gas diffusion results in the city.Different colors in the figures represent different concentrations, that is, the damage degree. The yellow means a high concentration and blue is relative lower. We can see that the shape of the gas diffusion likes an ellipse when look down the gas, which is explained by the equation (1).

Figure 2: *The scene of chemical industry park*

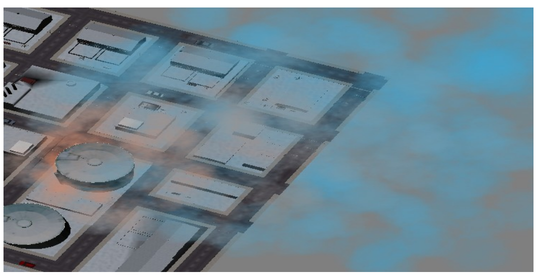

Figure 3: *The stereo diffusion status of gas leaking*

6 Conclusion

Public safety catches more concerns from both governments and researchers with the rapid development of society and economy. This paper focuses on the dangerous gas diffusion in chemical in industry park and proposes a virtual emergency rehearse system. With regard to four key factors of virtual emergency rehearse, modeling, simulation, rendering and decision making, this paper presents corresponding solutions.The Pasquill-Gifford model combined with Normal distribution has advantage of fast animation generation. Open source engine of OSG efficiently supports the rendering load of large scale of scene. Videos embedded with event tags are recorded for disaster history review. The overall system provides intuitive and useful visual information for all kinds of roles in emergency response, commanders, rescuers and evacuation crowds.

For the future work, gas diffusion model need to be improved to fit different temperature and wind conditions. Attributes of chemical material is necessary to be investigate with professional knowledge. Moreover, video need large space of store. One efficient way of 3D secne record with store models themselves should be found.

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