Preliminary Design and Implementation of Dynamic Emergency Evacuation Instruction System

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Abstract

In order to improve the efficiency of evacuation, the research into the application of shortest path under emergencies is initiated. In this article, an optimized algorithm for calculating the evacuation route is designed based on accident factors and crowd density. It is the main principle of the system, which holds the intention of achieving a dynamic solution when carrying out emergency plans. Real-situation data including human body sizes, moving speed and structure of the building are considered synthetically in the method of quantifying effects of accident factors and crowd density to help simulate the most effective escape route with Dijkstra algorithm. With the calculation completed, the results will be presented by the planted indicating lamps guiding the evacuees to the ideal solution. Dynamic adjustment of the optimal path has met the need of the emergency evacuation scheme to achieve a comprehensive disaster preparedness. The results show that compared with the traditional evacuation route planning, the improved shortest path planning reduces the evacuation time. Also, to renew the optimal path timely is more realistic and practical. It’s capable of avoiding secondary disasters caused by crowds and existing hazards in a greater extent. Therefore, the dynamic emergency evacuation instruction system provides a more secure and reliable solution to the crowd evacuation.

Keywords

Evacuation, Shortest route, Crowd density, Accident factor.

1. Introduction

With the continuous development of modernization, the structure and function of buildings have become more complex and diversified. Under such circumstances, it is realistic and essential to conduct research on how to effectively evacuate the population to a safe area in disastrous moment. Various building structures result in complicated or excessive routes, which in a great extent, increase the difficulty of the research on the shortest evacuation path and undoubtedly decrease the efficiency of escape. More critical it is when a fire break out in t both safe and takes less time is of crucial importance to the evacuation of the population. In order to calculate the safe and shortest evacuation route, scholars at home and abroad have carried out relevant research.

Xiang (2007) proposed an intelligent evacuation system by only switching on the lights that lead to the secure areas and eliminate the routes to the danger zone [1]. It was the pioneer study in the field introducing the idea of accident factors into emergency evacuation. Ant colony optimization algorithm was used to find the best evacuation route in the simulation program and received favorable effect recognition through two city maneuvers [2] (Forcael E. et al., 2014). The exercises made the research more reliable. Li et al. (2006) invented a smart emergency evacuation indication system [3]. It achieved centralized management control, and dynamic guidance for evacuees to avoid open fire and toxic gases. There are considerable studies on the shortest path and the dynamic indication based on development of the disaster. But rarely do researchers deal with the crowd congestion on the selected evacuation path. As a result, this paper will preliminarily design a dynamic emergency evacuation instruction system aiming for secure and shortest escape routes and solution to the overcrowded population. It can reasonably disperse the flow of people with the help of personnel density monitoring, so as to avoid congestions caused by the crowd's choice of a particular path.

2. Designing Principle

An emergency evacuation route which neglects the influencing elements such as disaster factors and crowd density is of no practical use. So, after giving weight to these two aspects, a fully considered evacuation plan is drown up with them included in the calculation.

2.1 Population density monitoring

As the method of population counting varies according to the congestion, there is no reason why we shouldn't only discuss the large densities as it wouldn't reduce the precision for other cases.

The precondition of a population count is to identify the individual, that is, to separate the individual from the environment. First, the video image is de-noised and the ALBP features of the human body are extracted on the basis of the image [4]. The image in the surveillance lens is divided into several parts according to the characteristics of the portrait. A large classifier is made up of these parts, which are also small classifiers. If all features passed the test, that is positive feedbacks were received from all classifiers, then the area is determined as human body. The simile classifier is used here, and its basic idea is that the attributes of an object can be obtained by comparison with other objects in the same category [5]. The main function of this classifier is to optimize the ability of using ALBP features to count the number of people. By comparing the number of other images, the number of the tested images is obtained.

2.2 Dynamic monitoring of the disaster

When a fire breaks out in a densely populated building, it is necessary to have a real-time understanding of the status on fire and smoke diffusion to ensure a safe evacuation route. To monitor the disaster, we can take the advantage of the Internet of Things for its function of sensing, transmitting and utilizing the targeted data. A dynamic monitoring system is established upon this to sense the distribution of temperature and concentration of CO as a layout of the risk [6].

The implementation procedures are roughly divided into hardware setting and software design. Step 1 is to insert the detector into the indicator light allowing it to collect ambient temperature, smoke concentration, and other environmental parameters. Step 2 is to connect all the detectors through the routing device and send the data to the gateway. Next, the data collected by the gateway is converged to the upper computer. Final step is to process and dynamically monitor the data by the host computer. This method can also be used as the initial control of the accident. When the concentration of smoke collected by the detector exceeds the set threshold, it will alarm immediately to evacuate the crowd. Similarly, it provides data for the path planning in the accident.

2.3 Shortest path

The aim of the research is to find out the route with shortest equivalent length under the influence of physical length, width, security issues and crowd density. There are many studies in this field, including methods evolved from modern technology such as ant colony algorithm. Here, Dijkstra algorithm is applicated in the article for its widely acknowledgement as a better solution and its rigorous acceptance for cases with weight greater than zero, which is consistent with the study object. Meanwhile, studies on this method has gone very far in recent years as to have developed various versions for code languages to run the calculation in software including MATLAB.

The basic idea of the algorithm is to start from the starting point and extend to the other points step by step to look for the shortest route. In the search process, each node is marked by its recorded passing route and length. A specific label consists of two parts: one is a letter, a symbol for the previous point; and the other part is a number, indicating the distance from the starting point to the current position. Labels are divided into two types: temporary and permanent. Initially, all nodes are labeled as temporary ones, and after each cycle of the algorithm one label is turned into a permanent mark. For a network graph composed of N nodes, the shortest route from the starting point to the end can be obtained through the N-1 steps maximum [7]. In this paper, the Dijkstra algorithm is used to calculate the shortest path, which incorporates various dynamic factors to provide intelligent path selection. Due to the changes in population density, the shortest path will vary accordingly. Therefore, the shortest path which utilizes real-time data from the surveillance to self-corrects in stages is proposed to improve the efficiency of evacuation. The implementation process is shown in Fig.1.

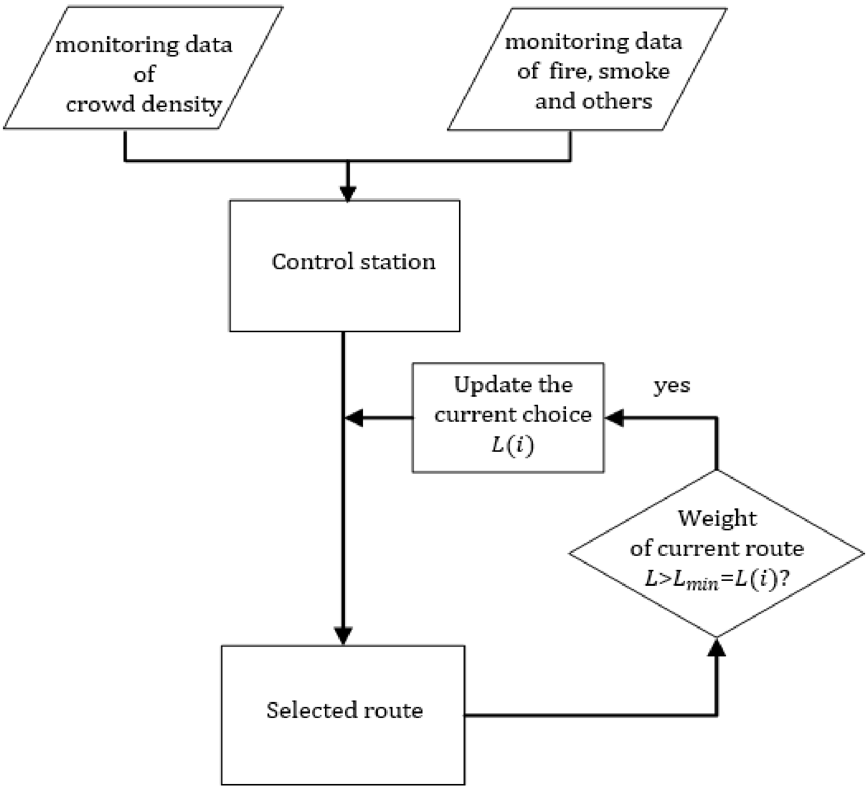

Fig.1 Demonstration of the system principle

3. The calculation method of the shortest path

After considering the geometric characteristics of buildings, population density and accident factors, the formula of equivalent length of the evacuation route is expressed as (1).

$$L(i) = l + C_1 \times l + C_2 \times l. \tag{1}$$

In the formula, l is geometric length of the route, C1 is the multiplier for the impact of the accident factor on the path equivalent length, and C2 is the multiplier for the impact of crowd density on the path equivalent length.

3.1 The derivation of the multiplier C_1

If a fire breaks out, a lot of heat and smoke will be released during the development of the disaster. These products will have a negative effect on human's body both physically and psychologically, which slows down their speed of action. Simplify the process and here only flue gas and temperature are taken as subjects that attribute to the reduction of efficiency. Two functions are introduced here: the influence coefficient f1(C) of the toxic gas concentration and the temperature influence coefficient f2(C). So, in this situation, the speed of personnel action is reformed into:

$$v = v0 \cdot f1(C) \cdot f2(C). \tag{2}$$

In the equation, v is the walking speed of evacuees and v0 is the standard human speed that is walking speed without fire in this case. In this article, it is taken as 1.2 m/s.

(1) Impact of Toxic Gas on the Speed of Personnel

Here, CO, the most important component in harmful gases, is studied to measure the effects of toxic gases on people. Studies conducted by foreign scholars have shown that CO at different concentrations has respective impact on people in a way that hinders human speed. The measured data by this researcher are shown in Table 1 [8].

Table.1 The measured data by this researcher

C_{CO} (%)	Exposure time(min)	Accumulated dose(%min)	The influence to people
0.02	120 ~ 180	2.4 ~ 3.6	slight headache
0.08	45	3.6	slight headache
0.32	10 ~ 15	3.2 ~ 4.8	dizziness
0.32	30	9.6	possible death
0.69	1 ~ 2	0.69 ~ 1.38	dizziness
1.28	0.1	0.128	faint

The subject studied here requires the data operational. Therefore, the quantitative estimation method is used to evaluate the effect of concentration on people's evacuation speed, as shown in Table 3.2.

Table 2 used to evaluate the effect of concentration on people's evacuation speed

C_{CO}(%)	Exposure time(min)	Accumulated dose(%min)	Decreased speed value(m/s)
0.1	n	0.1n	0.05n
0.15	n	0.15n	0.1n
0.20	n	0.2n	0.15n

It is generally believed that when the concentration of CO is less than 0.08%, the impact on personnel speed can be neglected. When CO concentration reaches 0.25%, people will faint or die or cannot move. After fitting in MATLAB with the data of Table 3.2, the influence coefficient of CO on the moving speed of personnel is proposed:

$$f_1(C) = \begin{cases} 1 & C < 0.1 \\ 1-(0.2125+1.788C)Ct & 0.1 \le C < 0.25 \\ 0 & C \ge 0.25 \end{cases} \tag{3}$$

In the formula, C is the concentration of CO and t is the time people exposed in harmful gas.

(2) Impact of temperature on the Speed of Personnel

Due to psychological factors, people tend to avoid high temperature in the escape and will speed up the action at certain heat. When it reaches somewhat degree, the high temperature will cause damage to the personnel, thus reducing the speed of escape. The human tolerance for different temperatures is studied by foreign scholars and displayed blow as Table 3 [9].

Table 3 The human tolerance for different temperatures

Temperature		Time for endurance
℃	℉	(min)
40	104	60
50	122	46
60	140	35
70	158	26
80	176	20
90	194	15

When it reaches Ts, people are stimulated by high temperature and speed up. If the temperature keeps increasing up to Tr, the speed of personnel is reduced. More seriously, people will die when the heat reaches 180℃ [10].

Suppose a person walks at a room temperature with the speed of v0, and his maximum speed is vmax when under aggressive stimulus. To simplify the process, it is assumed that the increment of the velocity is proportional to the increment of the temperature when the temperature is under Tr and the speed decreases at a certain rate as the temperature increases when the it exceeds Tr [11]. To measure the effect of temperature on human speed, data from Table 3.3 is converted into an estimated function 3-4.

$$v=\begin{cases} v_0 & T_0<T\le T_s \\ v_0+(v_{max}-v_0)\frac{T-T_s}{T_r-T_s} & T_s<T\le T_r \\ v_{max}-v_{max}\frac{T_r-T}{T_r-180} & T_r<T\le 180℃ \end{cases} \tag{4}$$

Naturally, the temperature influence coefficient $f_2(T)$ is deducted.

$$f_2(T)=\begin{cases} 1 & T_0<T\le T_s \\ 1+\frac{v_{max}-v_0}{v_0}\times\frac{T-T_s}{T_r-T_s} & T_s<T\le T_r \\ \frac{v_{max}}{v_0}-\frac{v_{max}}{v_0}\times\frac{T_r-T}{T_r-180} & T_r<T\le 180℃ \end{cases} \tag{5}$$

(3) The calculation of the multiplier C_1

Human body is affected by the temperature and CO. The parameters are closely related to the place where it is located. Therefore, the node setting is the same as the installation of the monitoring equipment. Suppose the node v_i has a neighborhood $\mathrm{U}(v_i)$ with an equivalent length of s_0 (s_0 tends to be 0). So, in two cases of no fire and fire, the time required by a single person to pass through the neighborhood is expressed respectively:

$$T_1=\frac{s_0}{1.2} \tag{6}$$

$$T_2=\frac{s_0}{v} \tag{7}$$

Convert the expression into the equivalent length of the path.

$$s'=T_2\times 1.2 \tag{8}$$

The variation in the equivalent length of the path is:

$$\Delta s=s'-s_0=1.2\times(T_2-T_1) \tag{9}$$

Finally, multiplier C_1 is calculated and shown as 3-10.

$$C_1(v_i) = \frac{\Delta s}{s_0} = \frac{1.2-v}{v} \tag{10}$$

3.2 The derivation of the multiplier C_2

Suppose there are n cameras on a path, and the crowd density monitored by each camera is $d_1, d_2, \ldots, d_n$. Ignoring the area of corners and turnings, it is assumed that the area covered by n cameras is the whole range of the path, and there is no overlap or excess area. On this path, there are a total of m nodes including $v_1, v_2, \ldots, v_m$. And the crowd density of each node is $\mathrm{d}(v_1), \mathrm{d}(v_2), \ldots, \mathrm{d}(v_m)$. When $i \in [1,m]$, $\mathrm{d}(v_i) = \frac{d_1+d_2+\cdots+d_{\left[\frac{n}{m}\right]+1}}{\frac{n}{m}}$. $\left[\frac{n}{m}\right]$ means the integral values of $\frac{n}{m}$.

The expression of the population density monitored by camera i is as follows:

$$d_i = \frac{N_i}{S} \tag{11}$$

Ni means the number of people in the monitoring area.

S means the acreage of the monitoring area.

The degree of congestion

When people evacuate under normal circumstances (the speed of escape is not affected), they will not be blocked by things upfront or pushed by things behind, same for left and right. In this case, a step of a person make is estimated to be of 1.2m. And the spacing of left and right sides for a person is 0.2m.

Set the range of a monitoring camera as $S = a \times b$ and the width of human body as w_0. As it is demonstrated in Fig. 2, in normal cases, the number of people in the monitoring range of a camera is set to be N_0.

$$N_0 = \left[\frac{a-0.2}{w_0+0.2} \times \left(\frac{b}{1.2}+1\right)\right]+1 \tag{12}$$

$\left[\frac{a-0.2}{w_0+0.2} \times \left(\frac{b}{1.2}+1\right)\right]$ means the integral values of $\frac{a-0.2}{w_0+0.2} \times \left(\frac{b}{1.2}+1\right)$.

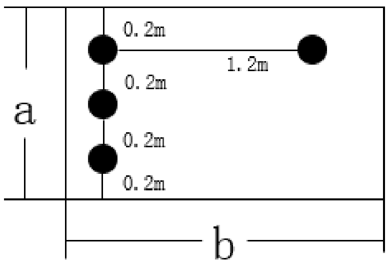

Fig. 2 Simulation graph of the escaping area

The relative crowd density of camera i is $D_i = \frac{N_i}{N_0}$, which makes the figure for node v_i is:

$$D(v_i) == \frac{D_1+D_2+\cdots+D_{\left[\frac{n}{m}\right]+1}}{\frac{n}{m}} \tag{13}$$

(2) The calculation of the multiplier C_2

When the evacuation route is unobstructed, it is nearer to the truth that people would run to the exit rather than walk in time of crisis. The average speed of a person running is 2.78m/s. Experiments show that, when extremely crowded (people can only move intimately with each other), the speed of their movement is about 0.5m/s. Suppose the node v_i has a neighborhood $\mathrm{U}(v_i)$ with an equivalent length of s_0 (s_0 tends to be 0). The time required by a single person to pass through the neighborhood in cases where the channel is open and most congested is shown separately as 14 and 15.

$$T_1 = \frac{s_0}{2.78} \tag{14}$$

$$T_2 = \frac{s_0}{0.5} \tag{15}$$

Convert the expression into the equivalent length of the path.

$$s'=T_2\times 2.78 \quad (16)$$

As is clearly demonstrated, the congestion has caused an increase in path equivalent, the variation of which is:

$$\Delta s = s'\text{-}s_0=2.78\times(T_2 - T_1) \quad (17)$$

And the multiplier C_2 for the most congested crowd is calculated:

$$C_{2max} = \frac{\Delta s}{s_0} = \frac{s'-s_0}{s_0} = \frac{2.78}{0.5} - 1 = 4.56$$

The relative crowd density for the most congested situation is $D_{max} = \frac{[\frac{b}{g}\times\frac{a}{w_0}]}{N_0}$, where g stands for the thickness of human body. In consequence, the multiplier C_2 that camera i monitors is expressed as 3-18, and the expression for node v_i is as 3-19.

$$C_{2i} = \frac{C_{2max}}{D_{max}} \times D_i \quad (18)$$

$$C_2(v_i) = \frac{C_{2max}}{D_{max}} \times D(v_i) \quad (19)$$

3.3 The basic steps of the Dijkstra algorithm

Set a starting point and an ending point as v0 and vm. The detailed steps of the Dijkstra algorithm are as follows [12].

Step 1: Mark the starting point as (-,0) and its adjacent nodes are labeled (v0, L (vi, v). The rest of the nodes are marked as (v0,∞). Set S as a set of vertices already obtained (initially it only contains the source point v0). And T is a set of undetermined vertices. T=V-S.

Step 2: If T=null, terminate the algorithm.

Step 3: Select a node vk, and it meets vk ∈T, L(vk) = min{L(vi)}, vi ∈T. The algorithm will be terminated if vk = vm. Otherwise, change the mark of vk into permanent label and set T=T- vk.

Step 4: Check all the adjacent nodes of vk, and change the mark of vk into (vk, L(vk)+L (vk, vi)) if L(vi)>L(vk)+ L (vk, vi). Return to Step2.

4. The example of application

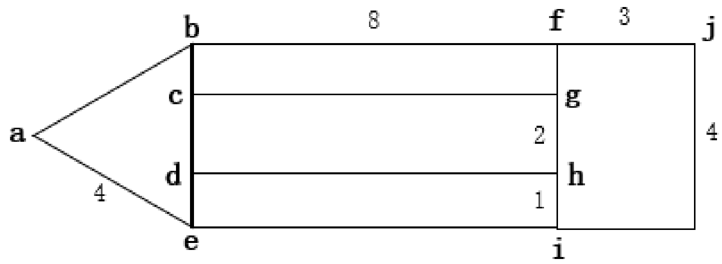

Fig. 3 Building structure example

The layout of a building is shown in Fig. 3 Area enclosed by a, b, e is a conference room where people gather together. Assume that the fire breaks out in the middle area of c-d-h-g, people are evacuated from point a to the exit point j. Physical length of the routes are marked in the drawing.

In the initial stage of the evacuation, the majority will choose the route a-b-f-j for its shortest physical length. But the crowd will undoubtedly cause a chaos and congestion on the course. Furthermore, with fire and smoke spreading, the optimal choice will most likely be something else. Assume that at a certain time t, parameters observed by each node are C as the concentration of CO, T as the temperature and D as the relative population density. Data of each node is presumed as shown in Table 4.

Table 4 Data of each node is presumed

Node	C_{CO} (%)	T (℃)	D
a	0.08	25	0.1
b	0.18	40	0.3
c	0.2	45	0.05
d	0.2	55	0.05
e	0.15	50	0.1
f	0.1	30	0.2
g	0.15	40	0.05
h	0.15	50	0.05
i	0.1	40	0.1

At this time being, the concentration of CO detected on point b is set as Cb, and the temperature is set to be Tb. Assume that the time required for personnel to pass through node b is 1 minute. Then it is easy to measure the effect of CO on evacuee's speed by the formula 3-3. Set the Ts as 30℃, Tr as 60℃ and vmax as 2.78m/s to quantify the effect of heat on human speed by formula 3-5. After the two calculations, people's current speed v can be computed by expression 3-2. The multiplier C1 is then obtained using equation 3-10.

As for the influence multiplier C2, first convert the crowd density monitored by cameras around node b into relative one and work out the data D(b) of node b using formula 3-13. According to the statistics of human body size [13], the width of the human body can be assumed to be 400mm, and the body thickness can be estimated to be 200mm. In this case, a high definition camera with a focal length of 3.3mm is implemented, whose visual range is about 1.5m x 2.0m, as to say that a=1.5m, b=2.0m. Dmax is then obtained with the data above to be 6.25. Substituting D(b) into equation 3-19 yields the multiplier C2 at last.

According to the method above, the data of each node are calculated as displayed in Table 5.

Table 5According to the method abov

Node	C_{CO}(%)	T (℃)	$f_1(C)$	$f_2(T)$	v(m/s)	C_1	D	C_2
a	0.08	25	1	1	1.2	0	0.1	0.07
b	0.18	40	0.904	1.439	1.56	-0.23	0.3	0.22
c	0.2	45	0.886	1.658	1.76	-0.32	0.05	0.04
d	0.2	55	0.886	2.097	2.23	-0.46	0.05	0.04
E	0.15	50	0.928	1.878	2.09	-0.43	0.1	0.07
f	0.1	30	0.961	1	1.15	0.04	0.2	0.15
g	0.15	40	0.928	1.439	1.60	-0.25	0.05	0.04
h	0.15	50	0.928	1.878	2.09	-0.43	0.05	0.04
i	0.1	40	0.961	1.439	1.66	-0.28	0.1	0.07

The multipliers of the path between two nodes are simplified as the arithmetic mean value of the according data. With the numerical effect on the length of route received, new path equivalent is distributed as Figure 4.2 shows.

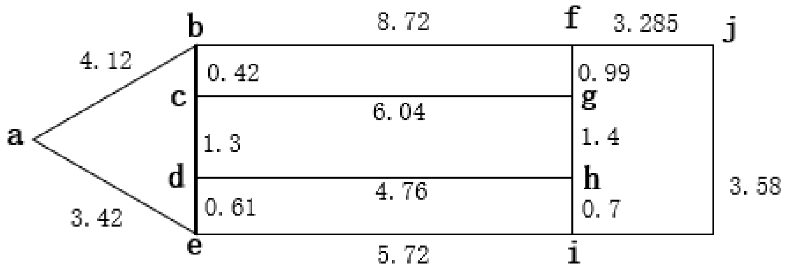

Fig. 4 new path equivalent is distributed

Next, Dijkstra algorithm is implemented to track down the optimal route for evacuation. The process is as follows:

(1) Mark the starting point a as (-,0), b as (a,4.12). And node e is labeled as (a,3.42). The rest of the nodes are marked as (v0,∞). Set T=T-a= {b, c, d, r, f, g, g, i, j}.

(2) T≠null

(3) L(vk) = min{L(vi)} =3.42,vi ∈T. → vk = e, T=T-e = {b, c, d, f, g, h, i, j}.

(4) Adjacent node of e, d:L(d)= ∞>3.42+0.61=4.03. Hence, change the mark of e to (e,4.03). i:L(i)= ∞>3.42+5.72=9.14. Accordingly, change the mark of i to (e,9.14).

(5) T≠null

(6) L(vk) = min{L(vi)} =4.03,vi ∈T. → vk = d, T=T-d = {b, c, f, g, h, i, j}.

(7) Adjacent node of d, c:L(c)= ∞>4.03+1.3=5.33. Hence, change the mark of c to (d,5.33). h:L(h)= ∞>4.03+4.76=8.79. Accordingly, change the mark of h to (d,8.79).

(8) T≠null

(9) L(vk) = min{L(vi)} =5,vi ∈T. → vk = b, T=T-b = {c, f, g, h, i, j}.

(10) Adjacent node of b, c: L(c)=5.33>4.12+0.42=4.54. Hence, change the mark of c to (b,4.54). f:L(f)= ∞>4.12+8.72=12.84. Accordingly, change the mark of f to (b,12.84).

(11) T≠null

(12) L(vk) = min{L(vi)} =4.54,vi ∈T. → vk = c, T=T-c = {f, g, h, i, j}.

(13) Adjacent node of c, g:L(g)= ∞>4.54+6.04=10.58. Hence, change the mark of g to (c,10.58).

(14) T≠null

(15) L(vk) = min{L(vi)} =8.79,vi ∈T. → vk = h, T=T-h = {f, g, i, j}.

(16) Adjacent node of h, g: L(g)=8.79+1.4=10.19<10.58. Hence, change the mark of g to (h,10.19). i: L(i)=8.79+0.7=9.49>9.14. So, the mark remains the same.

(17) T≠null

(18) L(vk) = min{L(vi)} =9.14,vi ∈T. → vk = i, T=T-i= {f, g, j}

(19) Adjacent node of i, h: L(h) = 9.14+0.7=9.84>8.79. So, the mark remains the same. j: L(j) = 9.14+3.58=12.72. Hence, change the mark of j to (i,12.72).

(20) T≠null

(21) L(vk) = min{L(vi)} =10.19,vi ∈T. → vk = g, T=T-g= {f, j}

(22) Adjacent node of g, f: L(f)=10.19+0.99=11.18<12.84. Therefore, change the mark of f to (g,11.18).

(23)T≠null

(24))L(vk) = min{L(vi)} =11.18,vi ∈T. → vk =f, T=T-f={j}

(25) Adjacent node of f, j: L(j)=11.18+3.285=14.465>12.72. So, the mark remains the same.

(26)L(vk) = min{L(vi)} = 12.72, vi ∈T. → vk = j. Terminate the process.

After considering the influence of the population density and the disaster factors, the shortest route is a → e → i → j. The total equivalent length is 12.72. This is even less than the equivalent length of the route a → b → f → j, which is the path with the shortest actual distance. It needs to be pointed out that the crowd density and disaster factors are changing over time. Therefore, in the evacuation process, we need to guide a group of people to adapt to the real-time optimal evacuation routes in time, that is, as depicted in Figure 2.1.

In practice, we use indicator lamps to lead the way: switch off the lamps which are jammed or close to the source of fire, and let the lights flash in a certain frequency on the best escape route.

5. Conclusion and Research Prospect

Due to the insufficiency of the current theoretical research on the shortest path in evacuation, a real-time dynamic optimal evacuation path calculation method is designed in this paper using the scientific method of sensor monitoring and crowd counting. It is proved by the example that it can save great amount of time by taking the actual length of the path, the density of the crowd and accident factors into the account of the evacuation route. Meanwhile, the real-time guidance offered by the indicator lamps can improve the efficiency of evacuation. As for the design of the system, this paper has only provided ideas, directions of the research, and has also completed the implementation of some of them. In further research, expanded functions of the system such as the visualization platform can be developed to help the rescue crews to help the crowd escape. Some of the issues that haven’t been addressed in this article including the layout of the indicator lamps and the influence of other factors on people’s actions during the fire will be supplemented in future studies.

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