Smart Fire Evacuation Service Based on Internet of Things Computing for Web3D

Fengting Yan[1], Jinyuan Jia[2], Yonghao Hu[2], Qinghua Guo[3], Hehua Zhu[3]

[1] School of Electronic and Electrical Engineering, Shanghai University of Engineering Science, China
[2] School of Software Engineering, Tongji University, China
[3] School of Civil Engineering, Tongji University, China
yanfengting2008@163.com, jyj1a@tongji.edu.cn, 542932638 @qq.com, 429822441@qq.com, geofbazd@263.net

Abstract

Fire hazard is the primary cause of crowd death in public buildings. To decrease the serious disaster from fire hazard, a rational IoT-based fire evacuation system fully considering manifold aspects of smoke hazards in Multi-agent path planning has been developed and is illustrated for Web3D. In this smart evacuation system, a WebVR technique based on volume rendering on Web and smoke diffusion data have been calculated to found an accurate and realistic fire scenario for the objective of high rate Multi-agent AI evacuation, which allows Multi-agent to practice an authentic and yet non-threatening smoke environment. Moreover, a comprehensive evaluation model of smog and narcotics hazards is also created as an important safety element for Multi-agent evacuation along optimization path planned using IoT-*a*ACO (Internet-of-Things-based adaptive Ant Colony Optimization) algorithm, which allows Multi-agent to identify how to find the optimal path. The position of every agent comes from every people's position using Internet of Things technologies. And the optimization path of every people will be sent to their mobile phones and environment-TVs through IoT technologies. There are two study cases of a rectangular metro station and a curve space structure metro station, which demonstrate the characteristic of accuracy, real-time and smooth interactive performance of the proposed Multi-agent evacuation system. The system is thus shown to be valuable for people who might become trapped in fire to learn the proper evacuation procedures.

Keywords: Web3D, Multi-agent path planning, Smoke hazard assessment model, Fire evacuation, IoT-*a*ACO

1 Introduction

Smog and heat of fire are both the serious disasters that commonly occur in huge-scale buildings, and commonly occur in metro station, frequently resulting in human death and human panic [1]. According to a latest worldwide investigation [2], smog and heat are the reason of up to 4/5 of all the death tolls in metro station every year in the world. The effective fire escape training is necessary for the public to take part in. The mass evacuation can help people choose the optimal path to avoid smog and heat hurt. In particularly, minimizing the toxicity of flue gas is critical to reduce death rate of the people who are trapped in fire buildings.

However, there are a lot of drawbacks in the real evacuation training, which has potential risks, high costs, and is not easy to develop evacuation training at any time anywhere [3-4]. Using computer technologies to train evacuation abilities is particularly necessary. Especially, the fire training system based on Web3D is the most popular, low-cost, convenient and efficient means, because the public can participate in the fire evacuation training anytime, anywhere via the Internet.

In recent years, some kinds of industry fire evacuation software have been developed, such as EXODUS emergency simulation system from the University of Greenwich, England [6]. And the British Legion Company develops the Legion series of software systems [7]. At the same time, Crowd Dynamics Company develops Myriad system [8], and Massive Company of USA develops Massive Software [9].

All the above systems are based on a whole computer, and recently, some companies are developing fire evacuation research catering for Virtual Reality. For example, the vrEXODUS [5, 10] emergency simulation system software can be used to build 3D evacuation scenario. However, the popular online fire evacuation training cannot be realized.

In the past research, the smog and the heat hazards have been taken into account in some 3D systems, yet no in the Web3D evacuation systems. Hence, a Web3D fire training system incorporating smog and heat hazards merits in-depth study for the efficient crowd evacuation using IoT-based adaptive Ant Colony Optimization (IoT-*a*ACO) algorithm through Multi-

*Corresponding Author: Fengting Yan; E-mail: yanfengting2008@163.com
DOI: 10.3966/160792642019032002019

agent method.

However, there are three crucial practical challenges in such a Web3D Multi-agent evacuation system: (1) A stable, efficient, and accurate Internet of Things system (IoTs) should be established. The IoTs should complete Peer-to-Peer information transmission; (2) The lightweight visualization fire scenario should be displayed on people's mobile phones or surrounding TVs; (3) And the huge dynamic smoke data will be lightweighted for path planning, and smoke hazards should be assessed.

For challenge (1), use GPS positioning system in people's mobile phone to locate their positions, which are send to computer server, and the fire evacuation scenario will be transmitted to the people's mobile phone or surrounding TVs which are in the building. The advantage of the system is that the evacuation paths can be transmitted peer to peer based on the nearby mobile phones or surrounding TVs.

For challenge (2), huge dynamic smog data visualization needs a lot of computer memory. Smog and poison gas of smoke would hamper the capacity of people to find the optimal evacuation path. It is very difficult to search for right exits in 6 minutes, thereby hindering evacuation [16]. Obviously, the accurate smog dynamic spreading is especially important for crowd evacuation in WebVR training. There are many literatures on the smog visualization [17-18]. For example, random variables methods, particle systems methods, and cellular automata method, which have been used to compute the spatio-temporal diffusion of smog. However, all these methods are not similar to the actual situation. Then, an accurate smog spreading data is essential, and the visualization of smog scenario is important for fire building scenario.

Obviously, it is necessary for an optimized Web3D virtual system to obtain spreading-smoke features (e.g. its spreading speed and concentration). The CFD (computational fluid dynamics) is a responsible approach [19] which is used to compute complex smog, narcotics, and heat spreading process. The FDS (Fire Dynamics Simulator) is one of the outstanding fire computing tools, which is an accurate and believable open source system software. The margin of error of the FDS is only 5-20% comparing with the real fire scenario. Such high accuracy makes FDS universal used in building fire calculation [19-20]. Moreover, the volume visualization can be used not only in CFD computing environment, but also can be used in Web platform. Consequently, the dynamic FDS data and volume visualization technologies are applicable to the research of computing out accurate and efficient smoke data for path planning and smoke visualization.

For challenge (3), light-weighted smoke data is necessary to make optimal path for people who are trapped in the dangerous fire building. The specific process to obtain lightweight smoke data consists of 4 steps (see Figure 3):

step1: remove redundant contents of raw heavyweight smoke data. Then, the zero data of smoke is removed.

step2: obtain effective smoke data using binary conversion. Then, the computing for smoke data is faster.

step3: unify smoke data, which is divided into 25levels.

step4: remove geometric repetitive smoke components. Then the same level voxels for a whole rectangle for rendering.

In the path planning process, an integrated assessment model with smoke hazard is important, and real-time path planning computing is necessary. In this paper an IoT-*a*ACO path planning algorithm is proposed based on IoT, considering smoke hazard. The optimal path planning is necessary to assist the Multi-agent evacuation in a fire station metro.

2 IoT-based Large-scale Web3D Fire Scenario Transmission

In this paper, a new WebTorrent framework is extended to transmit people's positions and Web3D scenario files. All the positions of people would be located by GPS of people's mobile phone. And the Web3D subspaces files are transferred via the Internet to the people's mobile phone or surrounding TVs in the fire building. Moreover that, the Web3D subspaces files can be transferred peer to peer. Especially, there are two-threads on Web-end used for package transferring and for rendering, respectively. A Web3D platform with three layer architectures is implemented in this Internet of Things.

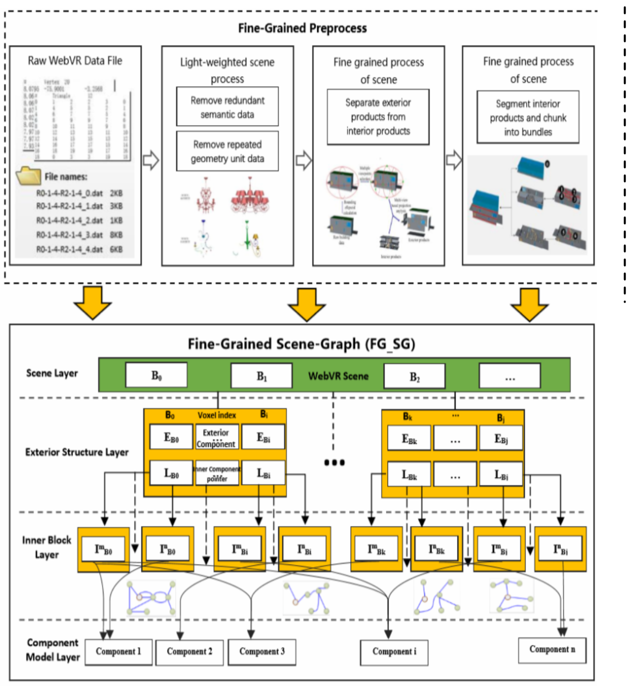


Figure 1. Technical roadmap for the Web3D fire scenario transmission

Peer-to-Peer networking is regarded as a potential solution to Web3D transmission bottleneck problem in the Internet of Things [35, 37-38]. There are lots of studies about this hot topic and latest survey can be seen in [11, 39] and [12, 40]. However, it is very difficult to transit the Web3D scene data into IoT environment with Peer-to-Peer technology. At present, almost all Peer-to-Peer Web3D studies were experimented on simulation platform. HU proposed a perfect simulation transmission platform FloD, which can conduct quickly finding neighbors [13, 41]. JIA developed the FloD into iFloD with incremental AOI theory [14]. WANG extended the iFloD with interests driven by P2P neighboring into iiFLoD [15]. However, the Peer-to-Peer technologies are only running on simulation platform, which is for away from Real Virtual scenario transmission before. Our contribution in this Web3D fire evacuation scenario consists of (1) a novel fine-grained preprocessing procedure addressed to divide the huge building scene into some sub scenes; (2) using an adaptive Internet bandwidth function, for which a novel packaging mechanism is provided to transit the Web3D fire scenario based on IoT.

3 Smoke Lightweighting and Visualization

3.1 Smoke Lightweighting

From the smoke computing method based on FDS, the raw heavy smoke data are obtained and they are not suitable for visualization, and cannot be used for path planning. The lightweight preprocessing is necessary to overcome the huge smoke computing problems.

In our solution for the heavy smoke visualization, a smoke lightweighting preprocessing solution is used in this paper and as a novel method for people evacuation based on IoT system architecture. Firstly, we obtain the heavy smoke data through FDS, and then a four steps lightweighting preprocessing solutions can be used, and at last the lightweight smoke data can be sent to the Web-end of mobile phone or TV device to visualize the process of building fire.

When someone's equipment has received the optimal evacuation paths, other people's electronic equipment would download the data of fire scenario or optimal evacuation paths from it. All these processes would be completed based on the IoT technologies. The detail process of lightweighting preprocessing is presented in Figure 2.

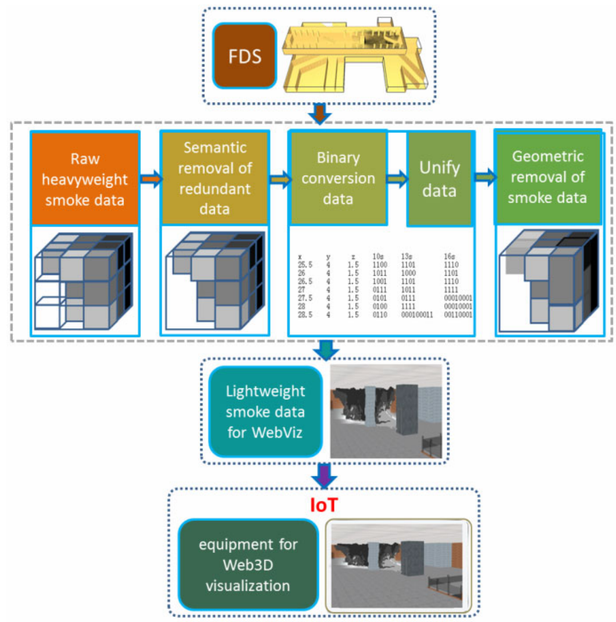


Figure 2. Lightweight processing of heavy FDS smoke data

3.2 Lightweighted Smog Visualization

In the fire calculation, the dynamic smog data in the Web3D station metro scenario are obtained from the FDS tool which is able to calculate more accurate smog spreading data than the detecting data from sensors does [27]. Volume visualization is usually adopted for depicting the smoke spreading process and is extremely suitable for the smog data which is computed using the FDS [28]. Hence, lightweighted smog visualization can be designed to establish precise smog scenario and vivid fire scenario.

In the spreading calculation of smoke, the FDS software is used to calculate the smoke spreading based on the grid, which usually divides a metro station geometrical space into some continuous volumes with accurate voxel side length parameter or space structure [20]. Moreover, the FDS divides the continuity of the simulation into a series of equal time interval steps automatically in the metro station space model, and the smog consistency value in every 3D grid is recorded by the FDS and forms a file in Q format at all-time steps [21]. For Web3D smoke visualization in mobile device, usually the volume visualization of every volume in 3D would use the 3D grid [28], and a 3D BIM building is created in the Web3D environment with voxel smoking dynamic spreading in real-time. The smog consistency value would be mapped into the opaqueness value of each voxel (see Figure 3). In the rendering process, the opaqueness of each volume would be adjusted based on the smog dynamic consistency data according to the time step. Based on the above method, a precise voxel smoke spreading process can be realistically visualized in the Web3D of IoT equipment.

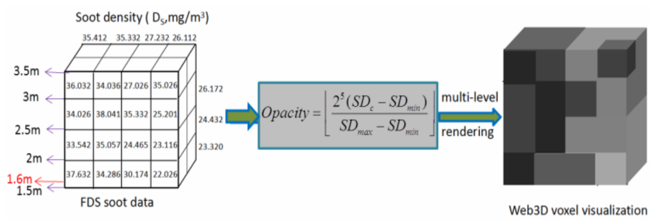


Figure 3. The opaqueness voxel grid from soot densities

In few minutes after a fire, huge amounts of spreading smoke data are increasing rapidly. To reduce the burden of huge data, an important lightweight technology named Soot Concentration systematics (SCs) is used herein to expedite the visualization calculation, and a lightweight multi-level visualization rendering of smog is presented. To accelerate the rendering calculation, the levels of opaqueness are from zero to 25 in each voxel (i.e. where zero signs the fully transparent, and the 25 signs completely opaque), and every voxel concentration value in Figure 3 is converted to opacity values, respectively. The conversion formula value is stored in the variable of Opacity. The calculation process is that the program obtains the maximum (SD_{max}) and minimum (SD_{min}) smoke values for a certain time smoke data, and then obtains the current position smoke concentration value (SD_c), so the Opacity can be obtained from Equation (1):

$$Opacity = \frac{2^5\left(SD_c - SD_{\min}\right)}{SD_{\max} - SD_{\min}} \tag{1}$$

Using the smoke visualization technologies, some experiments have been done with a B/S system mode. The experimental conditions are shown below: an Intel CPU of 3.40*GHz*, a video card, i.e. the GTX 690 (GPU104, 4*G* memory, 900*Hz*, widely used in desktop computers), and Google Chrome browser are used as the test platform. One voxel smoke visualization scenario is shown below:

On the mobile Web-end based on the raw heavy smoke data, when the metro station space grids are set 3,000, the frame per second (FPS) of the smog scenario rendering efficiency is lower than 15. The standard rendering efficiency should exceed 24*FPS*. In the same building scene, and the computer condition, when we use the lightweighted smoke data to render the smoke scenario as fire break out in a metro station, the smoke visualization efficiency can be kept on 55*FPS* on the Web of mobile phone through the Internet of Things. In addition, smart Multi-agent fire evacuation could execute AI path planning with smoke spreading visualization. The smoke toxicity could be considered to plan a minimal smoke toxicity path for every agent. This method can train and navigate the people to take part in Virtual Reality fire evacuation experiment.

3.3 Smoke Hazard Assessment

To plan a lowest smoke toxicity path for each Web-end user, smoke hazard assessment should be very detailed and accurate. That is the prerequisite for optimal path planning.

The leading hazard of smoke is toxicity, and smoke heat is another main element which causes death of the people. Many introductions can be seen from papers [23-26]. As the most popular evaluation model, the FED is used herein to calculate the integrated effects of multiple gases [21]. Based on the FED, the paper proposed the 7-Gas model to calculate the unitary toxic smoke of 6 gases (i.e. *HCN*, *CO*, SO_2, *HCI HBr*, and CO_2), and smoke heat is another element, all of which are expressed in Eq.(2):

$$\begin{aligned} FED_{T,H} = {} & \frac{|HCN|}{LC_{50,HCN}} + \frac{m[CO]}{|CO_2| - b} + \frac{21-[SO_2]}{21-LC_{50,SO_2}} + \\ & \frac{[HCI]}{LC_{50,HCI}} + \frac{[HBr]}{LC_{50,HBr}} + \frac{[CO_2]}{LO_{50,CO_2}} + H_{rad} \end{aligned} \tag{2}$$

Here, every kind of smoke from the 6 gases has a symbol which, in bracket, indicates the time-integrated average gas concentrations during 60 minutes exposure time. All the gas concentration values obtained from the accurate FDS computing, as mentioned above, of which the accuracy is more than 20%. LC_{50} is the density of a kind of toxic smoke which leads to 50% people's death during 60 minutes. The *m* and *b* variables represent the quantitative relationship between CO_2 and *CO*. The smoke heat mainly comes from the heat smoke radiation: H_{rad}.

The higher the *FEDT*, *H* value is, the more hazardous the smoke is. Counting this into the whole path of an agent, the computer can calculate the harm caused by smoke toxins.

Usually, if the smoke is lower than 1.6*m* in height, the smoke toxins will harm the lung cells, so we only need to consider if there is any smoke in the 1.6*m* voxel. In this paper, every voxel is 0.5×0.5×0.5 (m^3). In Figure 4, intuitive display is provided.

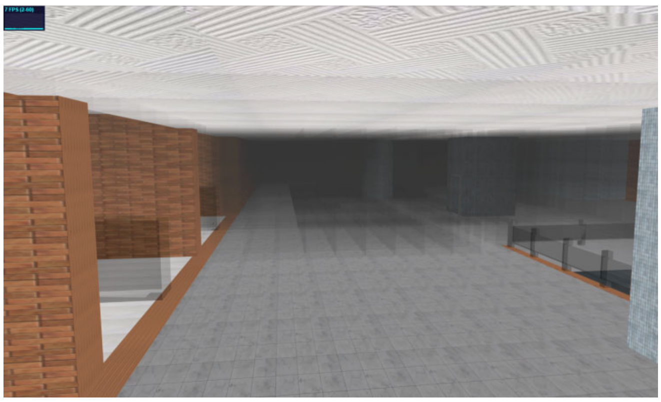


Figure 4. The voxel smoke visualization scenario

If any 1.6m voxel has the smoke, the path planning map corresponding to the plan grid is recorded as an obstacle area. The grids distributed with red dot are the smoke obstacle grids, and the green point position is the accessible area. This information is shown in Figure 5.

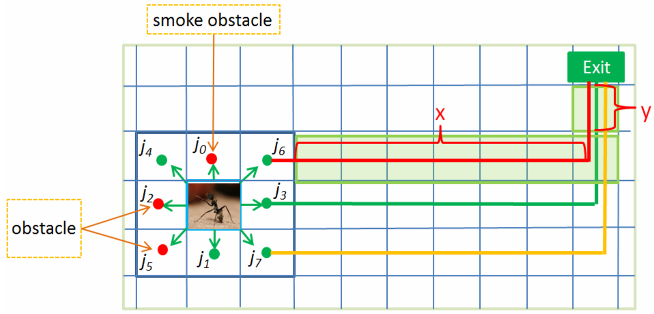


Figure 5. Smoke obstacles

4 IoT-*a*ACO Algorithm Incorporating Smoke Hazard Assessment

It is the first important issue about how to plan the safest path for each participator who is in the fire metro station taking part in the Web3D evacuation training. Multi-agent evacuation can use the ACO algorithm to find the path. Each agent corresponds to a people, whose position data come from the detector through the IoT. And every ant in the path finding could use the distance heuristic. From Figure 5, the j_6 distancing Exit is $d_6 = x + y$, which is 8 grids; the j_3 distancing Exit is 9 grids. The nearer position has the more heuristic value, which uses Equ.3's description:

$$\eta_{ij}(t) = 1/d_{(j,Exit)} \quad \textbf{(3)}$$

When an ant has passed a grid, it will leave the pheromone $\Delta\tau_{ij}$. The following ant finding path is based on the pheromone left by other ants. The pheromone has evaporation feature, and the evaporation rate is ρ

$$\tau_{ij}(t) = \rho * \tau_{ij}(t-1) + \Delta\tau_{ij} \quad \textbf{(4)}$$

Based on the $\Delta\tau_{ij}(t)$ and $\eta_{ij}(t)$, the ant can probabilistically decides which position grid should be the next step position. The probability selection formula:

$$P_{ij} = \begin{cases} \dfrac{\tau_{ij}(t)\eta_{ij}(t)}{\Sigma_{s\in allowed_k}\tau_{ij}(t)\eta_{ij}(t)}, & j \in allowed_k \\ 0, & others \end{cases} \quad \textbf{(5)}$$

If ACO path planning is trapped in local optimization, the adaptive ACO algorithm [15] should be used incorporating smoke obstacle. That is the ρ should be risen up, and the rising up coefficient is 1.15. But the ρ is not larger than $\rho_{\max}$. If the value of ρ is larger than $\rho_{\max}$, then the ρ value remains at $\rho_{\max}$. Based on smoke hazard assessment, the IoT-*a*ACO is proposed herein (see Figure 5).

$$\rho(t) = \begin{cases} 1.15\rho(t-1), if\ \rho_{\max} \geq (1.15\rho(t-1)) \\ \rho_{\max}, \qquad other \end{cases} \quad \textbf{(6)}$$

Using the IoT-*a*ACO, an optimization path is planned for every agent. The Multi-agent learn how to find the safest path in the smoking metric station scenario for evacuation. The optimal path of every people will be shown on the people's mobile phone or the other visualization devices by IoT technologies.

5 Web3D Evacuation Simulator

Based on the above AI Multi-agent fire evacuation system, a smart fire training server which based on Internet of Things is established. And the system considers the smoke spreading data from the FDS, and is created by adopting a Web graphics engine (WebGL) to set up the Web3D platform [31]. In this smart fire evacuation system, seven major steps are illustrated in Figure 6 about the entire system on Web3D: (1) the Web3D scene BIM models are created according to the actual building information which correspond the obj format of models. And the FDS building models are built based on the same building information; (2) the people's position data is obtained from the IoT for every agent; (3) the dynamic accurate smoke data of 6 kinds of gases and radiant heat data are obtained From FDS. In particular, the raw heavy smoke data are lightweight into light smoke data using four steps. And a 25 level data visualization method is proposed for real-time smoke rendering; (4) Based on the FDS environment grids, the voxel grids of Web3D scene are created, and a realistic fire evacuation scenario for Web3D could be completed; (5) the safest path planning using IoT-*a*ACO algorithm is safer than the optimal path planned by the Greedy algorithm. This means that the IoT-*a*ACO algorithm is better the people's path planning only depending on their own wisdom to find the optimal path; (6) using GPS location function of every people who are trapped in fire environment, the server computer obtains position data through the Internet of Things, and the building scene static data with smoke dynamic data compose input data for IoT- *a*ACO algorithm to make path planning; (7) using IoT technologies, all the paths data for Multi-agent are sent to the corresponding people who are trapped in the fire building. The optimal path displays on Web of mobile phones or TVs. And the Virtual Reality fire scenario showing on the above devices.

In the smart fire evacuation simulator, the Multi-agent system theory is applied, and every agent is corresponding to one people who lapped in the dangerous fire. The IoT-*a*ACO algorithm is used for path planning with considering smoke hazard, then the agent obtain its optimal path. The process gives the agent intelligence, so the path of the agent could navigate the people to escape from the fire building. Particularly, the evacuation process is visualization and the fire scenario is visual too. Lightweighting technologies have been applied in our paper to lightweight the large-scale 3D scene model, and to lightweight the huge amount of smoke data. A smart lightweight intelligent fire evacuation VR simulator is formed and the platform consists of Internet of Things additionally. Especially, the smart VR simulator can be used for realistic fire evacuation when some people lapped in dangerous fire. Because the people's realistic position data can be captured by GPS of their mobile phones, then the data are sent to server computer by Internet of Things. After optimal path planning which is for every agent is completed, the agent's optimal path data are sent back to its corresponding people's mobile phone or surrounding TVs to guide the people how to escape as fast as possible.

Not only that, the smart fire evacuation simulator can be used for the public to take part in online fire evacuation training effectively. The VR optimal paths are present to every people who are in fire building, and the people can follow the optimal path to escape. This way would assist the public to escape out from the fire building. If the public self-escape individually in the fire, they will obtain an assessment score of their path's toxicity, and the toxicity score will be compared with the optimal path's toxicity core, then the system gives the public the optimal path to guide them to explore how to find the optimal evacuation path. Such training experiences of the public will assistant people to decrease smoke hazard.

The optimal path and the toxicity core are all credible. Firstly, the 6 kinds of smoke data are computed from FDS, which is less than 20% of calculation error. Secondly, the obstacle map which is embedded static scene map data and dynamic smoke data. The static building static data are mapped into the obstacle map, and the dynamic smoke data which are lower than 1.6m are mapped into the obstacle map too. Then the novel IoT-*a*ACO algorithm makes optimization path based on the people's original position data, obstacle map data, and perform adaptive ant colony path planning.

Furthermore, the rendering efficiencies of some experiments in two large-scale metro station models keep on above 53*FPS*. The 53*FPS* rendering efficiency is higher than 30*FPS* that can ensure a satisfactory interactive performance [32]. High rendering efficiency ensures the smoothness of interaction on the Web-end of the public's mobile phones or TVs.

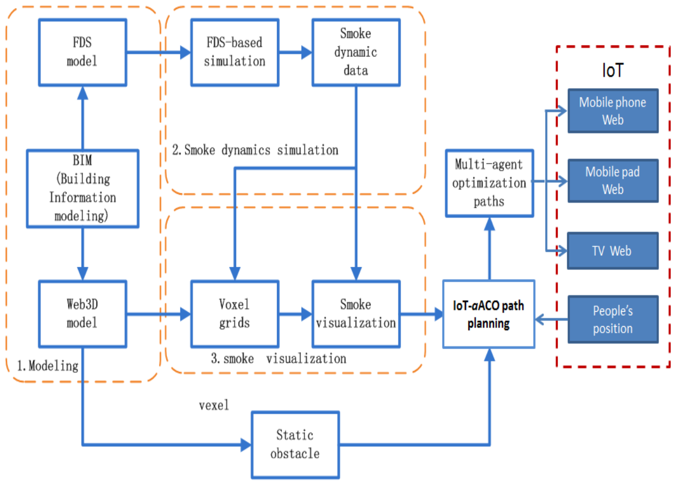


Figure 6. Flowchart of the proposed Web3D fire evacuation

6 Applications of the Proposed System

6.1 Fire Evacuation in a Rectangle Metro Station

In this paper, a double-tunnel metro station which is built to simulate fire evacuation is illustrated in Figure 7, and its geometry structure is rectangular. The metro station is BIM format file which is converted to obj format file to simulate fire evacuation catering to the smart Web3D fire evacuation simulator. In this metro station model, which is composed by two tunnels, and they are connected up and down by two stairways. The fire occurred at the lower steps of the stairs. Two scenarios are illustrated in Figure 7: (1) the lower tunnel, which is 80m long and 45*m* wide scene; (2) the upper tunnel, which is 80m long and 55*m* wide scene. Through Web3D evacuation path planning, the Multi-agent will learn how to plan the safest path using IoT-*a*ACO algorithm.

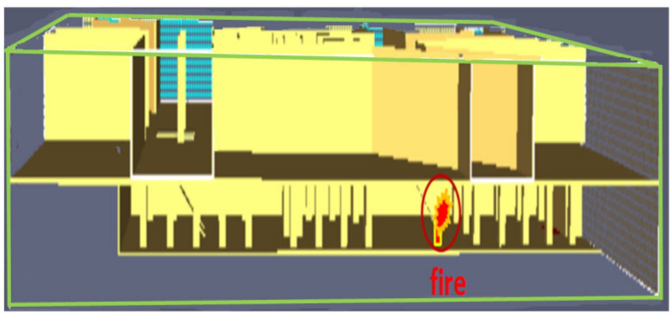


Figure 7. The terrible fire in a double-layer metric station

The first task is lightweight the scene model. In the smart Web3D fire evacuation system, the scene model's format is BIM. Specifically, we adopt IFC format in this paper. The fire data coming from FDS computing, and have been lightweighted. Both BIM data and lightweighted fire data are all as input data in this system, and the system performs an accurate, realistic, and dynamic VR fire scenario. The FDS system is used to compute the accurate 6 kinds of smoke data and 1 kind of heat data, as shown in Figure 7. The IFC format fire evacuation scene model is used for agent to make optimal path computing based on IoT-*a*ACO algorithm, and it is used for the public to experience VR evacuation process, and participate in interactive decision making. The Figure 8 is the lightweighted IFC format scene, which is the evacuation scene on Web3D. The Web3D model (Figure 8, Figure 9) shows the details information of the metro station, such as the 3D scenario, the columns and the fire source. All the fire and metro station are shown by the global layout method. In the computing process of the FDS smoke, the burning material is polyvinyl chloride or wood, all which prone to combustion reactions in daily life. In our experiment, the simulation burning time is 600*s*. The smoke data and heat data are all recorded by the FDS software, and the data are so huge that the current computer needs amount of computer memories to render the smoke scenario. It is necessary for the raw heavy smoke data are lightweighted into light smoke data for the fire scenario display. At last the important temperature, atmosphere concentrations data are obtained and which are used for smoke hazard assessment in optimal path planning.

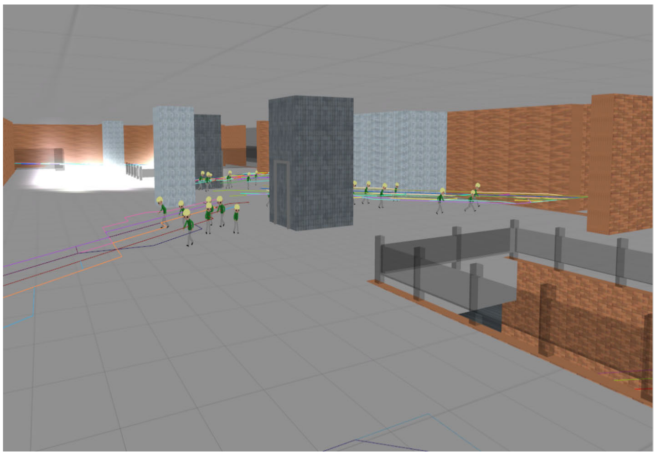


Figure 8. The Web3D scenario

In the evacuation process of the Multi-agent, the range of an imposed evacuation speed which is for every agent is 1-2*m*/*s* randomly. The speed data have been measured in actual fires [33], and the speed will be any alterations in the evacuation training.

In Figure 10, Figure 11 and Figure 12, there are Multi-agent participate in evacuation training through the rectangle metro station scenario when the smog is spreading in the building. The paths based on the IoT-*a*ACO algorithm for every agent is shown in the three pictures below, respectively.

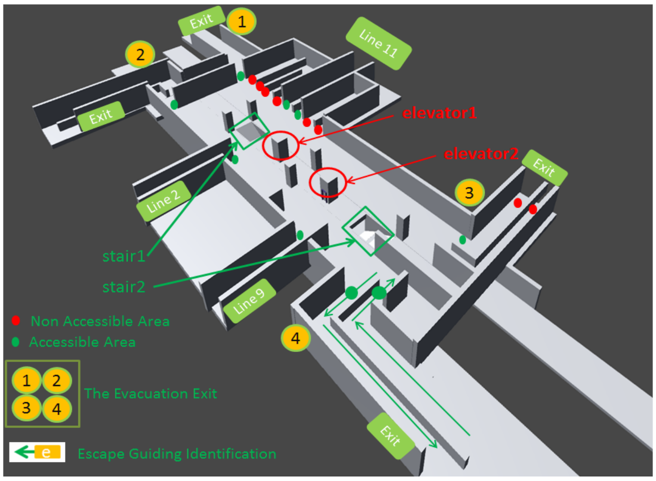


Figure 9. The detail structure

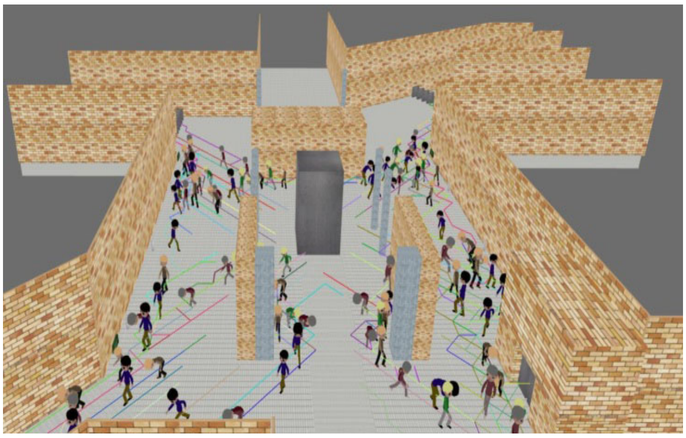


Figure 10. Evacuation training bases on IoT-aACO for Web3D (1)

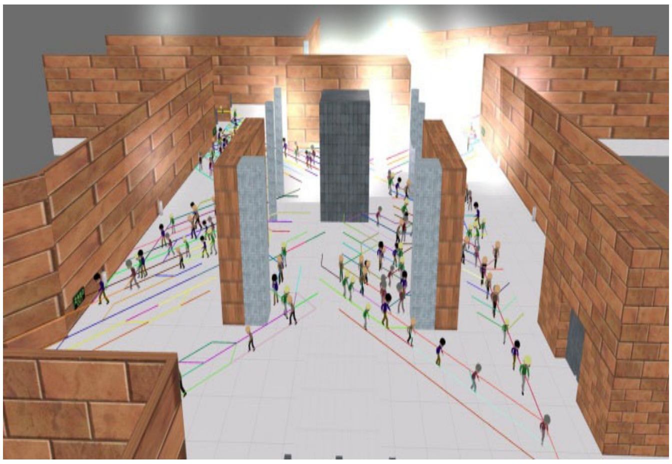


Figure 11. Evacuation training bases on IoT-*a*ACO for Web3D (2)

Figure 12. Evacuation training bases on IoT-*a*ACO for Web3D (3)

It is very important to ensure the accuracy of the dynamic data in Web3D fire environment. A correlation coefficients measure method is used to compare the FDS smoke voxel distribution with the Web3D scene space smoke voxel distribution. From some famous paper [34-35], the smoke distribution can be located based on its typical feature. Because the specific smoke height (1.6*m* in this study) affects people's evacuation decision significantly. At the height of 1.6*m*, people's eyes usually cannot see the metro station environment clearly. So we choose the height position of 1.6*m* as critical level to compare the FDS smoke voxel data with the IFC smoke voxel data. The data from FDS are stored in a M_1 matrix, and the data for the Web3D lightweighted smoke data are stored in next matrix M_2. Compared the matrix M_1 with matrix M_2, and we calculated the variation and the maximum error, and the results illustrated in Figure 13. In our computing, the maximum change is 2.1×10^{-4}, and the variations of the correlation coefficients are basically close to 1. Consequently, accurate spatial-temporal distribution uniformity of smoke positions can ensure the credible smoke rendering. Furthermore, the lightweight smoke data ensure the realistic of the public's interaction fire evacuation.

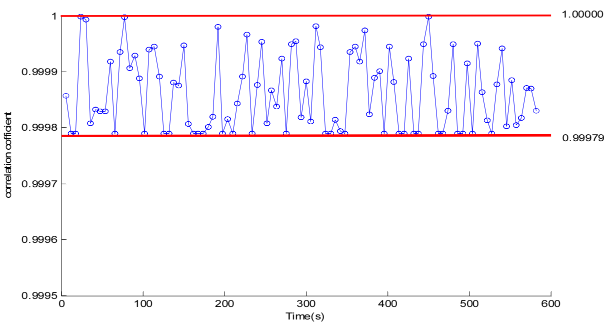


Figure 13. Correlation coefficient dynamic difference of the smog between the Web3D and the FDS scenario

In addition, in this paper, two kinds of path planning algorithms are proposed herein. To ensure the efficiency and accurate of the IoT-*a*ACO algorithm path planning, the Greedy algorithm [41-43] for path planning is used to compare with it. As the Greedy algorithm is very close to the people evacuation performance when the fire break out suddenly. And two AI agents are selected for the comparing of the two kinds of path planning algorithms. The two agents start their path planning from the same position in the upper metro station, and then they would walk allowing the planed path with the dynamic spreading. The rendering efficiency of this fire evacuation VR scenario attains 55*FPS* above on mobile computer, based on the IoT technologies with Peer-to-Peer network transmission method. A widely-used video card (NVIDIA GeForce GTX 960, 4*G* memory, 900*Hz*) is used in the experiment.

In the VR path planning process, the realistic smoke scenario is reappear which using the FDS fire dynamic data [44-45], from which the smoke hazards data abstracted. The smoke hazard value can be calculated using Eq.(2), and the smoke hazard spreading process displayed by heat graph, as demonstrated in Figure 14. It can be seen from the Figure 14, the smoke hazards seem to come from the stairway in the upper scene. But when we see the lower scene from the Figure 15 we will find the smoke hazards are from a supermarket which in the lower scene. Using heat graph [46] and 3D visualization [47] methods, the public can find the fire and smoke dynamic spreading situation. Then, based on the lightweighted dynamic smoke data, the IoT-*a*ACO and Greedy algorithm can be used to make path planning from the same start position and escape to safety area.

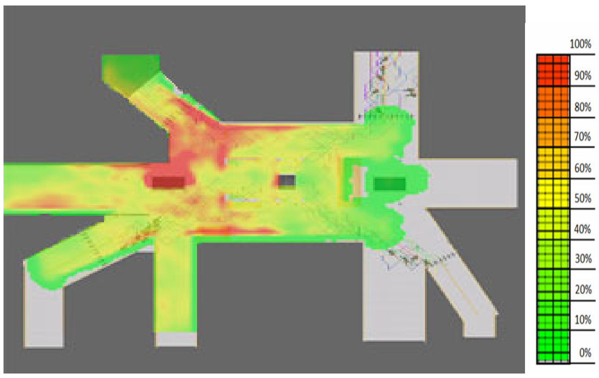


Figure 14. Distribution of Smoke Hazards in Upper Scenario

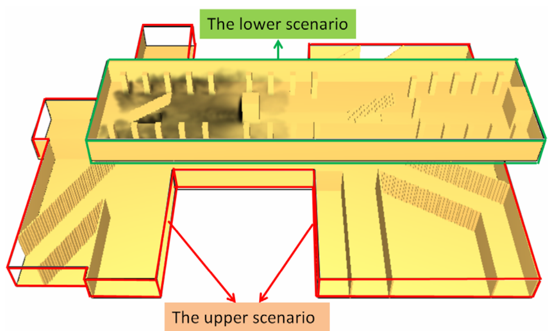


Figure 15. Distribution of smoke hazards in Web3D scenario

Considering the hazards from the smog, the poison gas, and the heat, based on the two kinds of path planning methods above, the damages over time of each agent are accurately calculated, and two paths are found, as presented in Figure 16. The Greedy algorithm finds the Path 1, and IoT-*a*ACO algorithm finds the Path 2. In the Path 1, the 23.5 *s* time is taken for the agent evacuation. And the $FED_{T,H}$ is 25 (*min*/10000*min*); however, based on the IoT-*a*ACO algorithm, the Path 2 is calculated which spends 14.5 *s* for the agent fire evacuation. And the $FED_{T,H}$ is 3 (*min*/10000*min*). All the above obviously reveal that the Path 1 is longer evacuation duration than the Path 2. Therefore, the Path 2 is safer than the Path 1.

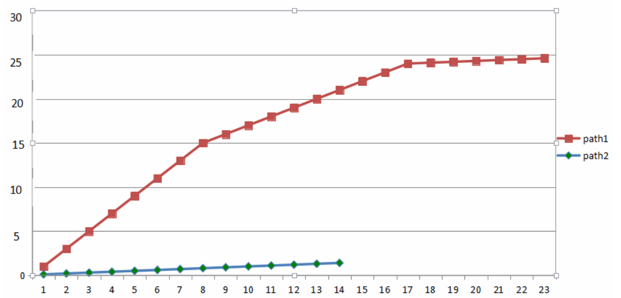


Figure 16. Hazards in the IoT-*a*ACO or Greedy Algorithm Path

6.2 Fire Evacuation in a Curve Space Structure Metro Station

The curve space metro station is more complex than the Rectangle space metro station. The complex curve space metro station is adopted in this paper to test the effectiveness, and efficiency of lightweight and intelligent path planning scheme.

The fire scene is a curve structure space which is 86m long, 65m wide and 5m high. The fire is in a supermarket position of the metro station. The whole metro station is shown in Figure 17. Because of the fire in the metro station, all the agents are trapped in it, and there are some agents who are near the supermarket. Here we use the IoT-*a*ACO algorithm to make path planning for 220 Multi-agent, all the Multi-agent can evacuation from the fire environment when they follow the path made using IoT-*a*ACO algorithm. However, 8 agents trapped in the fire and died when the Greedy path planning is used.

In above experiment, the two people are trapped in the supermarket of metro station, and the fire breaks out from the supermarket, where many wood and plastic are firing, then the FDS computing the smoke spread situation data for 10min. Using the CFD data which have been calculated by the FDS, the smog data lightweighted completed then, an Web3D smog scenario is built for the agent to make AI evacuation. In Figure 17, as one people (the red point in Figure 17) is trapped in supermarket of the metro station, Web3D environment provides the people with two kinds of path planning algorithms (Greedy algorithm, and the IoT-*a*ACO) comparison which reveals the hazard in the Path 1 (using the Greedy algorithm) is much heavier than that of the Path 2 (using the IoT-*a*ACO algorithm). Hence, the agent who is in the supermarket lapped in the fire is likely to consider Path 2 as the better choice. The smoke spread process in the metro station is shown in Figure 18. The process shows that the smog spreading is consistent with the FDS scenario. In addition, the rendering efficiency is 53 *FPS* in the Web3D metro station. Therefore, the above results provide an effective interactive environment for the Multi-agent.

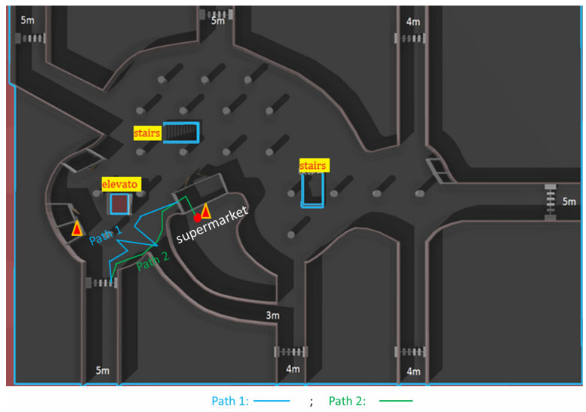
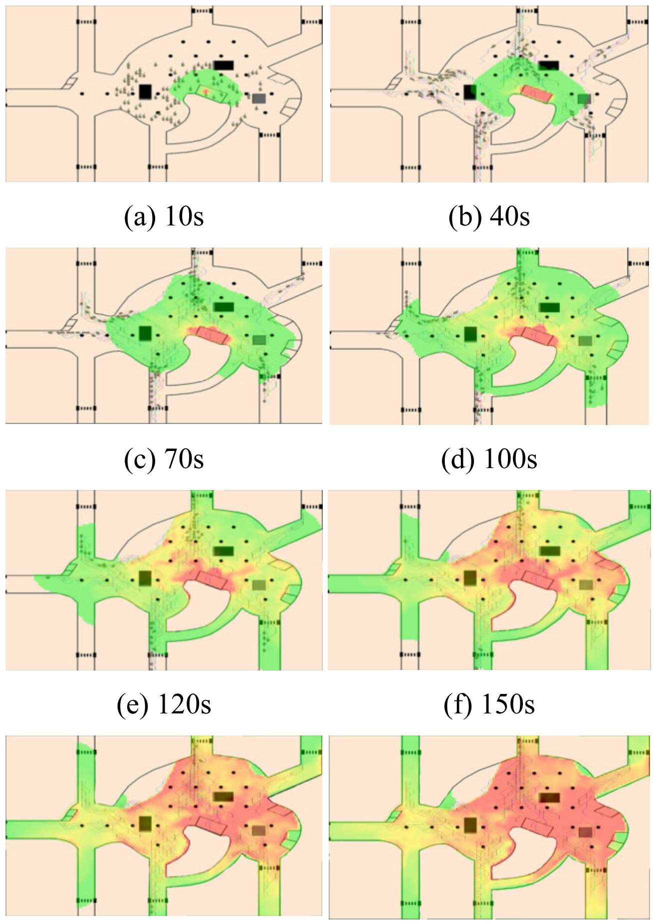


Figure 17. The curve space structure subway station



(a) 10s (b) 40s

(c) 70s (d) 100s

(e) 120s (f) 150s

(g) 180s (h) 200s

Figure 18. Smoke spreading

From the experiment above, the evacuation speed of the people in the fire metro station ranges from 1 to 2.0 *m*/*s*. Based on our Web3D evacuation training, the experiments show that the Path 1 uses 32*s* for agent evacuation and the Path 2 uses 19.5*s* for agent evacuation (see Figure 19). Based on the same speed evacuation of the same kind of agents, under the visibility restriction of the smog, the evacuation speed of the agent is slower in the Path 1 than in the Path 2. The Different speed takes remarkable difference evacuation time. That means the agents are suffered different harms (i.e. $FED_{T,H}$), as show in Figure 17. The $FED_{T,H}$ in the Path 1 reaches 40 (*min*/10000*min*), whereas the $FED_{T,H}$ in the Path 2 is only 5 (*min*/10000*min*). Given that the Path 2 is shorter and lower hazard level, which is much safer, the Path 2 is considered a better choice.

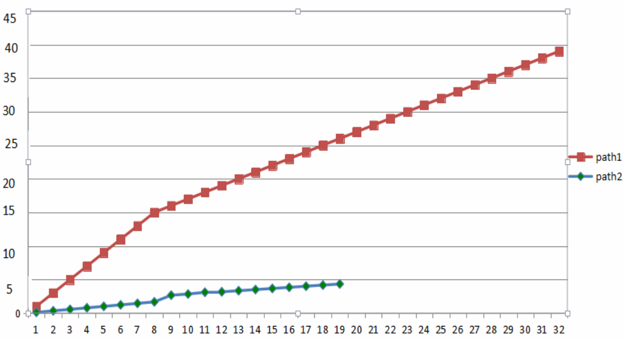


Figure 19. Hazards in The IoT-*a*ACO or Greedy Algorithm Path

7 Conclusions

In this paper, according to the IoT technologies which is addressed above, all the people's positions would be sent to server end, and the optimization path (planned by IoT-*a*ACO algorithm) could be sent to their mobile phones or surrounding TVs through the IoT. Based on the FDS fire data which is useful and dynamically spreading, the volume visualization can be realized in the Web3D scenario. So this paper uses the FDS to compute the dynamic smoke spreading data, and using lightweight technologies to remove redundant smoke data, at last the light data is reduced, and the correlation coefficients are always close to 1, that means the above methods is accurate and useful.

Then, the realistic real-time fire scenario can be simulated, and a Web3D fire scenario can be displayed on the Web-end of mobile phone based on the Internet of Things. After the Peer-to-Peer network transmission technology is completed, the fire scenario can be transmitted by Peer-to-Peer technology. The realistic smoke environment and the interaction are smoothly on the Web-end of mobile phone.

In the path planning, the integrating hazards coming from fire and smoke is considering and as an important element in the IoT-*a*ACO path planning algorithm. The smoke-based pheromone reused and adaptive ant colony algorithm can compute accurate path for Multi-agent in real-time in the fire scenario with smoke hazards. Then the optimal path of each agent could be sent to people's mobile phones and surrounding TVs based on IoT.

At last, a rational Web3D fire training simulator with lightweighted large-scale building, lightweighted huge smoke data, and people's realistic position, the IoT-*a*ACO path planning model is proposed and is used for the agents to make the safeties path, and send the path data to the people's Webs of their equipment based on IoT. And two huge metro scenes are used for the experiments, and giving the safeties paths for the training of the public.

Acknowledgments

The authors are grateful for the financial support received from the National Nature Science Foundation of China (No. 2012BAC11B00-0403), and the basic scientific research business expenses of Central University (No. 20153797).

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Biographies

Fengting Yan is a Ph.D. student in the School of Software Engineering at Tongji University. He received his M.S. and B.S. degrees from Shandong University of Science and Technology. His current research interests include the Machine Learning, Web3D, Internet of Things, Building Fire, and Distributed Virtual Environment.

Jinyuan Jia is a Professor in the School of Software Engineering and Director of Graphics and Image Research Center at Tongji University. He received his Ph.D. degree in Computer Science from Hong Kong University of Science from Hong Kong University of Science and Technology and M.S. Degree from Jilin University. His research is primarily in the areas of the Computer Graphics, Geometric Modeling, Web3D, Internet of Things, and Game Engine.

Yonghao Hu is a M.S. student in the. He received his B.S. degrees from School of Software Engineering at Tongji University too. His current research interests include the Web3D, Internet of Things, Building Fire, and Distributed Virtual Environment.

Qinghua Guo is a Ph.D. student in the School of Civil Engineering at Tongji University. He received his M.S. and B.S. degrees from Taiyuan University of Technology. His current research interests include the Digital Underground, Information Technology in Geotechnical, and Underground Disaster Prevention.

Hehua Zhu is a Professor in the School of Civil Engineering and Dean of School of Civil Engineering at Tongji University. He received his Ph.D. degree in Structural Engineering from Tongji University in 1989, and M.S. Degree from Chongqing University in 1986. His research is primarily on Design Theory for Tunels and Underground Structure, Digital Underground and the Information Technology in Geotechnical Engineering.