Simulation on Escaping Process in Closed Construction Based on Multiple Model

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Abstract. In order to obtain the optimal escaping route in closed building and evaluate the escaping time, an evacuation model was established. The cellular automata model and ant colony algorithm was utilized in this process. Firstly, the cellular automata model was used to estimate escaping time. Using distances from individual locations to the exits to build risk of each point, then the evolving process was modified by factors like ability of individuals for innovation which can reflects escaper’s health, ratio of flurried people and the rules of people entering into next floor. Besides, ant colony algorithm method was used for the optimal routine. The equations of information judgement and accumulation was used, then take the broken down exits into consideration for an innovation. In the end, estimated escaping time and optimal evaluation route of Louvre was obtained by this model as a check and through the results some suggestions in evacuation was concluded.

1. Introduction
Recently, certain travelling cities and countries are struck by violent protest and fire, and the safe evacuation of tourists in the scenic area has attracted more and more attention. Hence, models were needed to simulate the escaping scene in closed constructs. Cellular automata model and the ant colony algorithm are commonly utilized in simulating individuals’ action and their affects to each other. Based on these specialties, these two models will be compounded to help safeguard to find escaping route and interval of escaping time.

2. Building Process of Cellular Automata Model
Cellular automata model is defined as a dynamic system which evolves in discrete time dimension on a cellular space composed of cells with discrete and finite states according to certain local rules. Here the Moore model will be used which is shown in Fig. 1.

|   |   |   |
|---|---|---|
| 1 | 2 | 3 |
| 4 | A | 5 |
| 6 | 7 | 8 |

The condition in boundary 1–8 can affect A’s behaviours determined by movements of the other cells, but A’s behaviours will also be affected by the rules determined by the designer.

Figure 1. Moore model map
2.1. Digital Map
The maps of buildings can be digitalized as follows: 0—inaccessible district; 1—accessible district; 2—the stair leads downstairs; 3—exit. The scale of the real map of Louvre is one block to four meters, which is implementation specific scale. Then the matrixes regarding of the real structure were imputed into Matlab as data of maps.

2.2. Definition of Risk at Each Grid Point
Risk at each grid point \( R \) is regarding of the distance to exits assigned as 0, inaccessible points assigned as 195. This value represents the safety of each point which is key to guard people to the safe route. Hence, \( R \) is defined by Eq.1:

\[
R(x,y) = \begin{cases} 
0 & \text{(exit)} \\
195 & \text{(inaccessible points)} \\
D(x,y) & \text{otherwise} 
\end{cases}
\]

Where

\[
D(x,y) = \text{square average of } ((x-x0)^2+(y-y0)^2), \ (x0,y0) \text{ means the point of the exits.} \tag{1}
\]

2.3. Improvement of Basic Moore Map
Assume 30% of the trapped people can not obtain the information of exits at beginning of escaping period, so assign occupying ability \( O=0.5 \) with 10% weak people and the left 90% people’s \( O \) is defined as 1 representing unequal competitiveness in conflict, which makes this model more realistic.

2.4. The Rule of CA Model

2.4.1. First rule of this model. Randomly input people in where can stand and assume every motion of each of them costs 0.25 second. Then they compare the risk of eight adjacent cells, and the grid point with the smallest position risk is regarded as the target grid point of the personnel at the next movement. The occupied blocks they move to will change from 1 to 195. If there is no more suitable point than where people are located they will be stationary.

2.4.2. Second rule of this model. When selecting the next target grid point, if there are multiple grid points with the minimum risk in the moving area, the personnel will randomly select one of them with the same probability as the next target grid point.

2.4.3. Third rule of this model. There may be multiple people competing for a free position at the same time. If there is a conflict between people and “O” of them are the same, the system will randomly select a person with move to the grid point, while the unselected person will stay in where he is. If there are weak people \((O=0.5)\), double the number of the healthy people and then choose one person casually (one healthy person stands for two weak persons), and then the responding person will stand on it.

2.4.4. Forth rule of this model. When people move to the exit, he disappears on this map. After 0.25s, he will appear in next floor map randomly. It can be assumed that everyone is going downstairs.

2.4.5. Fifth rule of this model. Use the stair to connect the five floor and calculate the whole time five floor costs. Change the H do many times of checking.

2.4.6. Sixth rule of this model. The people without information at beginning choose random one of eight adjacent cells to move until the number of the people in this floor is equal to 80% as it at the beginning.

3. Check of Cellular Automata Model

3.1. Input the Second Floor of Louvre
Map of second floor of Louvre shown as Fig. 2, then input the map into the model, the changing process can be observed clearly in Fig. 3, where \( H=0.1 \), white block means the people.
3.2. Input the Whole Five Floor of Louvre

Input the whole five floors of Louvre, collect the data of escaping time and repeat it again, after certain times check, the average time of escaping under certain human density can be obtained. And the results are shown in Table. 1 and Table. 2.

| Table 1. Average time of evacuation |
|-------------------------------------|
| floor | T (H=0.1)/s | T (H=0.3)/s | T (H=0.5)/s |
|-------|-------------|-------------|-------------|
| 2     | 37          | 60          | 77          |
| 1     | 37          | 83          | 138         |
| 0     | 19          | 60          | 87          |
| -1    | 41          | 131         | 207         |
| -2    | 45          | 139         | 226         |

| Table 2. Whole T of the evacuation |
|-------------------------------------|
| T (H=0.1)/s | T (H=0.3)/s | T (H=0.5)/s |
|-------------|-------------|-------------|
| 179         | 473         | 735         |

4. The Building Process of Ant Colony Algorithm Model

In the process of personnel evacuation, the behaviour characteristics of personnel and the ant colony system have certain similarities, all of them are diverse, and the correlation of mutual influence and the integrity of the system as a whole moving. The purpose of this model is to study the problem of safe evacuation of building personnel in emergency with adaptive ant colony algorithm. According to the adaptive ant colony algorithm to search for the optimal path algorithm, the optimal evacuation path is selected.
4.1. The Introduction of Symbol

Table 3. Symbol introduction

| variables                                      | symbol |
|------------------------------------------------|--------|
| Amount of people in building                   | m      |
| Amount of node in evacuation                   | \(Y_i\) |
| The number of evacuees at the node at time t   | \(b_{wi}(t)\) |
| Pheromones on the path at time t (wi,wj)       | \(\tau_{wi*wj}\) |
| Heuristic function                             | \(\eta_{wi*wj}\) |
| The collection of information amount on evacuation channel \(wi*wj\) left by node \(wi\) and \(wj\) at time t | \(\Gamma_{wi*wj}\) |

4.2. The Rule of Ant Colony System

4.2.1. Collect the information. People will consider the amount of information in each path and the heuristic information of the channel and the use the rule to choose the next node, the rule is take node into Eq. 2 first.

\[
w_{j} = \left\{ \begin{array}{ll}
\arg \max_{x \in N_{i}^{k}} \left\{ \left[ \tau_{wi*wj}(t) \right]^{\alpha} \left[ \eta_{wi*wj}(t) \right]^{\beta} \right\} & \text{if} \quad q \leq q_{0} \\
\text{otherwise} & \end{array} \right.
\]  

(2)

4.2.2. Judge the direction. When \(q > q_{0}\), evacuees at the node set as Eq. 3.

\[
w_{j} = J = w - \arg \max_{x \in N_{i}^{k}} \left\{ \left[ \tau_{wi*wj}(t) \right]^{\alpha} \left[ \eta_{wi*wj}(t) \right]^{\beta} \right\}
\]  

(3)

\[
P(w_{i}, w_{j}) = \frac{\left[ \tau_{wi*wj}(t) \right]^{\alpha} \left[ \eta_{wi*wj}(t) \right]^{\beta}}{\sum_{x \in N_{i}^{k}} \left[ \tau_{xi*xj}(t) \right]^{\alpha} \left[ \eta_{xi*xj}(t) \right]^{\beta}}, \quad w \in N_{i}^{k}, \quad \tau_{wi*wj}(t) < \Gamma_{wi*wj}
\]  

(4)

4.2.3. Accumulation. When choosing the path of personnel to achieve a certain number \([m / 3]\), or most evacuees \([m / 5]\) after selecting the path for the current distance than the last time the optimal path length and termination of traversal, take \(-10/d\) information update, greatly cut the amount of information every path to make it tend to be the average of the amount of information, so that the evacuees to current is not all the selected channel has a strong ability of exploration, to balance in the process of evacuation is the strong role.

When the number of personnel tends to be general when selecting the current path, the current pheromone is enhanced and \(1/\) is taken as increment. The update of local pheromone is carried out according to the Eq. 5. \(^{[1]}\)

\[
\tau_{wi*wj}(t + 1) = \begin{cases} 
\frac{\tau_{wi*wj}(t) - 10/d_{wi*wj}(t)}{\tau_{wi*wj}(t) + 1/d_{wi*wj}(t)} & \text{if} \quad q \leq q_{0} \\
\tau_{wi*wj}(t) & \text{otherwise}
\end{cases}
\]  

(5)

5. The Check of Ant Colony Algorithm Model

5.1. Input the Node of Floor Two

We take the map of floor 2 as the example and draw the node on the map shown in Fig. 4, where 4, 6,7,8,11,13,16,17 is stair. \(^{[4]}\)
5.2. Find the Optimal Route
Then through the method, the optimal escaping routine in floor 2 can be obtained as Table 4 and Table 5.

**Table 4.** The optimal escaping routine

| Position | target | Position | target | Position | target |
|----------|--------|----------|--------|----------|--------|
| Node 1   | 4      | Node 8   | Exit   | Node 15  | 16     |
| Node 2   | 8      | Node 9   | 11     | Node 16  | Exit   |
| Node 3   | 2      | Node 10  | 12     | Node 17  | Exit   |
| Node 4   | Exit   | Node 11  | Exit   | Node 18  | 20     | 16     |
| Node 5   | 6      | Node 12  | 13     | Node 19  | 18     | 17     |
| Node 6   | Exit   | Node 13  | Exit   | Node 20  | 7      |
| Node 7   | Exit   | Node 14  | 16     | Node 21  | 4      |

**Table 5.** The time and amount of people of each node

| Node | Number of people | Node | Number of people | Node | Number of people | Node | Number of people |
|------|------------------|------|------------------|------|------------------|------|------------------|
| 1    | 229              | 9    | 188              | 15   | 235              | 20   | 321              |
| 2    | 213              | 10   | 368              | 20   | 254              | 21   | 133              |
| 3    | 144              | 12   | 351              | 18   | 277              |      |                  |
| 5    | 297              | 14   | 298              | 19   | 333              |      |                  |

6. Summary
**Cellular automata.** This is adopted to simulate the changes in the process of personnel evacuation, so as to strengthen the guiding effect on the areas prone to blockage in the simulation diagram and add emergency exits.

**The ant colony algorithm.** This is adopted to calculate the optimal path, and the guidepost is provided at the corresponding position.

**Key point to keep fluency escaping line.** When the accident coming, the first thing is to let visitors know the path of the building as much as possible, and make sure to clear up the optimal number exit is prone to blockage. Then reduce the barriers at the key exit as much as possible, which can avoid causing congestion to most extent. Then provide simple training for visitors before entering the museum, and each person will be offered a simple map to facilitate the evacuation of tourists. Cameras and voice players should be set up in the whole museum, so that the staff can know the situation of the
whole museum at any time, and can timely convey the situation, such as congestion and dangerous areas, to tourists.

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