Design and Research of Virtual Simulation Experiment of Optimal Fire Escape Strategy Based on Internet of Things

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***Abstract*—With the urgent demand for Internet of Things professionals, colleges and universities are faced with the challenge of training integrated talents of Internet of Things. Combined with the social background of high incidence of fire and difficulty in escape of high-rise buildings, we designed the simulation experiment of optimal escape route selection for fire distribution prediction based on the intelligent fire virtual simulation teaching platform. The simulation experiment takes Unity3D as the tool, comprehensively utilizes computer simulation technology and big data technology of Internet of Things to establish mathematical models of fire data in various situations, and dynamically simulates the scope, intensity and spread trend of different fires. In addition, according to different fire situations, combined with the overall structure of the building and multi-sensor data, based on the optimal path planning principle, the system plans the optimal escape route for personnel in case of fire, so as to guide students to conduct fire escape drills based on different real scene simulation. The teaching system takes the three-layer structure of the Internet of Things as the main line and adopts the "bottom-up" teaching concept to enable students to master the theoretical knowledge and key technologies of the Internet of Things. By completing the simulation experiment designed by us, students should be able to solve practical problems by comprehensively applying Internet of Things engineering technology. The simulation experiment has been put into practical teaching, which has received positive response from students and achieved good teaching effect.**

***Index Terms*—optimal fire escape strategy, Internet of Things teaching, numerical simulation of fire**

I. Introduction

In recent years, with the continuous development of urban construction, high-rise buildings are becoming more and more common. Although high-rise buildings can effectively save land resources, there are still some shortcomings, especially the hazard of building fire is higher [1]. The fire situation is shown in Fig. 1. High-rise building fires are characterized by rapid spread of fire, numerous safety hazards, and difficulty in escape of personnel. In the event of a fire, disorderly articles piled up in the building, the height of the floor and the density of people are all important factors affecting the evacuation of people [2]. According to statistics, there were 6,974 fires in high-rise buildings in China in 2019, and the number of fires in high-rise buildings rose 10.6 percent year on year while the number of other fire types declined. Therefore, combining the overall structure of the building with the distribution of fire protection facilities, predicting the fire distribution trend in advance so as to design the escape route flexibly and realize rapid and efficient fire evacuation becomes the problem we hope to solve. However, obtaining actual fire survey data is challenging. To carry out actual fire test requires a large number of tests and a long test cycle. The test costs a lot of manpower, material resources and financial resources, making it difficult to carry out in practice [3].

Figure 1. The fire situation

The recently proposed intelligent fire protection that applies the Internet of things to fire rescue provides a new idea for fire data collection, fire management and rescue under the background of emerging technology [4, 5]. Intelligent fire protection proposes to combine numerical simulation technology [6] with big data technology [7] in fire engineering practice, so as to realize the purpose of building fire data model, simulating fire situation dynamically and designing escape strategy flexibly.

In view of the above social background and application requirements, our teaching team built a virtual simulation teaching platform for intelligent fire fighting, designed a simulation experiment based on the Internet of things, combined with fire distribution prediction and optimal escape strategy. The simulation experiment realizes the numerical simulation of fire based on multi-sensor parameters and designs the optimal fire fighting and

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escape strategy under different fire conditions. The design of escape strategy makes full use of multiple types of big data in the Internet of Things, serves the application layer of the Internet of Things, and reflects the important characteristics of the Internet of Things, which is "data-based and service-centered". As a comprehensive experiment of virtual simulation experiment of the Internet of Things, it realizes the "top-down" systematic experimental teaching. Students can master big data analysis and application methods of the Internet of Things by completing simulation experiments. The construction of the intelligent fire virtual simulation teaching platform aims to enable students to master the overall architecture and design process of the Internet of Things from four aspects, namely, system design and development, sensor principle, communication technology and data application in an all-round way under the background of intelligent fire protection. Meanwhile, the simulation experiment of optimal escape strategy not only strengthens students' comprehensive mastery and application of technologies related to the Internet of things, but also propagates the knowledge of fire escape, which has strong educational significance.

II. Related Work

The increasing incidence of fire accidents has aroused widespread concern in various countries. More and more researchers are focusing on how to use emerging technologies to solve fire problems. More and more researchers pay attention to how to use emerging technologies to solve fire protection problems. They hope to better guide the site selection of micro-fire stations and fire hydrants through dynamic simulation of fire occurrence, and enable fire departments to timely grasp the fire situation and better design rescue and escape strategies by pushing real-time fire site information.

There are a lot of related work at home and abroad to simulate the scope, intensity and spreading trend of fire by computer simulation technology. Xiang et al. proposed a full-scale numerical simulation strategy for the rest living area of a protection project by using FDS software according to the engineering protection requirements and ventilation conditions, studied the smoke control and exhaust effects of four ventilation modes, and conducted performance-based evaluation of personnel safety evacuation [8]. Liu used FDS software to simulate the fire source in the room and corridor of a high-rise residential building. By testing flue gas concentration, CO concentration, temperature and visibility at three different measuring points, the optimal evacuation time was obtained [9]. Liu. Fang *et al*. took wooden ancient buildings as the research object, carried out temple fire experiment under the full-foot high fire load model, discussed the growth and spread of fire through smoke and flame, and used FDS software to simulate the occurrence and development of fire under different fire scenes [10].

For the design of the optimal escape strategy in the event of fire, Zhang *et al*. proposed a subway escape route planning method based on the gray Markov prediction model, and optimized the subway escape route planning based on the smoke data [11]. Around the world, many research institutions have designed fire escape systems, for example: In order to reduce the risks firefighters take at rescue sites, some French researchers have developed "hand-held tracking devices" that can accurately locate trapped people in smoke-filled rooms; In addition, some foreign companies comprehensively use GIS technology [12], optimal path escape technology and Android application development technology to plan escape routes for trapped people in the scene of fire accidents. By communicating the escape route and emergency knowledge to the trapped in time, guide the trapped to escape effectively in the case of fire accident.

The research on intelligent fire rescue in various countries is in the stage of rapid development. Intelligent fire protection based on Internet of Things shows great advantages in fire management, dispatching and rescue. The rapid development of Internet of Things technology also makes an urgent demand for talents in the direction of Internet of Things. Therefore, based on the investigation and summary of previous work, this paper designed a fire escape simulation experiment based on the Internet of things, which filled the gap in the teaching of the Internet of Things based on the background of fire rescue.

III. Proposed Methods

Our design is based on the Internet of Things, combined with fire distribution prediction and optimal escape strategy simulation experiment. It is a typical Internet of things application scenario with "intelligent fire protection". The experiment built a campus scene fire escape drill platform based on Unity3D [13], [14] simulation software, and used numerical simulation technology to simulate different fire scope, intensity and spread trend. At the same time, based on the big data technology of Internet of Things, the system can present the distribution trend and the location of fire, establish the corresponding 3D fire data model. According to different fire situations, the experimental platform simulates the best fire extinguishing scheme by combining the distribution of fire hydrants and reserved emergency passageways in the building. For the trapped people, the platform uses multi-parameter big data for comprehensive analysis, obtains the optimal escape strategy based on the optimal path planning principle, and guides the students to carry out simulation experiment.

A. Introduction to Key Technologies

1) Unity3D simulation software

Virtual simulation experiment is an organic fusion of educational theory and new technology. It constructs various virtual experiment environments and simulates various experimental projects carried out in real environment through virtual reality technology. It has the characteristics of simulation, strong interaction, openness and low cost. Unity3D provides strong technical support for the platform construction of virtual simulation experiment. It is a comprehensive creation tool for

creating interactive contents such as 3D video games, architectural visualization, real-time 3D animation, etc., with a hierarchical comprehensive development environment. A complete Unity3D program consists of several scenes, each scene contains many models, and their behavior is controlled by scripts.

Using Unity3D simulation tool, we built a 3d structure of the building based on the real scene in the system, set up different distribution of fire fighting facilities, and used the comprehensive analysis of sensing data to build a 3D fire data model.

2) Numerical simulation technology

Numerical simulation software FDS based on computational fluid dynamics field [15] has been widely used in fire data simulation field. Through computer numerical calculation, FDS software simulates five stages of indoor fire based on room structure, ventilation condition, fuel quantity and other conditions, realizing a comprehensive analysis of different fire scope, intensity and spread trend. The five stages of indoor fire includes ignition stage, initial growth stage, flasking stage, overall development stage and decline stage.

The main process of computer numerical simulation in fire accident investigation is as follows: Firstly, according to the basic data of the fire site, such as the basic size information of the building, the type, quantity and the location information of the items, the model of the building before the fire was built on the FDS numerical simulation software. Secondly, the attributes of the items in the building are set on the FDS numerical simulation software by inquiring relevant data. Thirdly, information such as ventilation mode, fire source location and heat release rate of fire source is set in FDS simulation software. Finally, the development and spread of fire accidents are reproduced to assist fire accident investigation.

3) Principle of optimal path planning

The main part of the simulation experiment of optimal fire fighting and escape strategy is to calculate the optimal escape path quickly by combining the spreading trend of fire with the overall structure of the building. Based on the optimal path planning principle [16], [17], the experiment we designed guided the students to explore and master the correct escape strategy by interactive operation.

Dijkstra algorithm is a typical algorithm to realize the optimal escape path planning of trapped people in fire scene. The core idea of the algorithm is to plan the shortest path between one node and any surrounding nodes. Based on greedy algorithm, Dijkstra algorithm gradually expands to the epitaxial path that is the easiest to escape from with the initial location of the trapped person as the center, and focuses on the exit of the escape path to form the optimal escape path. The multi-sensor measurement data and building structural attributes provide weights for path calculations.

B. Experimental Design

The fire escape simulation experiment proposed in this paper is based on the intelligent fire protection virtual simulation teaching platform. The system is based on Internet of Things technology, which has comprehensive functions, complete management mode and high usability. The overall functions mainly include experimental background introduction, hardware platform construction, simulation experiment implementation, experimental report writing, evaluation mechanism, fire escape drill, fire virtual exhibition hall and map library, etc. The system realizes the three teaching objectives: Internet of Things system teaching and practice, fire escape simulation drill in real scene, and fire safety knowledge publicity and education.

The experimental design of the intelligent fire virtual simulation teaching platform follows the three-layer architecture of the Internet of Things, namely, the perception layer, the transmission layer and the application layer. The perception layer consists of a variety of sensors and sensing terminals. It is the source for the Internet of Things to identify objects and collect information; The transmission layer consists of a variety of private networks, Internet, wired and wireless communication networks, network management systems, and cloud computing platforms. It is responsible for transmitting and processing information acquired by the perception layer. The application layer is the interface between the Internet of Things and users. It makes comprehensive use of big data storage and processing technology and application service technology to realize the intelligent application of the Internet of Things.

The experiment we designed is a comprehensive experiment of intelligent fire Internet of Things teaching, involving professional theoretical knowledge and technology throughout the three-layer structure of the Internet of Things. Therefore, the fire escape experiment is set as the last step of the intelligent fire protection virtual simulation course in the way of "bottom-up, step-by-step". By understanding and mastering the previous knowledge, students can independently complete the fire escape simulation experiment, so as to realize the review and comprehensive application of what they have learned. Some of the experiments in the curriculum are as follows:

1) The perception layer

Based on embedded technology, different types of sensor experiments are designed to enable students to learn typical sensor-related technologies and realize data acquisition of various sensors. We use the virtual simulation experiment platform and the actual device synthetically to realize the experiment teaching way of "the combination of the virtual and the real"; In addition, we also set up an experiment of NFC electronic tag technology to realize P2P wireless communication between Bluetooth devices. Through this part of the experiment, students can master the sensor data acquisition technology applied in the fire escape experiment. The experimental process of the perception layer is shown in Fig. 2.

2) The transmission layer

The platform has set up simulation experiments of Zigbee, NB-IOT and other communication technologies to learn the configuration of Zigbee network

communication system coordinators, routers and sensor nodes. Based on NB-IOT network communication technology, experiments of key-triggered network attachment, key-triggered data transmission, and data acquisition and submission have been completed. OMNet++ technology is used to carry out virtual deployment of fire nodes on the whole structure of the building, and the simulation experiment of cluster routing is designed. The experiment in the transmission layer strengthened students' understanding of the communication technology, network routing protocol and data exchange technology of the Internet of Things, and provided theoretical reserves for the successful implementation of the comprehensive experiment. The experimental process of the transmission layer is shown in Fig. 3.

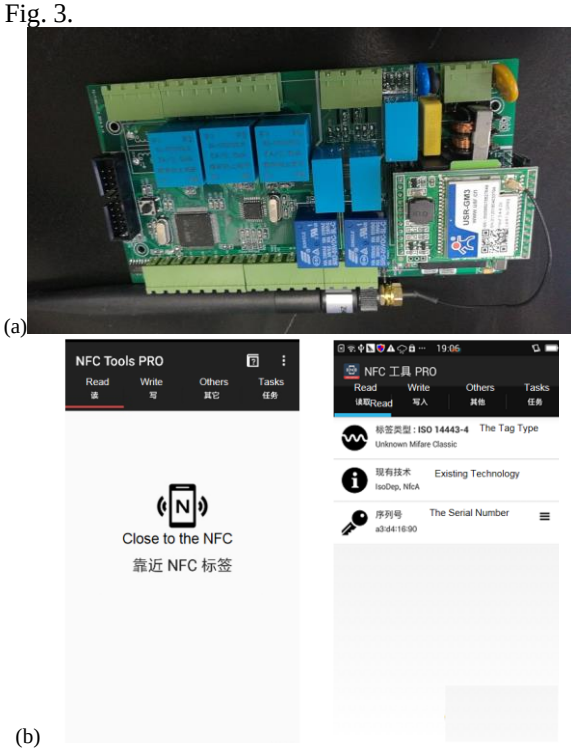


Figure 2. The experimental process of the perception layer. (a) Wireless sensor node concentrator (b) NFC device communication experiment interface

3) The transmission layer

In the application layer, students need to learn knowledge related to database and server deployment to complete simple web page test, MySQL installation and configuration, database basic operation and other experiments. After completing the experiment, students can master theoretical knowledge and practical skills, such as establishing database and basic table structure with virtual data, updating database, setting up development environment, etc. In addition, the system designs the mobile terminal development simulation experiment, enables the students to use the database virtual data to connect and query, and realizes the mobile terminal data display function. The experimental process of the application layer is shown in Fig. 4.

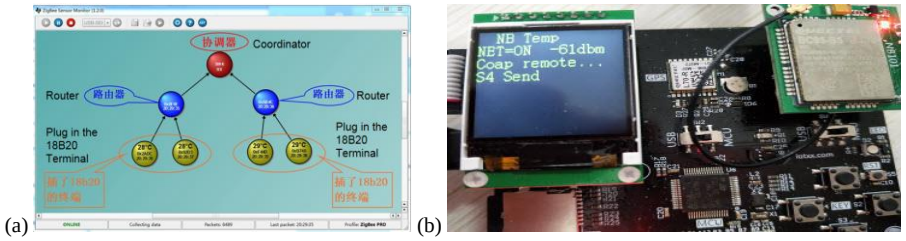
4) Simulation experiment of optimal escape route

The simulation experiment of optimal escape route comprehensively uses the knowledge points and main technologies involved in the basic experiment based on the three-layer structure design of the Internet of Things, so that students can master the big data analysis and application of the Internet of Things. In the comprehensive experiment, the transmission layer technology is fully applied to obtain the data collected by the perception layer, and the multi-dimensional data is combined to serve the application layer and realize the interactive function. Through numerical simulation of multiple sensors, the experiment simulates the change of fire situation. According to the change of fire situation, the optimal escape route is selected and information is pushed to users. The analysis of the spread of fire is shown in Fig. 5.

The simulation experiment of optimal fire escape strategy designed in this paper enables students to have a new understanding of the Internet of Things as a whole. By completing all the experiments designed in the course, students can master and skillfully use the key technologies in the three layers, and to a certain extent, popularize and publicize the knowledge of fire rescue and escape.

IV. Results

The intelligent fire fighting virtual simulation teaching system built by our teaching team has been completed and put into practical application, which has achieved good teaching effect. The system is deployed in the virtual simulation experiment teaching project sharing platform of Nankai University, with the domain name of iot.nankai.edu.cn and the IP address of https://222.30.40.128/. In this paper, the simulation experiment based on the Internet of things, combined with fire distribution prediction and optimal escape strategy, is set up in the teaching system for the experimental teaching of students. The scope of experimental teaching covers 3 colleges and 8 majors, serving more than 500 students. The interface of simulation experiment is shown in Fig. 6.



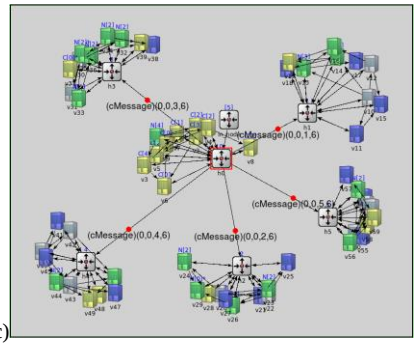
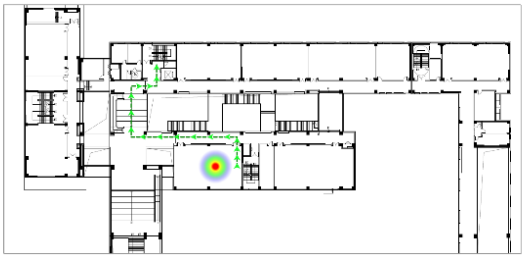
(c) 

Figure 3. The experimental process of the transmission layer. (a) Zigbee network communication transmission simulation experiment interface (b) NB-IoT communication hardware experimental system (c) Simulation experiment of network topology based on OMNet++.

(a) 

(b) 

Figure 4. The experimental process of the application layer. (a) Cloud server configuration . (b) Mobile terminal design interface.

(a) 
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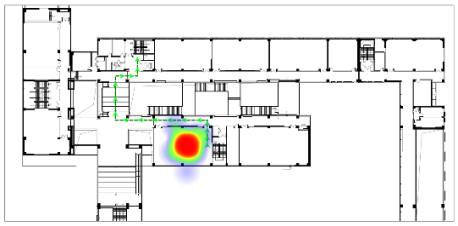
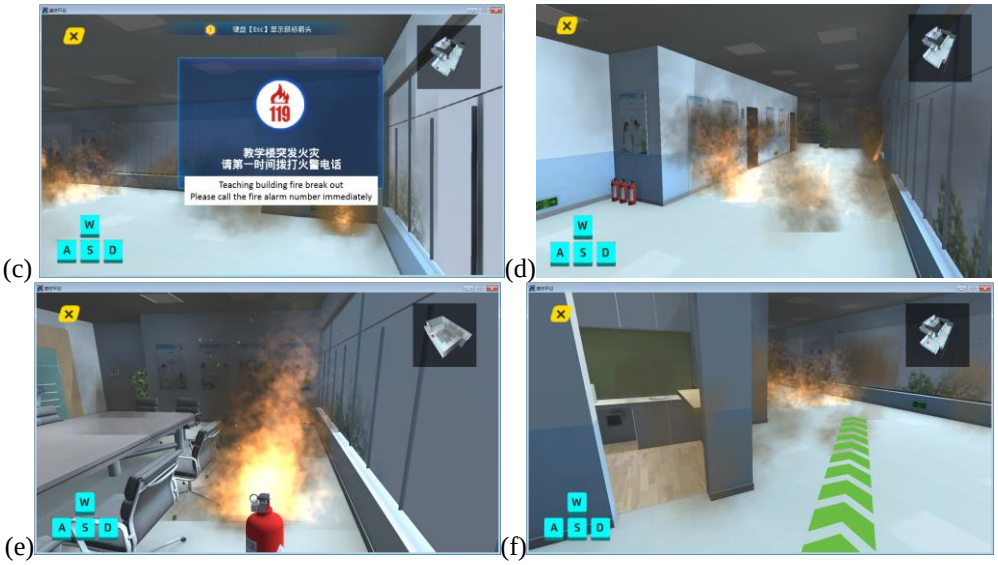
(c) 
(d) 

Figure 5. Fire distribution prediction simulation. (a) (b) (c) (d) represent the spread of the fire respectively.

(a) 

(b) 



(c) (d) (e) (f)

Figure 6. The interface of simulation experiment. (a) Registration-free system login interface. (b) Fire escape drill scenario simulation based on real scene. (c) Prompt to dial the fire alarm telephone interface. (d) 3D Fire scene. (e) Fire extinguishing interface. (f) Escape route indication.

The fire escape strategy simulation experiment proposed in this paper adopts the computer simulation technology and fire safety engineering principle, and makes full use of the field data collected in advance and real-time to analyze a series of data models such as the overall structure and layout of the building, the distribution trend of the fire, and the multiple location of the fire. Then, the details such as personnel distribution, escape route, fire hydrant and reserved emergency passage in case of fire are simulated. The data model can also be used to predict the possible emergencies on the site, so as to make reasonable disposal before putting out the fire.

In the intelligent fire protection simulation experiment system, our simulation experiment takes the real campus scene as the background and simulates different types of virtual fires in the 3D scene, such as the big fire in the teaching building and small fire in the office. The whole process of voice guidance and interactive operation is adopted to guide students to avoid, make decisions and take correct actions by moving, so as to explore and master correct escape strategies. In the course of the experiment, students can use the "small blackboard" function of the system to query the knowledge points of the current experimental design at any time. In addition, the system adopts the way of no-registration and login, and the mobile phone number is directly logged in through verification. After logging in, science popularization users inside and outside the school can use the fire drill module without authentication, which is applicable to the popularization of fire safety knowledge for teachers and students of the whole school.

In the process of experiment, the system is based on the real scene to simulate the complete process of escape of trapped people in the event of fire. At the beginning of the experiment, the system guides the students to complete the operation of dialing the fire alarm, turning off the power and pressing the fire alarm bell. The ground route guidance is provided throughout the simulated escape process, which is coordinated with the voice guidance to guide students to complete the correct escape operation. In case of wrong behavior, an error warning will be triggered. During the experiment, there are a variety of matters needing attention in the process of fire escape, such as covering the mouth and nose with a wet towel when the fire is serious, opening the door carefully and paying attention to the temperature of the door when escaping, and aiming the fire extinguisher at the flame root. The simulation experiment of optimal fire escape strategy designed by us makes full use of the sense of reality of virtual reality technology to give students an immersive feeling and simulate the real fire scene.

V. Conclusion

Aiming at the social application background of intelligent fire protection, this paper designs a simulation experiment based on the Internet of things, combined with fire distribution prediction and optimal escape strategy, relying on the virtual simulation teaching platform of Internet of Things built by the teaching team. The simulation experiment takes Unity3D as a tool, comprehensively utilizes computer simulation technology and big data technology of Internet of Things to establish fire models of various situations and dynamically simulate fire spread trend. In addition, the experiment combined the overall structure of the building and multi-sensor data, based on the optimal path planning principle, planned the optimal escape route for personnel in case of fire, and realized the fire escape drill based on the simulation of different real scenes. The setting of the simulation experiment realized the teaching purpose of enabling students to master and comprehensively apply the Internet of Things engineering technology to solve practical problems. At the same time, the experiment enables students to deeply understand the "data-based and service-centered" characteristics of the Internet of Things, which is of strong educational significance.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Guiling Sun contributed to the design of teaching framework and ideas, as well as the overall construction of the virtual simulation experiment of optimal fire escape strategy; Sirui Wang contributed significantly to algorithm design of the optimal path planning and wrote the manuscript; Yi. Gao designed the 3D scene of the fire escape experiment and the platform construction; Hai Wang completed the design of the fire protection knowledge publicity part of the system and contributed to the teaching application; All authors had approved the final version.

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