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To cite this article: Jinqiang Ma et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 218 012090

View the article online for updates and enhancements.
Design of evacuation simulation system for subway station personnel in fire environment based on SPH

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Abstract. Based on the crowed places (subway stations are mainly considered), a personnel evacuation coupling model combined with fire environment is proposed in this project, and a computer simulation system is developed. Firstly, a model of personnel evacuation considering environmental factors is established based on the social force model, and the model is dispersed into particle system model by the smoothed particle hydrodynamics (SPH), namely the evacuation SPH coupling model. And then, a personnel evacuation simulation system based on virtual reality technology is developed, implementing the modules of specific personnel evacuation warning and emergency evacuation decision-making. This system can provide technical support for fire control room staff, fire management departments and policy experts. This project has important guiding significance for personnel evacuation safety analysis in the building, which can provide a reference for the establishment and application of the safe evacuation analysis method in our country, and provide theoretical basis and technical support for preventing a stampede and emergency evacuation.

1. Introduction

The study of personnel safety evacuation has important guiding significance for building fire protection design, personnel safety evacuation plan formulation, and safety rescue. According to the actual observed phenomenon and the general law of personnel movement, it is a relatively economic and effective research method to establish the corresponding personnel evacuation mathematical model and carry out computer simulation. At present, the common personnel evacuation model is divided into macroscopic model and microscopic model. The macroscopic model adopts the mature research method in fluid mechanics, and regards the crowd as a continuous flow medium, which does not distinguish individual differences of pedestrians, and uses parameters such as density and average speed. To describe the movement characteristics of the crowd. The micromodel considers each pedestrian as an independent individual, taking into account the individual differences of individual individuals. The current personnel evacuation model is too ideal for the setting of individual attributes, and the impact on the interaction between individuals is neglected. It is assumed that a single person can evacuate according to the shortest path in an emergency, and the individual behavior is not affected. The influence of other individuals, which is largely deviated from the reality, makes the evacuation model based on simple individual attributes may lead to a decrease in the credibility of the evacuation simulation results. Therefore, it is necessary to combine the advantages of macro and micro models (social force models) to establish a new model and algorithm, through simulation technology to improve fire evacuation ability, reduce casualties and property losses during disasters.

Here, the smooth particle hydrodynamics (SPH) method is used to fuse the advantages of the macroscopic model and the microscopic model, and further consider the differences in the process of
evacuation behavior caused by smoke, heat radiation and other factors in the fire environment. QT and multi-threading technology designed the fire simulation system in the subway station scene.

2. Research architecture based on SHP method
Smoothed Particle Hydrodynamics (SPH) is a particle-based Lagrangian algorithm. The basic idea is to discretize fluid materials into a series of randomly distributed particle sets. Each particle has corresponding physical properties. By searching for other particles in the neighborhood, the smooth kernel function is used to interpolate to calculate the property value of the particle at the next moment. SPH is a meshless method. Its main feature is that the spatial derivative of the calculation function can be transformed into the derivative of the smooth kernel function, and the smooth kernel function differential analytic can be obtained in advance, so that no space grid is needed. Directly ask for the function derivative. In addition, the radius h of the smooth kernel function is finite. The calculation of the attribute value of the particle only involves adjacent particles, and the calculation amount can be greatly reduced. When the accuracy is satisfied, the calculation efficiency can be effectively improved. The evacuation coupling model of the subway station fire environment is based on the SPH algorithm. In the process of evacuation model, the SPH method is used to discretize it into a particle system, and the fixed particle group is used to represent the obstacle. The particle density is used to simulate the pressure. The repulsion force and the squeezing force between the particles are generated, and the tangential friction force between the particles is generated by the artificial viscous, and the target guidance, obstacle avoidance, bypass, and pushing in the evacuation process are realized. Then, the fire dynamics simulation software FDS is used to simulate the building smoke diffusion process, and the personnel smoke load and smoke density are coupled into the personnel movement model, so as to simulate the evacuation of personnel in the subway station. The system research framework is shown in Figure 1.

3. Subway station personnel evacuation simulation software function analysis
The evacuation simulation software of the subway station can simulate the flow of personnel in various evacuation passages and stairs, dynamically and intuitively display the situation of personnel congestion, and provide relevant data for rescuers and decision makers to simulate the evacuation time of personnel under different conditions. It provides a good reference for scientific and reasonable decision-making and rapid response. The simulation system can import the floor plan of the subway station, generate a subway station simulation scene, and set initial parameters of the simulation scene, including personnel distribution, personnel composition, fire source location, and the like. The system realizes the FDS fire model interactive rapid generation and FDS calculation data loading function. The subway station personnel evacuation simulation software can visualize the simulation personnel

Figure 1. Research architecture based on SHP method.
evacuation process and can export the simulation result data. The system has the decision support function of subway safety assessment and emergency response plan. As shown in Figure 2.

![Subway station evacuation simulation system in fire environment](image)

Figure 2. Subway station personnel evacuation simulation software functional structure diagram.

4. Main implementation technologies

4.1 Qt technology
Qt is a cross-platform c++ graphical user interface application development framework developed by Trolltech in 1991. It is fully object-oriented, easy to extend, and can be applied to component programming. Qt is easy to learn, the documentation is relatively complete, a few lines of code can develop a simple client; Qt is easy to make beautiful interface and cool animation; Qt source code can run on multiple platforms, lowering Development costs. Qt is mainly used in desktop program development and embedded development. Qt supports Unix, Linux, Windows, WinCE, Symbian and other operating systems.

4.2 Multi-threaded parallel computing technology
Multithreading is the programming concept and advanced technology that breaks down the running of a program (sometimes called a task, or a process) into multiple segments (threads) that run in concurrent mode. Multi-threading technology can make full use of CPU resources, so that programs have concurrent running and real-time processing functions, and can truly achieve interactive operations. At present, multi-threaded parallel computing technology has become a very important tool in software development. The personnel movements in the subway station evacuation simulation scene are independent of each other, that is, each person has his own set goals, and advances toward the goal, and the targets are related to each other according to the requirements of the SPH method. Therefore, the multi-thread parallel computing technology is used here to realize the evacuation of personnel in the fire, at the same time, the use of multi-threading technology to maximize the use of computer performance, making calculation accuracy and speed.

4.3 CUDA technology
CUDA (Compute Unified Device Architecture) is a new infrastructure that uses GPUs to solve complex computing problems in business, industry, and science. It is a complete GPGPU solution that provides a direct access interface to the hardware without having to rely on a graphical API interface to implement GPU access as in the traditional way. A new computing architecture is used in the architecture to use the hardware resources provided by the GPU, which provides a more powerful computing power for large-scale data computing applications than the CPU. CUDA uses C language as a programming language to provide a large number of high-performance computing instruction development capabilities, enabling developers to build a more efficient and intensive data computing
solution based on the powerful computing power of the GPU. Using CUDA’s built-in thousands of parallel units, it is convenient to simulate the evacuation of people in the scene. In addition, CUDA technology can also be used for rendering processing. Reach software to take full advantage of hardware performance.

5. System implementation

5.1 SPH algorithm implementation

Apply the SPH method to the social force model (1):

\[ \frac{d\rho}{dt} = \rho \frac{v^e(t) - v(t)}{\tau} + f_R + f_B + f_V \]  

Where \( \rho \) is the density of the fluid, \( f_R, f_B, f_V \) are the repulsive force, the squeezing force, and the friction between the particles, respectively. Here, the pressure in the fluid can be used to calculate the repulsive force and the squeezing force. Use the viscous force in the fluid to express the friction.

\[ f_R = -\nabla P_R, f_B = -\nabla P_B, f_V = \mu \nabla V \]  

Here, \( P_R \) is a kind of pressure exerted by the psychological interaction between groups, in order to maintain a certain distance between individuals, \( P_B \) is the pressure due to physical (physical) contact between individuals, and \( \mu \) is the viscosity coefficient. In this way, the repulsive force \( f_R \) is used to simulate the avoidance behavior between the personnel, and the personnel's bypass behavior to the obstacle; The squeeze force \( f_B \) is used to simulate the crowding behavior between personnel and between personnel and obstacles during evacuation; The frictional force \( f_V \) simulates the tangential friction generated by the mutual contact between individuals during the evacuation process.

First, people and obstacles are represented by individual particles. One active particle represents a person, and multiple adjacent fixed particles can form an obstacle. A discrete model of human evacuation can be obtained by SPH method:

\[ \frac{dv}{dt} = \frac{v^e(t) - v(t)}{\tau} + a_{Ra} + a_{Rb} + a_{V}, (a = 1, 2, \cdots, N) \]  

among them:

\[ a_{Ra} = -\sum_b m_b \left( \frac{P_{ba}}{\rho_a} + \frac{P_{ab}}{\rho_b} \right) \nabla W(r_{ab}, h_R) \]

\[ a_{Rb} = -\sum_a m_a \left( \frac{P_{ba}}{\rho_a} + \frac{P_{ab}}{\rho_b} \right) \nabla W(r_{ab}, h_B) \]  

\[ a_{V} = -\sum_a m_a \nabla W(r_{ab}, h_V) \]  

5.2 The calculation steps of the SPH discrete model:

- Calculate the density of particles:

\[ \rho_a = \sum_b \rho_b \frac{m_b}{\rho_b} \nabla W(r_{ab}, h), (a = 1, 2, \cdots, N) \]  

- Calculate the pressure.
- Calculate the particle acceleration.
- Calculate the displacement of the particle using leap Frog:

\[ \begin{align*}
\nu(t + 0.5\Delta t) &= \nu(t - 0.5\Delta t) + a(t)\Delta t \\
r(t + \Delta t) &= r(t) + \nu(t + 0.5\Delta t)\Delta t
\end{align*} \]  

5.3 Simulation scenario
The subway station evacuation simulation software can import the completed CAD drawings, or import the generated scene files, and can import information such as the number of people in different rooms in the scene, the age structure, the position of the door, and the safe evacuation exit. The software reads the information in the *.dxf file, reads the building wall information in the CAD drawing file (including lines, arcs, etc.), and the program decomposes these line segments into particles, instantiated into static particles, simulated in real-time simulation. Under the settings, the program renders these particles under the OpenGL framework to form a scene model.

5.4 Analog parameter settings
Setting the personnel parameters will allow the user to select a point to set the location of the person, the number of people, and the age structure of the person, and set scene information such as evacuation exits and room exits. When the user sets up a person in a certain scene, the program will automatically create the same number of SPH mobile class instances, i.e., personnel classes, around this point. By setting the human life value and the action speed to simulate the people in different ages in the fire. Evacuation escape speed.

The evacuation simulation software of the subway station can set the time interval from the fire to the evacuation of the personnel, that is, the reaction time, and the expected speed of evacuation of personnel of different ages in the scene. These parameters mainly determine the escape speed of different people in the fire and the degree of smoke tolerance.

5.5 Introduction of FDS flue gas simulation data
The software reads the FDS flue gas scene file to determine the smoke concentration at different locations and at different times. The concentration of flue gas will affect the evacuation of personnel. Personnel may die in areas with high smoke concentration and become fixed obstacles.

6. Evacuation simulation
All simulations in this simulation system rely on the calculation engine to start the calculation. The calculation engine is responsible for scheduling the data between the threads. It is also used as the clock engine. In the real-time simulation mode, the calculation engine simulates on the real time scale, allowing the user to dispatch. There may be more threads for parallel computing. The calculation engine performs block calculations based on the realities in the scene, making the effects between particles more realistic. In the fast simulation mode, the calculation engine will use the unit time as the engine time interval. This time interval is dynamic and is determined by the user's computer performance. At the same time, the calculation engine will summarize the records generated by the fast simulation and finally present it to the user.

The subway station evacuation simulation software performs real-time simulation based on the previously set simulation parameters. The simulation methods are divided into three categories. The first type is real-time simulation. The user can see from the simulation start to the simulation end in the real-time simulation. The personnel are evacuated dynamics. The second type is fast simulation. In this mode, the program will not display the real-time simulation situation, and will present the simulation situation report to the user at the fastest speed. The third category is the planning mode. In this mode, the program will attempt to simulate the best simulated evacuation path for this building parameter and present the report to the user. In the software, you can set the maximum number of threads (CPU) for the drive engine to be mobilized and whether to use CUDA (GPU) acceleration. In addition, the program will give the maximum acceleration after enabling the above two functions according to the user's hardware, and the user can determine if these features are turned on. The subway station evacuation simulation software can assist the user in planning the evacuation path within the building and assisting in the production of fire evacuation indication maps within the building. The simulation effect is shown in Figure 3.
7. Conclusion

In this paper, a human evacuation model considering fire environment factors is established, and a method of coupling fire environmental factors into the evacuation model is designed. Based on the SPH method, a subway station evacuation simulation software is developed. This study will provide reference for the establishment and application of the safety evacuation analysis method system in China, and provide theoretical basis and technical support for the prevention of stampede events and emergency evacuation under emergencies. Through the simulation experiment, the rationality of the model is verified, the software simulation degree is good, the personnel evacuation degree is high, such as the movement law of the personnel in the smoke; the crowding behavior of the personnel will reduce the escape speed. However, there are still some complicated phenomena that need to be perfected in the personnel evacuation model, such as crowded trampling, increasing individual differences, and the familiarity of the people in the scene.

References

[1] David Iclänzan, Anca Gog, (2012) Cell state change dynamics in cellular automata. Memetic Computing.,10:1-9.
[2] Miao Zhihong, (2014)A Coupling SPH Model for Occupant Evacuation in Building Fires, Journal of Automation., 27:935-951.
[3] MEI Yanlan,(2018) Modeling and Simulation on Emergency Evacuation Capability of Crowds in Metro Station, JOURNAL OF WUT( INFORMATION & MANAGEMENT ENGINEERING ) .,8:370-375.
[4] RONCHI E,(2013)Testing the predictive capabilities of evacuation models for tunnel fire safety analysis.Safety Science., ( 59 ) : 141-153.
[5] LIU Yi, (2018) Influence factors on the route choice for evacuation in metro station hall, Journal of Fuzhou University( Natural Science Edition) ., 46:410-415.
[6] GUO Y G,(2012) Route choice in pedestrian evacuation under conditions of good and zero visibility, Transportation Research Part B: Methodological ., 46( 6 ) : 669—686.
[7] ZHAO G M , (2010) The Study on Evacuation Discrete Time Computational Model for Subway Station, Journal of Disaster Prevention and Mitigation Engineering., 2:152-157.