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Mobile Fire Evacuation System for Large Public Buildings Based on Artificial Intelligence and IoT

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ABSTRACT The complexity and variability of the internal environment of public buildings prompt to think about how to protect people in the fire and quickly reach the safe area. With the help of the Internet of Things, firefighting facilities, such as fire hydrants, fire extinguishers, safety evacuation signs, fire sprinklers, fire pumps, smoke, temperature, and fire doors in buildings can be dynamically monitored and controlled. In addition, based on the relevant fire emergency evacuation strategies and ideas at home and abroad, the artificial intelligence technology is used to construct an efficient and intelligent dynamic evacuation path solving model, and an intelligent mobile terminal fire evacuation system was built for large public buildings based on artificial intelligence technology. When a fire breaks out, the system can help guide people to evacuate from the building real-time and reach the safe exit quickly, so as to reduce casualties and economic losses.

INDEX TERMS Artificial intelligence, IoT, fire evacuation, mobile terminal.

I. INTRODUCTION

With the development of science and technology, the design of modern architecture is becoming more and more complicated and large-scale, and the large-scale public buildings such as shopping malls, office buildings, and science and education centers are increasing dramatically. Large public buildings are densely populated, with various structures and complex functions [1]. In case of sudden disasters (fire, earthquake, gas leakage, etc.), the evacuation is inefficient due to the lack of effective evacuation guidance and panic psychological instructions. On the one hand, large public buildings usually have a larger internal area, their channel setting and internal structure design are relatively complex, and the overloaded electricity may easily cause fire [2]; on the other hand, the fire smoke and fire in large buildings spread over a wide range of areas, and it is easy to produce chimney effect in elevator well, exhaust pipe, etc [3]. Therefore, efficient and safe evacuation of people in building fires has become the focus of research, and it is of great significance to protect the safety of life and property in large public buildings. Thus, it is very important to study the channel setting, structure and fire-fighting parts layout of complex large public buildings, and to consider the dynamic changes of scene during evacuation [4], the determination of fire points and personnel positions, the planning and guidance of rescue evacuation escape routes, etc.

In order to solve the problem of fire evacuation path dynamic planning and immediate indication in large public buildings, this paper proposes to establish a fire dynamic evacuation path solving model by utilizing the artificial intelligence technology. According to an engineering example of a shopping mall, a grid environment model is established, and the best evacuation route is planned by analyzing three different stages of fire with improved ant colony algorithm [5]. Finally, the intelligent evacuation indicator is dynamically displayed. The research on intelligent fire evacuation system based on mobile terminal aims to provide a new mode for fire evacuation of public buildings. The results may provide data validation and decision support for virtual drilling and emergency rescue of urban disaster events quickly and efficiently, and also provide useful reference for improving emergency

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management system of public events and risk management system of major disasters in China [6].

II. LITERATURE REVIEW OF FIRE EVACUATION SYSTEM

The complex internal structure of the building limits the evacuation process and increases the difficulty of controlling the fire spread process [7]. The study of fire evacuation requires considering the personnel behavior, the form of the fire site, the rationality of the deployment of firefighting equipment and the integrity of the function, as well as the building structure and other factors.

In the field of fire protection, many foreign scholars have applied GIS to urban fires, forest fire assessment and firefighting. Early in 1983, Australian scholar Markators introduced his fire spread prediction program in his research paper, which used the digital elevation of GIS to simulate the spread of fire [8]. The review in Enrico Ronchi's study showed that evacuation models can be effectively employed to study relocation strategies and safety issues associated with high-rise buildings. There is not a definitive model to be used but that the predictive capabilities of evacuation modeling techniques would be enhanced if more than one model is employed to study different egress aspects [9]. Timo Korhonen proposed an evacuation simulation method which is embedded in a CFD based fire modeling programme. The model follows each agent individually and each agent has its own personal properties, like mass, walking velocity, familiar doors, etc. The fire and evacuation calculations interact via the smoke and gas concentrations [10].

In China, with the continuous development of urban fire protection, most fire control departments have established fire evacuation assistant decision-making system based on GIS and satellite positioning system. The fire evacuation emergency decision-making system centered on GIS is becoming an important part of modern fire engineering.

Focusing on the key technologies of fire prevention and control in large public buildings, Professor Huo Ran of the Key Laboratory of Fire Sciences has carried out key research on fire risk assessment and performance-based fire prevention design method, evacuation model and evacuation guidance technology, optimal control of smoke, and integration of intelligent detection and alarm system and linkage fire extinguishing system [11].

At present, China's intelligent evacuation is still in the preliminary stage. An intelligent evacuation system needs to be studied and developed, which uses the intelligent algorithm to plan the evacuation route reasonably according to the actual situation of the fire scene, and analyzes the building structure and the information of the fire scene, so as to guide the crowd to flee the fire scene in time and effectively [12].

III. DYNAMIC FIRE EVACUATION MODEL BASED ON ARTIFICIAL INTELLIGENCE ALGORITHM

For the scene of fire evacuation for large public buildings, the researchers are committed to solving the problem of optimum evacuation route selection. When a fire breaks out, according to the internal structure of the building and the actual fire situation, an evacuation route with the shortest effective length and the safest is supposed to work out, so that it may guarantee people to escape the fire and reach the safe area smoothly. The dynamic fire evacuation route designed in this paper breaks the conventional way of thinking - the shortest route is the optimal route, with consideration of factors such as temperature at the fire site, smoke concentration and carbon monoxide concentration. Traditional geometric paths are replaced by effective lengths, and the optimal dynamic fire evacuation path is obtained by using an improved ant colony algorithm.

A. INTRODUCTION OF ANT COLONY ALGORITHM

The ant colony algorithm is an intelligent optimization algorithm for searching the shortest path based on the principle of ant colony foraging in nature. The ant colony algorithm is implemented to simulate ant colony behaviors by artificial ant, so that it has the same goal as ant colony in nature and the positive feedback mechanism of mutual cooperation.

The design idea of fire dynamic evacuation combined with ant colony algorithm is [13] as follows: When a fire breaks out, the cooperative behavior of people searching for safe exit during evacuation is similar to that of ant colony. Based on this, it is reasonable to introduce the ant colony algorithm into dynamic evacuation designed in this paper. When there is no fire, that is, in the static environment, without considering the impact of fire, the best route calculated by ant colony algorithm is the shortest path after avoiding static obstacles; in the dynamic evacuation process in case of fire, considering the influence of fire products (smoke concentration, temperature, carbon monoxide concentration), the ant colony algorithm is optimized, and the actual length of evacuation path is equivalent to the effective length according to the set interference factor. With the development of fire scene, the interference factor will be updated at any time, so the heuristic function design is closer to reality, and the evacuation route obtained is more reasonable and effective [14].

B. DYNAMIC EVACUATION IMPLEMENTATION FLOW BY ANT COLONY ALGORITHM

Dynamic evacuation implementation flow by ant colony algorithm is as follows. Firstly, the internal structure of the building is analyzed and the building plan into multiple working areas is refine, so as to establish a two-dimensional grid environment. Secondly, static and dynamic nodes are set, and the parameters relevant to the ant colony algorithm related are initializes. Thirdly, the effective length matrix of the evacuation path is calculated, and an experimental simulation to plan the optimal evacuation route with MATLAB is conducted combined with improved ant colony algorithm [15]. The detailed process steps are as follows:

First step: Initialize the ant colony algorithm related parameters. Set the number of ants $m = 30$, parameter that characterizes the importance of a pheromone Alpha, parameter that characterizes the importance of a heuristic factor Beta, pheromone evaporation coefficient Rho, maximum number of iterations NC_max, pheromone increase intensity factor Q, initial smoke concentration matrix as Y, initial temperature matrix as T, initial carbon monoxide concentration matrix as C, Initial pheromone matrix Tau, taboo table as Tabu.

Second step: Start iteration. Set the start node *start*, put all the *m* ants on the start node.

Third step: Determine a node and find out all free raster nodes adjacent to the current raster node, and then determine the next raster node to pass through the roulette selection strategy, and then update the taboo table Tabu in real time.

Fourth step: Record the iteration route and length, to determine whether it has reached a safe exit. If so, then record the iteration route and length, and update the information matrix Tau, heuristic factor information Beta; if not, then return to the third step.

Fifth step: Output the optimal evacuation route map. Determine whether the number of iterations meets the maximum number of iterations. If so, output optimal evacuation route map and convergence curve; if not, then return to the second step.

Parameters such as Alpa, Beta and Rho in the ant colony algorithm have a great influence on the performance of the algorithm. The magnitude of the alpha value indicates the extent to which the amount of information left on each node is valued. The larger the Alpavalue, the more likely the ant is to select the route that was previously passed, but the excessive alpha value will cause the search to fall into the local minimum solution too early. The magnitude of the beta value indicates the extent to which heuristic information is valued. The larger the Betavalue, the more likely the ant is to choose a node closer to it. Rho represents the retention rate of the pheromone; if its value is not appropriate, the result will be poor. It can be seen that the optimal configuration of the parameters Alpa, Beta and Rhois of great significance for the role of the ant colony algorithm in practical problems. In Zhiweiye's study, taking traveling salesman problem as an example, he concluded that in an ant colony algorithm model, when Alpa was set as 1, Beta was set as 5 and Rho was set as 0.5, the quality and stability of the solution would be optimal [16]. Therefore, the ant colony algorithm parameters in this paper are set as: Alpa = 1, Beta = 5, Rho = 0.5, NC_max = 50, and Q = 15.

C. ESTABLISHMENT OF DYNAMIC EVACUATION MODEL

The fire dynamic evacuation model proposed in this paper uses ant colony algorithm to realize two-dimensional space evacuation based on two-dimensional grid map. According to the example project, analyze the internal structure of the building, and introduce the grid identification method to construct a two-dimensional raster map. Here the researchers use the floor plan of a shopping mall as an engineering example, shown in Figure 1.

According to the actual floor structure, the shopping mall, the floor plan of the shopping mall is refined into 10 areas are shown in Figure 2.

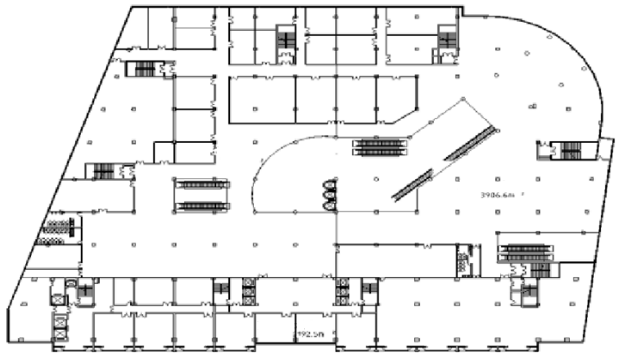

FIGURE 1. Plane drawing of a shopping mall project example.

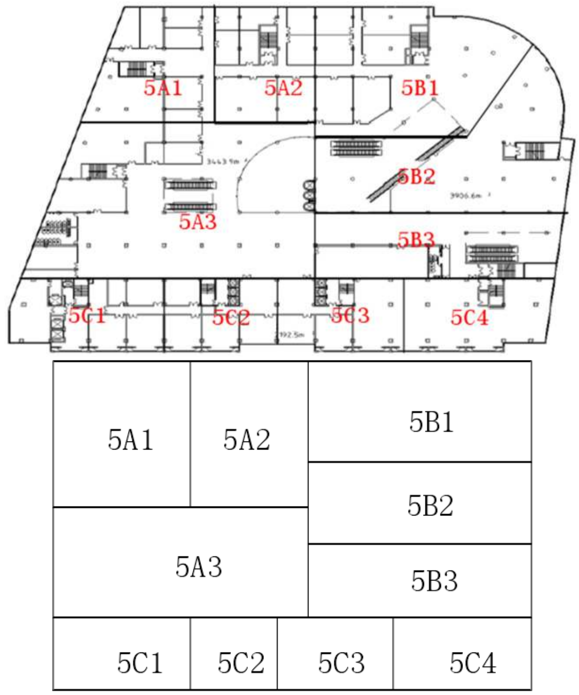

FIGURE 2. Marketplace plane zoning map.

There are too many areas refined in the above plan, so the researchers only build raster maps for area 5A, into 5A1, 5A2 and 5A3 areas. In the process of fire development, as the fire becomes larger, the smoke concentration, temperature, and carbon monoxide concentration are also increasing. Once the fire reaches an unbearable level for evacuation, then the traveling node will become a dynamic obstacle node.

The principle of grid definition is as follows:

a) The door of each room area is a passage node, represented by a white grid; other areas in the room are static obstacle nodes, represented by black grids.

b) The escalator connects the upper and lower layers and forms an opening between the layers. It is set as a static obstacle node, represented by black grids.

c) Fire elevator is an elevator specially designed for fire evacuation and is set as static obstacle node, represented by black grids.

d) Dynamic obstacle nodes are represented by red grids.

e) Safety exit node is represented by green grid.

f) Starting node is represented by blue grid.

The authors rasterize the 5A1, 5A2 and 5A3 area, the grid environment diagrams are shown in Figure 3. The G1, G2, G3 points in the figures respectively represent the stairway of the 5A1, 5A2, and 5A3 areas.

The relationship among the three regions' structures corresponds to the raster map one by one. In the algorithm model, G is defined to represent the grid map matrix; 0 to represent pass node; 1 to represent Static obstacle node, such as walls and pillars; 2 to represent dynamic obstacle node, that is, the smoke concentration, temperature, carbon monoxide concentration, etc. that affect the passage when a fire occurs; 3 to represent exit; 4 to represent starting node.

When a fire breaks out in the stairwell, if the detector detects a fire in one of the corridors, then it must not be used as an escape route. If a fire breaks out in the stairwell, the stairwell cannot be used as an evacuation node for vertical evacuation, and the safety exit node will become a dynamic obstacle node. The number of floors is set as m and the exits of each layer as n, so as to build the matrix and derive the possible paths that can be evacuated based on the fire. Then, combined with the plane evacuation scheme made by each exit with each layer, a three-dimensional evacuation scheme can be obtained.

D. ALGORITHM SIMULATION

1) SIMULATION EXPERIMENT ENVIRONMENT AND INITIALIZATION

In the indoor environment of the internal structure of the building, the model in a two-dimensional grid environment is established. Here the researchers perform algorithm simulation on the grid environment of the 5C1 area established earlier. The experimental simulation environment is a two-dimensional environment of 18m × 18m; the rasterized environment is a two-dimensional raster map environment of 18 × 18. The size of each grid is 1m × 1m, 324 grids in total, the original coordinate of the rid map is (0,0). The parameters of the improved ant colony algorithm are initialized as: The number of ant m = 30; parameter that characterizes the importance of a pheromone Alpha = 1; heuristic factor Beta = 5; the maximum number of iterations NC_max = 50; pheromone volatile factor Rho = 0.5; pheromone increase intensity factor Q = 15. The grid environment of 5C1 area is shown in Figure 4.

2) DYNAMIC EVACUATION PATH SIMULATION

The dynamic environment indicates that the smoke concentration, temperature, and carbon monoxide concentration change continuously as the fire increases. The fire development process is divided into three stages: initial stage, growth stage and spread stage [17]. Besides, the researchers use the ant colony algorithm to solve the three-stage fire evacuation

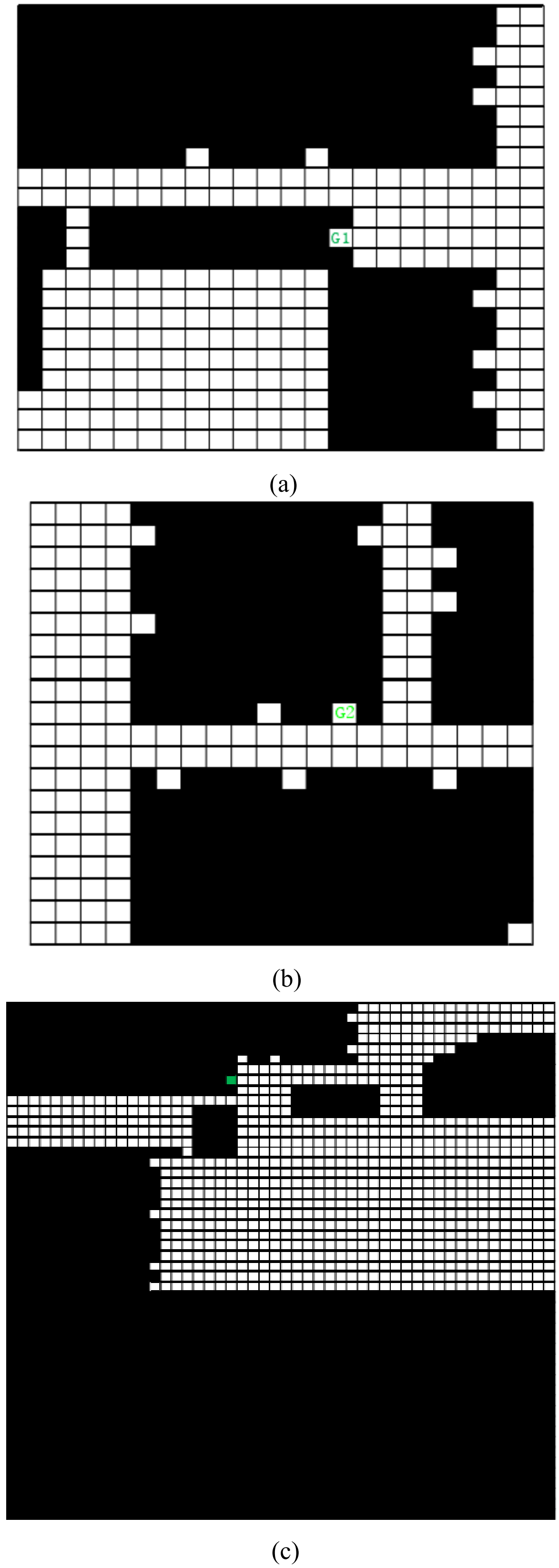

FIGURE 3. Diagram for grid environment in 5A area. (a) Diagram for grid environment in 5A1 area. (b) Diagram for grid environment in 5A2 area. (c) Diagram for grid environment in 5A3 area.

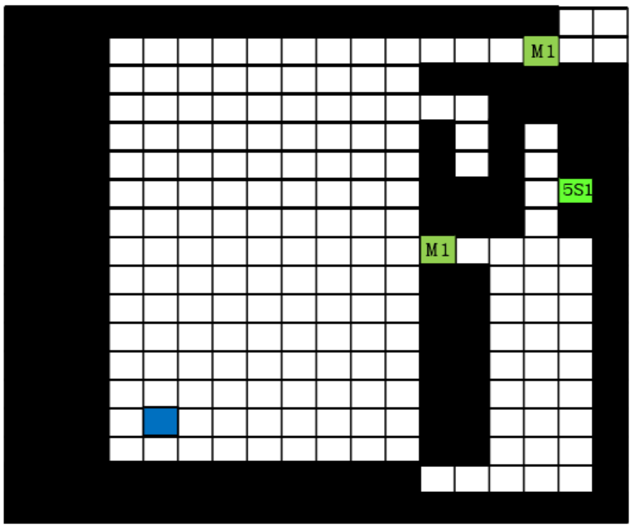

FIGURE 4. Grid environment in the 5C1 area.

path, and to obtain convergence curve of shortest path length and average path length, and optimal evacuation route. The average path length represents the average length of all ants' paths, while shortest path length represents length of the shortest path.

a: FIRST STAGE: INITIAL STAGE

In the early stage of the fire, it is characterized by lower temperatures, with small amount of smoke concentration and carbon monoxide concentration, so there is little interference with evacuation from the fire site. The temperature, carbon monoxide concentration and smoke concentration of the fire scene in the first stage of fire occurrence are set as dynamic obstacle nodes. Fire scene personnel can directly find the shortest path through M1, and get to the nearest evacuation staircase.The operation results of the optimal evacuation route at the initial stage are shown in Figure 5 and Table 1.

b: SECOND STAGE: GROWTH STAGE

When the fire is in the growth stage, it is characterized by the gradual spread to the surrounding with the fire. As a result, some of the original traffic nodes have formed obstacle nodes due to the growth of fire. Dynamically update the dynamic obstacle node of the second stage of the fire in the model. Due to the increasing interference caused by fire evacuation, fire scene personnel must bypass the area where fires form interference when evacuating and escaping, and then pass M1 to reach the evacuation stairway. The operation results

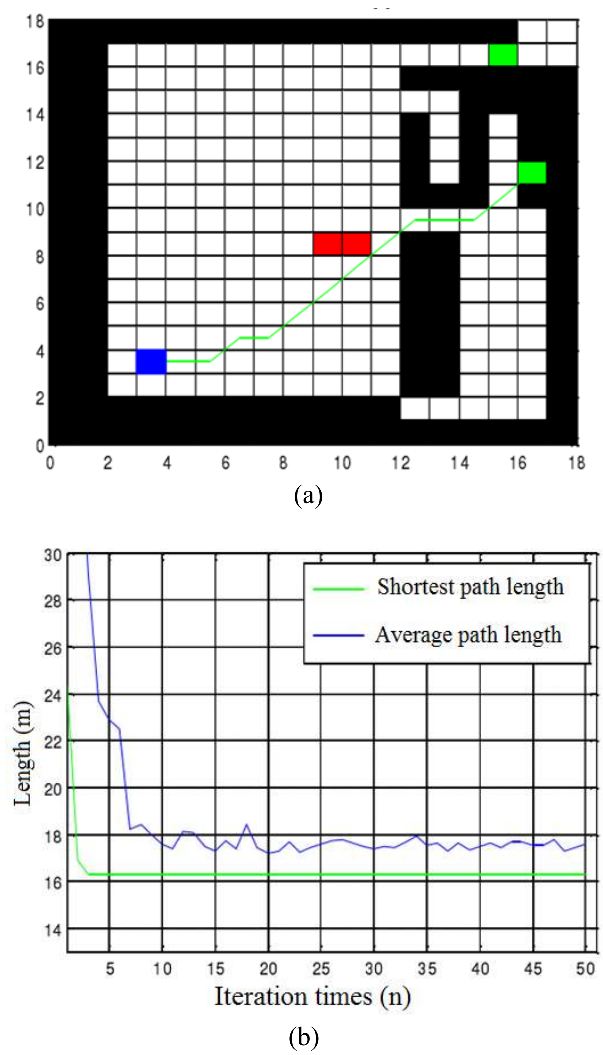

FIGURE 5. Operation results of the optimal evacuation route at the initial stage. (a) Optimal route map for fire evacuation. (b) Convergence curve.

of the optimal evacuation route at the growth stage are shown in Figure 6 and Table 2.

c: THIRD STAGE: SPREAD STAGE

As the fire continues to spread, the evacuation of personnel at the fire site is further affected by the fire products. The temperature, carbon monoxide concentration and smoke concentration at fire site are updated as the dynamic obstacle nodes. Under given fire product influence parameters, M1 has been completely blocked by fire products, so people can only pass M2. The operation results of the optimal evacuation route at the spread stage are shown in Figure 7 and Table 3.

TABLE 1. Optimal evacuation route at the initial stage.

Optimal evacuation route	Optimal evacuation route length
256, 257, 258, 241, 242, 225, 208, 191, 174, 157, 158, 159, 142, 125	16.3137m

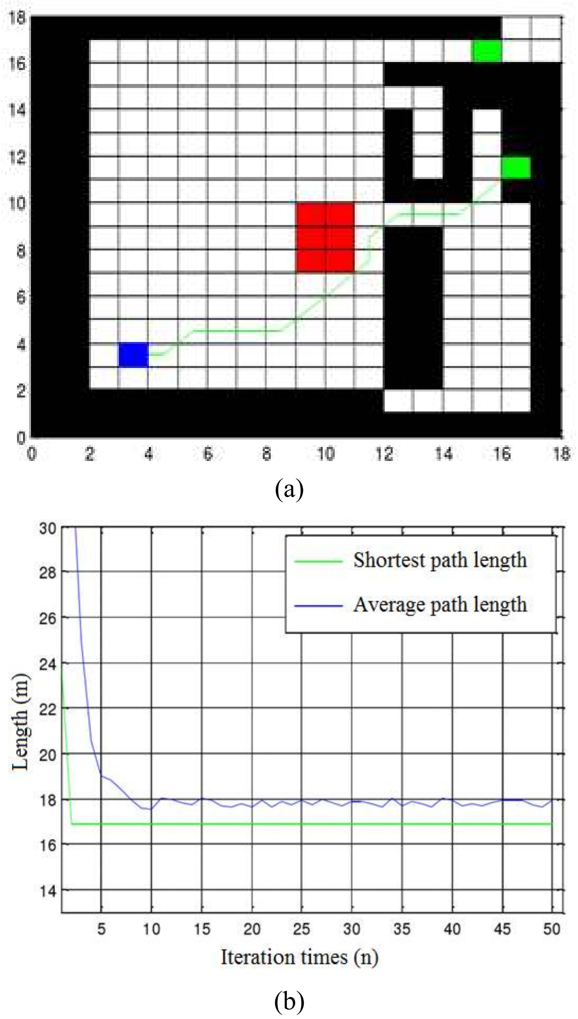

FIGURE 6. Operation results of the optimal evacuation route at the growth stage. (a) Optimal route map for fire evacuation. (b) Convergence curve.

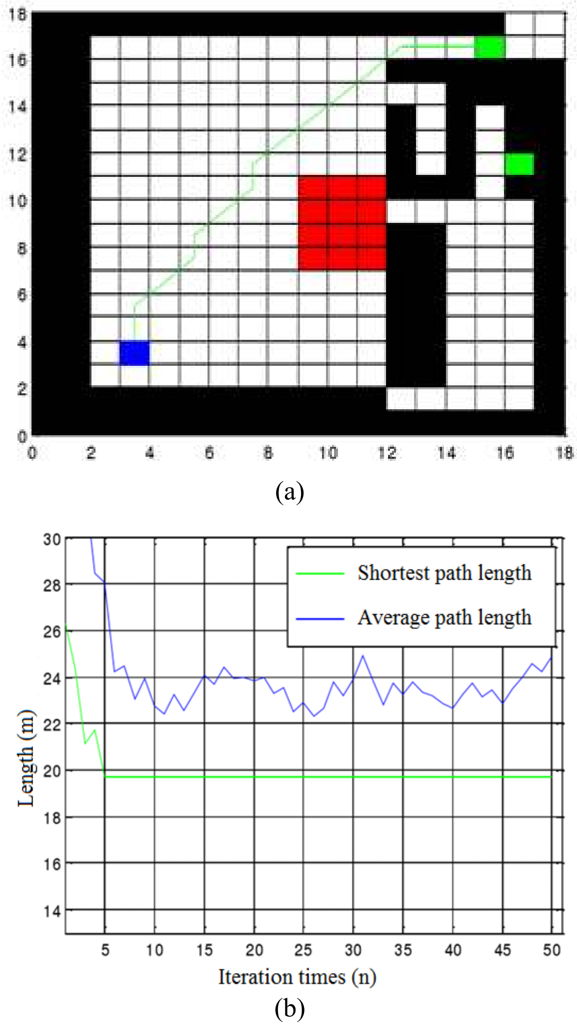

FIGURE 7. Operation results of the optimal evacuation route at the spread stage. (a) Optimal route map for fire evacuation. (b) Convergence curve.

TABLE 2. Optimal evacuation route at the growth stage.

Optimal evacuation route	Optimal evacuation route length
256, 257, 258, 240, 241, 224, 225, 208, 209, 192, 174, 157, 158, 159, 142, 125	16.8996m

IV. DESIGN OF MOBILE TERMINAL FIRE EVACUATION SYSTEM BASED ON ARTIFICIAL INTELLIGENCE

A. OVERALL SYSTEM FRAMEWORK

With the development of science and the rise of Internet of things technology, the theory of spatial intelligence has gradually been expanded. Through smart devices or in a space with smart devices, the researchers can sense the events that occur in current environment [18].

The overall framework of intelligent fire evacuation system for large public buildings based on mobile terminal is shown in Figure 8.

As shown in Figure 8, this study is based on the powerful spatial analysis function of GIS, and uses the IoT, sensor network and artificial intelligence algorithm to analyze events in the intelligent space processing system, to support the development of intelligent fire evacuation systems for large public buildings. Large public building intelligent fire evacuation system takes mobile terminal as carrier, and install sensors, RFID tags, etc. in the interior space of the building, aiming to provide technical services such as emergency evacuation guidance and escape rescue for the personnel in the disaster [19].

In the system, IoT equipment, RFID equipment and laser rangefinder are mainly used for building and personnel information collection. The information as well as spatial data is processed and stored in the system, which is divided into four modules: basic operation, information management, emergency evacuation and user management.

TABLE 3. Optimal evacuation route at the spread stage.

Area	Optimal evacuation route	Optimal evacuation route length
5C1	256, 238, 220, 203, 186, 168, 151, 134, 116, 99, 82, 65, 48, 31, 32, 33, 34	19.7280m
5A3	314, 1265, 1216, 1167, 1118, 1069, 1020, 971, 921, 872, 822, 772, 722, 672, 622, 572, 522, 472, 422, 371	20.2190m

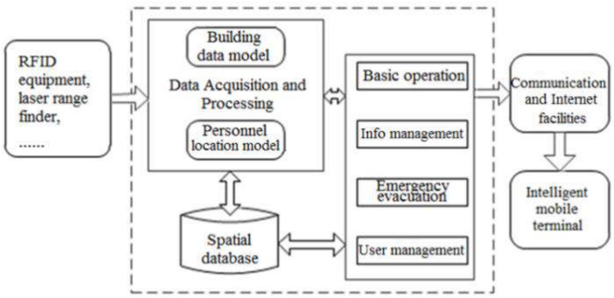

FIGURE 8. Overall framework of the system.

The overall system framework is composed of two parts: one is data acquisition equipment, containing RFID tags, building data model and personnel location information, etc.; another is the spatial database constructed from basic data of large public buildings, as shown in Figure 9.

When a disaster occurs, the system can combine the current location information of the people to evacuate the escape route planning based on artificial intelligence algorithm, and at the same time, with voice broadcast to guide people in real time to quickly escape from the danger zone to reach the safe exit. The whole system is supported by GIS technology and artificial intelligence technology, with the aim of intelligent concept, to truly solve the problem of personnel safety in emergencies.

B. SYSTEM FUNCTIONAL STRUCTURE

After the preliminary research and analysis of the system requirements, the overall functional structure of the system is designed, as shown in Figure 9.

As shown in Figure 9, the mobile terminal fire evacuation system consists of five functional modules [20]: basic operation, information management, emergency evacuation, intelligent fire protection and user management. Among them, the basic operation module refers to common operations such as navigation, zooming and roaming of indoor map spatial data, so as to meet the users' daily map data operation needs; the information management module means the management of spatial attributes of indoor hierarchical household data, mainly including selection queries and keyword queries; the emergency evacuation module is the core function module, including fire location, one-click call, path planning and voice broadcast functions; the user management module provides users with registration and other services, and manages the information such as gender, age, and contact information, etc., which would provide scientific rescue decision support for the implementation of fire rescue work in emergency situations through big data analysis.

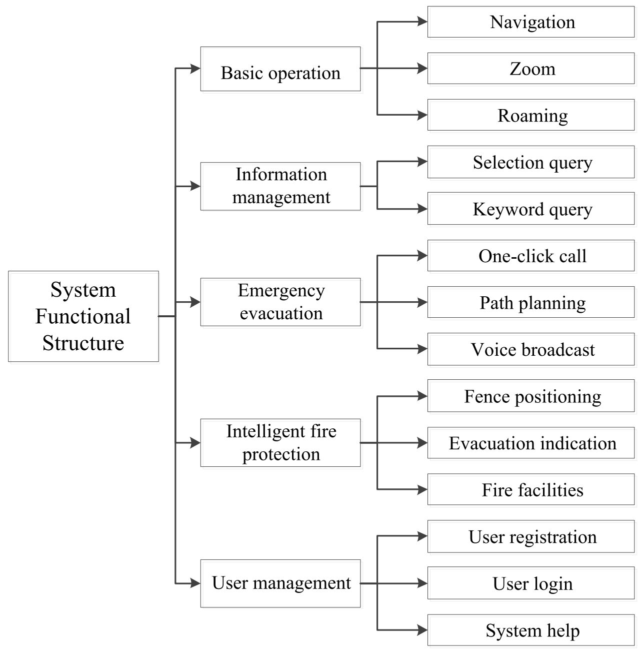

FIGURE 9. System functional structure.

C. DESIGN OF PROTOTYPE SYSTEM

The mobile terminal intelligent fire evacuation prototype system for large public buildings is implemented based on the construction of indoor maps and road network models, indoor positioning technology and dynamic evacuation model by ant colony algorithms, using ArcGIS Android SDK 10.1 to provide users with GIS spatial graphics expression interface, to design prototype system on Android platform [21]. The system interface is designed with Material Design style.

1) IMPLEMENTATION OF MENU BAR

In order to display the layered building map in a window as large as possible on the mobile terminal, the menu bar of the system is arranged in the form of sideslip. The buttons set in the menu bar mainly include spatial and attribute data query, nearby environment, optimal route, one-click call, voice broadcasting, off-line map, system settings, data cache cleaning, etc. The core function of the system mainly realizes the routine operation of layered map, such as zooming, translation and so on. In addition, the functions of indoor location acquisition, location optimization, one-click call and voice broadcasting are also designed.

2) DATA QUERY

Data query includes fuzzy query and selection query. Fuzzy query is to use the identifiable partial location information to query when the person cannot accurately confirm the specific location in the room; selection query is to query directly on the indoor map by clicking on the point, line and polygon features on the layered indoor map.

3) PATH PLANNING

The fire evacuation path planning is designed in detail. The improved ant colony algorithm, the system can plan the optimal evacuation route according to the actual fire situation, and fuse plane evacuation and vertical evacuation, to lift two-dimensional space evacuation to three-dimensional space evacuation, making the fire dynamic evacuation more intelligent and providing accurate and effective path planning for intelligent evacuation indication intelligent control. When there is a fire inside the building, Personnel at the disaster site can quickly escape to the safe exit through the evacuation optimal path provided by the intelligent mobile terminal application, and meanwhile. In addition, the fence positioning technology is utilized, and the voice broadcast is combined to command people evacuation, so as to avoid confusion in the process of evacuation. The path planning system interface is shown in Figure 10.

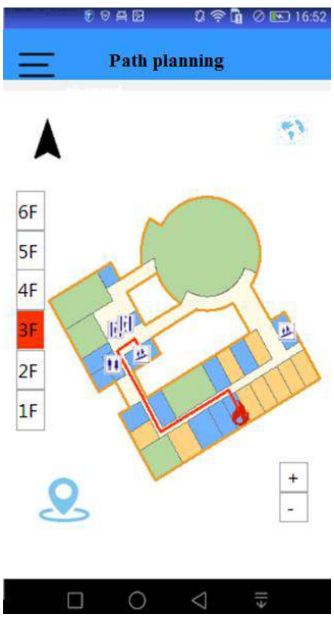

FIGURE 10. Path planning system interface.

4) ONE-CLICK CALL

In a sudden disaster, People are prone to impulses, congregations, panic and other reactions, mostly spontaneous escape, they have no idea whether the fire rescue reaches outside the building or not. The one-click call function can send rescue requests directly to the nearest fire brigade via the server, and call Baidu map path planning and map service functions to get the current location, so that complete the rescue request service function of the disaster scene personnel to the fire control center, and then display the request result in real time on the application so the staff can view it at any time.

V. CONCLUSION

The complexity and variability of the internal environment of public buildings prompt to think about how to protect people in the fire and quickly reach the safe area. Based on the relevant fire emergency evacuation strategies and ideas at home and abroad, this study uses artificial intelligence technology to construct an efficient and intelligent dynamic evacuation path solving model, and then builds an intelligent mobile terminal fire evacuation system for large public buildings based on artificial intelligence technology. The work of this paper is summarized as follows:

1) According to the results of the fire dynamic evacuation path calculation, when a fire breaks out, the improved ant colony algorithm can help effectively bypass the fire point, so it indicates that the improved ant colony algorithm used in this paper has good practical value in the application of dynamic evacuation in large public buildings. Through analysis of the results of the operation under three conditions in a dynamic environment, for the three stages of the fire, the set starting point and end point (safe exit) are the same. With the development of the fire, smoke concentration, temperature, and carbon monoxide concentration continue to increase, and they also have an increasing impact on evacuation. As a result, the length of the optimal evacuation path is also increasing, but it can effectively protect personal safety. Therefore, with consideration of smoke concentration, temperature carbon monoxide concentration in the fire, the application of ant colony algorithm in fire intelligent evacuation is reasonable and reliable, and the purpose of intelligent evacuation is achieved.

2) Based on the research foundation of building data model construction, intelligent fire evacuation application, indoor location, shortest path solution and other issues, an intelligent fire evacuation system for large public buildings based on mobile terminal is constructed. The overall system framework, application functional structure and emergency evacuation process are designed in detail. Also, the implementation of the prototype system is described, including the functional module of menu bar, data query, path planning, one-click call, etc. When a fire breaks out, the system can help guide people to evacuate from the building in real time and reach the safe exit quickly, so as to reduce casualties and economic losses.

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