Study of Emergency Evacuation Model of Louvre Museum Based on A* Algorithm

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Abstract: In this paper, we have built a complete model to provide the Louvre's optimal crowd evacuation plan in most kinds of possible situations. Firstly, by analyzing the structure of the Louvre and the distribution of the exhibition halls, we refer to the principle of cellular automata to discretize the space of Louvre. Then we transform the 3D model into a 2D model and we use the Modified A* Algorithm to obtain the initial set of evacuation paths. The path self-learning algorithm and path self-optimization algorithm further optimize the evacuation path set. Finally, a gain evaluation algorithm evaluates the entire evacuation paths set, and obtain the optimal evacuation paths set.

1. Introduction

Nowadays, the rapidly increasing number of terror attacks in France requires many popular destinations to equip an emergency evacuation plan. The Louvre, one of the world's largest and most visited art museum, receiving more than 8.1 million visitors in 2017. And the number of guests in the museum varies throughout the day and year, which puts a higher demand for the Louvre's perfect emergency evacuation plan.

2. Establishment of Model

2.1 Principle of Model Establishment.

In order to design a scientific and reasonable evacuation strategy for the Louvre, we must firstly abstract and model the Louvre. Referring to the social force model based on behavioral heuristics and the principle of cellular automata, we will discretize the space of the Louvre according to a certain size, and the selection of this space size will directly affect the accuracy and scientific of the model.

Fig.1 The Rational Discretization of the Louvre

2.2 Modeling.

We create a model of the underground, the ground, as well as the first and second floors of the Louvre. Then connect the four floors according to the stairs and elevator facilities in the guide map. After getting the 3D model of the Louvre, we use Excel to transform it into two-dimensional model in order to solve the problem more conveniently, thus establishing a plane sketch of the Louvre from the underground to the second floor. In order to solve the problem further, we transform the plane sketch into a discrete mathematical model.

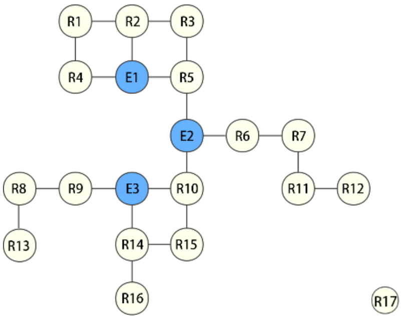

Fig.2 The Ground Floor

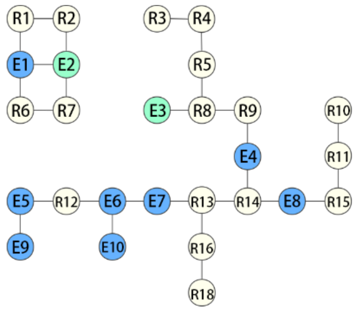

Fig.3 The Underground Floor

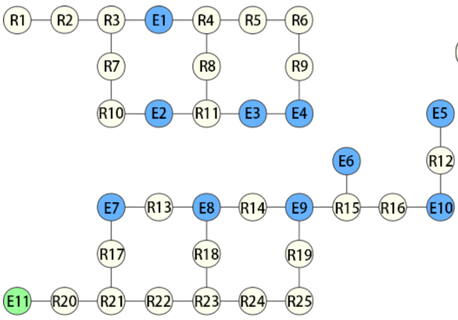

Fig.4 The First Floor

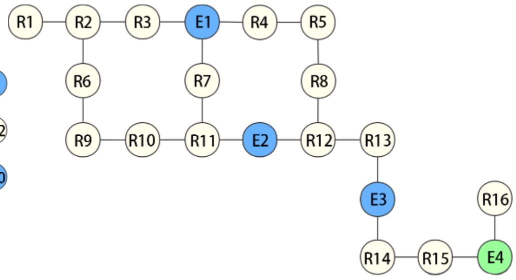

Fig.5 The Second Floor

After obtaining the mathematical model of each floor, if we find the optimal path of each layer separately and then connect them, we may not find the overall optimal evacuation path. So we need to connect the mathematical model of the four floors as a whole and form the overall discretization model of the Louvre. And then develop the plan as a whole, so that we can get the overall optimal evacuation plan of the Louvre.

3. Path Selectin

3.1 Modified A* Algorithm

We firstly evaluate and calculate the evacuation time of each unit space, and then take it as the weight value of the path. Then, starting from the starting point, select the nearest exhibition hall with the shortest evacuation time for evacuation every time until it reaches the exit. At the same time, in the case of large crowd congestion, the crowd congestion situation when going downstairs is more complex, and there may be congestion between floors, so the weight value needs additional consideration. The heuristic function of A* algorithm is as the follows:

$$F(n) = G(n) + H(n)$$

Among them, F(n) is the evaluation function of A* algorithm for each point, G(n) is the actual cost from the starting point to the current node n, that is, the weight of the path, which is the moving time from the starting hall to another unit space n in the question. The moving time depends on the length of the path l and the speed of evacuation v, and the evacuation speed of the crowd is affected by many factors, such as crowding, maximum capacity of the path and so on. Studies have shown that the speed of evacuation is less affected when the degree of crowding is small, and the maximum is Vmax = 1.5m/s; while when the degree of crowding is large, the speed of evacuation decreases with the increase of the degree of crowding, which can be described by an exponential function. The function of evacuation speed is as follows:

$$V = v_{max} \cdot e^{-0.5w}$$

Among them, ω is the congestion situation of the Louvre crowd, which is difficult to quantify due to the crowd congestion. Therefore, we uses the waiting time t and the maximum waiting time T_{max} provided by the entrance queuing time evaluation software "Affluences" provided by the Louvre, and uses the formula $\omega = t/T_{max}$ to indicate the current congestion of the Louvre. So the time needed to move the adjacent unit space, that is, the weight of the path is p = l/V . The relationship between the evacuation speed and the degree of congestion of tourists is shown as follows.

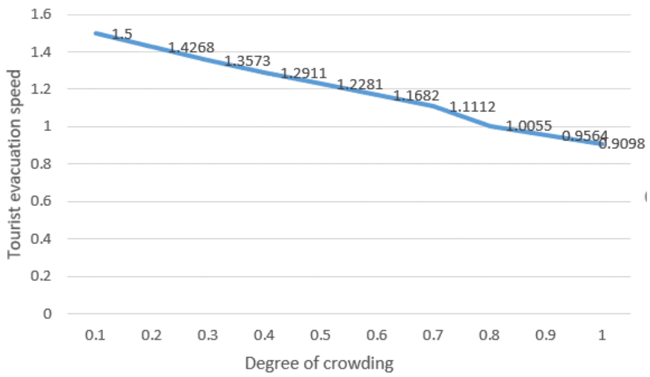

Fig.6 The relationship between the evacuation speed and the degree

H(n) is the distance evaluation value from the current node n to the end point. This is an estimate of the cost from the current node n to the end point, that is, the moving time from the current unit space n to the final exit in the problem, whose evaluation method is similar with the G(n). For the problem to be solved in this paper and the discrete model constructed, $D_{Manhattan}$ is the actual path length (not the Euclidean geometric plane distance) to go through from one unit space to another for two connected unit spaces.

$$D_{Manhattan} = |x_1 - x_2| + |y_1 + y_2|$$

So the time T from one unit space to another is defined as:

$$T = p \cdot D_{Manhattan}$$

The p is the weight determined by the above method. In this problem, from a certain point n to the optimal evacuation exit, it is necessary to continuously pass through the adjacent points, and sometimes it is necessary to consider the complicated situation of the downstairs, and the distance evaluation of the adjacent points needs to use the Manhattan distance. Through multiple evaluations and shortest distance selection, the best H(n) can be obtained

3.2 Path Self-optimization and Learning

After the A* algorithm determines the set of optimal evacuation paths, there will be some problems in the path obtained by using discrete space units due to the selection of the size of each spatial unit during the discretization of the Louvre. For example, some paths in the set of evacuation paths may have duplicate key points, resulting in the resulting path not being the actual shortest path. Inspired by previous studies, we proposes a path self-learning optimization algorithm for the problems faced in this paper. The specific algorithm steps are as follows:

Firstly, input the optimal path set obtained by the A* algorithm. Then traverse all the key points on the path, and search for the same unit space at different positions on the search path. If find, merge the two identical nodes on the path and generate a new path. After eliminating duplicate critical paths by using path optimization algorithm, the size of the optimal evacuation path set will be further reduced. When the size of the unit space is large, the number of paths in the path set is small, but the original path information loss is large, and it is impossible to provide correct evacuation suggestions for pedestrians; conversely, the number of evacuation paths is large, and the evacuation information is rich, but the calculation amount will be increased accordingly.

4. The Gain Evaluation of the Path

In order to improve the feasibility of evacuation strategy and ensure the stability of crowd evacuation process, we need to carry out the gain evaluation of the obtained path set. And in order to make it more clear and convenient, we introduces the concept of "path-related nodes".

Path-related nodes: Assuming two paths A and B, the sequence of paths is $a1, a2, \cdots, an, b1, b2, \cdots, bn$. If the node ai and bj are in the same space, then we call the two nodes “path-related nodes”. For example, the paths A, B and D, B in the figure below have a path-related node B.

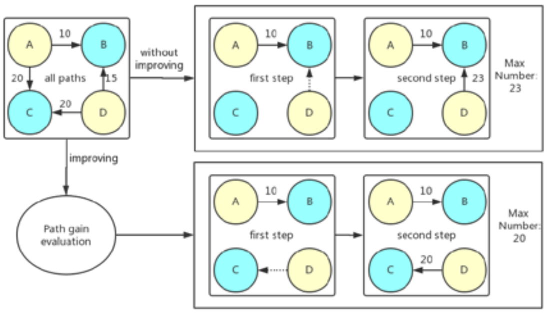

Fig.7 Path-related nodes

In the actual process of the route selection, the choice of candidate paths is actually the pedestrians’ perception of the current environment. Although there are many potential factors affecting the path selection, in the case of emergency evacuation, there are two main factors affecting the evacuation path: the length of the path and the degree of congestion of the path nodes. In this paper, the factors affecting evacuation are quantified, and the path evaluation function is used to evaluate all the nodes of the path repeated in the evacuation plan. The basic principle of the evaluation is that the higher the value of the evaluation function, the greater the impact on the weight of the nodes of the path. The formula is as the follow:

$$\Phi^{t+\Delta t} = \frac{\alpha\omega^{t+\Delta t} + \beta D^{t+\Delta t} + \Phi^{t}}{\Phi^{t}}$$

Among them, $\Phi^{t+\Delta t}$ is the evaluation value after the gain evaluation, α is the parameter determined by many factors such as the congestion degree of the path node, the capacity of the path, etc. $\omega^{t+\Delta t}$ is the congestion degree after the crowding degree ω of the path-related node is superimposed on the congestion degree of the path-related node in the current situation, β is a parameter determined by the length of the Louvre's overall exhibition hall, $D^{t+\Delta t}$ is the distance between the current path node and the exit of the path, and Φ^{t} is the original gain function value of the current path node. The weight of the path node after gain evaluation is:

$$G^{t+\Delta t}(n) = \Phi^{t+\Delta t} \cdots G^{t}(n)$$

After the gain evaluation of the path-related nodes, the weights of the path nodes are updated. Then the adjusted weights are taken into the A* algorithm to solve the problem, and the same operations are performed on all the related nodes. Finally, the optimal path set after path gain optimization can be obtained.

5. Summary

The model has strong adaptability, flexibility and practical strain ability. And it can give the corresponding schemes for the different population variables. It can change the Louvre mathematical model according to the actual situation or special requirements to make the model more accurate. But every coin has two sides, under the influence of some objective factors, the actual crowd evacuation speed may be faster or slower than expected.

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