Louvre evacuation route planning based on ant colony algorithm

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Abstract: In this paper, in order to evacuate the personnel in the building under a potential threat, the floor topology and the node map are established for preliminary model analysis using the Ant Colony Algorithm. In the analysis, different needs for path planning of evacuators and emergency personnel are considered and the preliminary evacuation model is modified to acquire a three-dimensional dynamic evacuation model for multi-layer buildings which can be commonly applied in a variety of emergencies. To update the path planning in real time, the WSN is introduced to realize the real-time monitoring and data update and develop the latest evacuation plan.

1. Introduction

With the rising frequency of terror attacks in France[1], the public are worrying about their security. As well, the Louvre, which is one of the world's greatest and most attractive art museum receiving over 8 million tourists from all over the world per year[2], is facing the challenge in keeping their art, their architecture and their visitors from danger.

When under potential threat, all the individuals should be evacuated from the museum as soon as possible, while the emergency personnel can enter the building in time. A reliable plan for emergency evacuation is required to evacuate the visitors in order, avoiding the stamped accident.

In this paper, in order to clear the building in a short time and ensure the crowd's safety, an emergency evacuation model will be build to plan the best route to exit from the museum for every visitor in different parts of the building.

2. Related work

2.1 Restatement of the Problem

•Path Planning and Optimization Problem

In the emergency situation, the target of the evacuators move to the safe area as soon as possible, which is an optimal path planning problem that the destination is the safe areas.

Conversely, for the emergency personnel, the target is to move to the area where the potential threats occur and solve the problem that the destination is the dangerous areas.

•Solutions to the Special Situations that Occur during the Evacuation Process

In the actual evacuation process, the probability of occurrence of various unexpected situations will be greatly increased. Therefore, the problems to be solved are the evacuation diversion arrangements and the plan to solve the passage congestion like the bottleneck to avoid the secondary accidents.

2.2 Assumption

•The potential threat occurs inside the building while that from the outside like air raid is not considered in the model.

•The living and security rights of the individuals are equal and no one have an absolute priority to evacuate.

•Every evacuator moves under the direction of the evacuation system and the crowd will not be in panic.

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•All elevators will be shut down in case of emergency to prevent possible accidents.

•The speed of evacuators is assumed as , while the speed of different types of evacuators will be modified with a coefficient.

3. The Evacuation Model

3.1 Building of the Evacuation Model

The traditional evacuation model only indicates a fixed direction, which cannot confirm the direction of the nearest available exit or identify whether it is a safe passage when an accident occurs, while the evacuators may be misled during the evacuation process. In an emergency situation, people are usually phototactic and follow the crowd. Thus, the evacuation indication system plays an important role in the emergency escape process.

The Shortest Path Algorithm is the core algorithm of the evacuation model in the intelligent evacuation system. Presently, the Dijkstra Algorithm, the Simulated Annealing Algorithm and the Genetic Algorithm are commonly used, which are computationally inefficient and complex. The Italian scholar Macro Dorigo proposed an ant colony algorithm based on population heuristic bionic evolution system in the early 1990s by simulating the ants' collective behavior of path finding, which has the characteristics of distributed computing, information positive feedback and heuristic search and has the advantages of strong robustness and excellent distributed calculating system.

In this model, the floor topology is simulated to establish a map of floor evacuation nodes and the shortest path from node to exit is calculated by the Ant Colony Algorithm. The MCMF node preprocessing method is proposed to optimize the order of the nodes processed by the Ant Colony Algorithm in order to reduce the time that the evacuation model discovers the shortest path.[3] In this case, the change of passage capacity is not considered and the emergency personnel only enter the building via extra entrances, not affecting the evacuation of the evacuators.

3.2 Ant Colony Optimization Algorithm

The Ant Colony Algorithm is a bionic algorithm which originates from a biological phenomena found by Macro Dorigo when he observed the ant foraging process that the subsequent ants will choose the direction of movement based on the concentration of pheromones released in the foraging path of preceding ants, which can help ants to find a better path to food quickly and effectively.[4]

3.2.1 The Topology Construction of the Building

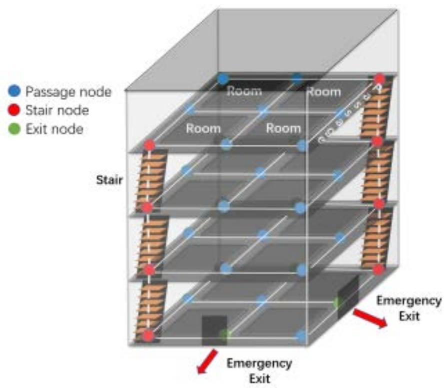

Figure 1: The Three-dimensional Topology for a Building

In the topology, several nodes are set at the intermediate node, the turning point, the security exit, etc., then the nodes are sequentially numbered and the connection relationship between the nodes is determined. The node number set is defined as $V_{node} = \{1,2,...,n\}$, the connection relationship is defined as the edge set $F = \{f_1, f_2, ..., f_n\}$ and the relationship between nodes is established as the directed weight graph $G(V_{node}, F)$, in which V_{node} represents the node set and F represents the passage set. Additionally, the emergency exits are preset and the nodes are stored in two-dimensional coordinates.

3.2.2 The Ant Colony Algorithm with Multiple Targets

The Ant Colony Algorithm is an adaptive algorithm for the local update of the Heuristic Algorithm, in which the accuracy of the calculated shortest path is positively related to the numbers of iterations and loops.

It is assumed that the tabu list $Tabu_k(k = 1,2,...,m)$ records the node that the ant k is currently passing, m is the number of ants, α, β respectively represent the effects of the information accumulated by the ant and the heuristic factor in the path selection, $\tau_{ij}(N_c)$ represents the pheromones concentration between i and j at the iteration N_c, $\eta_{ij} = \frac{1}{d_{ij}}$ is the heuristic factor and d_{ij} is the weight value of the passage between node i and j. $P_{ij}(N_c)$ represents the possibility of the ant k moving from node i to node j at the iteration N_c, which is determined by the formula as follows:

$$P_{ij}(N_c) = \begin{cases} \dfrac{[\tau_{ij}(N_c)]^{\alpha} \times [\eta_{ij}(N_c)]^{\beta}}{\sum\limits_{k\in allowed_k} [\tau_{ik}(N_c)]^{\alpha} \times [\eta_{ik}(N_c)]^{\beta}} & , if j \in allowed_k \\ 0 & , other\ situations \end{cases}$$

In this Formula , $allowed_k$ is the set of nodes that have not been visited.

If the ant k uses $P_{ij}(N_c)$ to determine the next node to move to only based on the moving possibility, the convergence speed will be fast, which may result in a local optimal solution. To prevent this, r is defined as a random number which is between 0 and 1. If $r < P_{ij}(N_c)$, the node will be selected to expand the search range. $Tabu_k$ is dynamically adjusted as the evolutionary process and the nodes that have passed are placed in it, which are no longer used to make the decision of which node to move to. Each ant ends the loop when finding the target or reaching the maximum number of cycles and saves the path. When finding the shortest path to the target at a certain generation of cycles, the concentration of pheromones on the path will be updated as below:

$$\tau_{ij}(N_c + 1) = (1 - \delta)\tau_{ij}(N_c) + \Delta\tau_{ij}$$

In Formula , δ is the coefficient of pheromones evaporation and $\Delta\tau_{ij}$ represents the pheromones increment between node i and j released by the ant reaching the target at each generation of cycles. When the ant k discovers the shortest path in a certain cycle, the pheromones concentration on which is updated through the Ant-cycle Model as below:

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{Q}{L_k} & , if\ the\ antkpassesi, jin\ this\ cycle \\ 0 & , other\ siuations \end{cases}$$

In Formula, Q is the total amount of pheromones released at each cycle, which is a constant, L_k is the path length the ant k finishes at this cycle and τ_{ij}^{k} is the concentration of pheromones the ant k releases on the path to the target at a cycle.

3.2.3 Initial Optimization of the Evacuation Model

The evacuation model obtains the shortest paths to the exit from certain nodes through the Ant Colony Algorithm, so it is necessary to apply the algorithm for multiple times. The operation time of the intelligent evacuation model is mainly determined by the operation time of the Ant Colony Algorithm, thus the key to optimization is to reduce the frequency of calculations by the Ant Colony Algorithm. The MCMF method is to sort the nodes according to the distances from the nodes to the exits. In order to reduce the frequency of calculations, the number of nodes at each time of calculation should be increased and the passed nodes should not be calculated repeatedly. In the emergency situation, the coordinate values and connection relationships of the nodes and the exits as the targets are set as input data to acquire the shortest path from the node to the exit through the Ant Colony

Algorithm.

3.3 Improvement of the Evacuation Model

In the case of a real emergency, the herd mentality of evacuators is quite similar to the ant colony foraging behavior. The application of the Ant Colony Algorithm in the evacuation model leads the crowd to exit from the building as soon as possible. In the traditional Ant Colony Algorithm evacuation model, the pheromones lacks at the beginning and the dynamic changes of the crowd flow and the passage's passing capacity, which may result in the random selection of the path by the algorithm at the beginning that falsely leads the evacuators to dangerous areas while the crowd may jammed or even stamped at the later stage of the algorithm due to the accumulation of pheromones.

Therefore, sensors and detectors can be applied to learn the evacuation state of the building, then leading the evacuator flow to avoid barriers in time effectively. This method can compensate for the lack of pheromones at the beginning of the algorithm and optimize the update parameters of the subsequent pheromones. The evacuator flow in real time can be monitored by the cameras to optimize the algorithm to avoid congestion caused by early convergence by introducing passing coefficient of the passage.

3.3.1 Evacuation Traffic Status

The evacuation traffic status is collected by the video detectors, which is defined as the evacuator flow q determined by the flow density ρ, the flow speed v and the width of the passage w.[5] The following formula show the relationship of q, ρ, v and w:

$$q = \rho \times v \times w$$

It is assumed that the maximum density of the evacuators at an area is $\rho_{max} = 5person/m^2$.

3.3.2 The Improved Ant Colony Algorithm

In the particular application of the evacuation model, the Ant Colony Algorithm may be affected by the environment factors, such as the passage congestion, the crowded traffic and other unknown hidden dangers, which causes poor local search results and low overall efficiency.[6] Thus, the relevant parameters are updated as follows:

The Real-time Monitoring Information Collected by the Sensors and Detectors and the Jam Evaluation of the Building The distance between two positions is set as follows:

$$d_{ij} = \begin{cases} \infty & ,j \in Z \\ \gamma l_{ij} & ,j \in Z_0 \end{cases}$$

In Formula, Z represents the set of the positions of barriers and potential threats, Z_0 represents the set of positions of dangerous area around the potential threats and γ is a area condition parameter obtained from the synthesis of environment information including secondary threats, threat ranges and their spreading speed. These parameters can be combined and be obtained by the WSN.[7]

When the area that is possible to move to belongs to Z, there is a barrier or a threat at it and it is not allowed to move to. The value of d_{ij} is set to $d_{ij} = \infty$, thus $\eta_{ij} = 0$ and $P_{ij} = 0$, which is matched with the actual situation.

$$\gamma = \begin{cases} \infty & ,j \in Z \\ 1 & ,j \geqslant 2 \\ 1.5 & ,j = 1 \end{cases}$$

In addition, the real-time data of the evacuator flow sniffed by the cameras is still considered in the path searching process that the distance between two positions are optimized as below:

$$d_{ij} = \begin{cases} \infty & ,j \in Z \\ \varphi\gamma l_{ij} & ,j \in Z_0 \end{cases}$$

In Formula, φ is a weight parameter obtained by combining the number of evacuators and the width of passages which are real-time data for analyzing the crowd's density by the cameras.

$$\varphi = \begin{cases} 1 & , \rho < 50\%\rho_{max} \\ 1.1 & , 50\%\rho_{max} \leqslant \rho < 60\%\rho_{max} \\ 1.5 & , 60\%\rho_{max} \leqslant \rho < 80\%\rho_{max} \\ 2 & , 80\%\rho_{max} \leqslant \rho < \rho_{max} \\ 3 & , \rho \geqslant \rho_{max} \end{cases}$$

The Update Mechanism of Pheromone Concentration According to the real-time information of the building collected by sensors and detectors, different initial values are respectively set for dangerous area around the potential threats, barriers and potential threats and others as below:

$$\tau_0 = \begin{cases} 0 & , j \in Z \\ 0.5C & , j \in Z_0 \\ C & , other\ situations \end{cases}$$

Dynamic Adjustment Method of Pheromone Volatility δ and Q The next volatilization coefficient and total pheromone released are determined according to the difference between the path length$L(k,m)$ and the average path length L_{aver} in order to avoid local optimal solutions and slow convergence.

$$Q(k) = \begin{cases} Q & , 0 < k \leqslant \frac{1}{3}K \\ 0.5Q & , \frac{1}{3}K < k \leqslant \frac{2}{3}K \\ 0.25Q & , \frac{2}{3} < k \leqslant K \end{cases}$$

Z represents the set of the positions of barriers and potential threats, Z_0 represents the set of positions of dangerous area around the potential threats and γ is a weight parameter obtained from the synthesis of environment information including secondary threats, threat ranges and their spreading speed. These parameters can be combined and be obtained by the WSN.

The Update Mechanism of Pheromone Concentration for the Emergency Personne , For the emergency personnel, initial values are respectively set as follows:

$$\tau_{0(emer)} = \begin{cases} 2C & , j \in Z \\ 1.5C & , j \in Z_0 \\ C & , other\ situations \end{cases}$$

Dynamic Adjustment Method of Pheromone Volatility δ and Q, The pheromone volatility δ and Q do not change using the dynamic adjustment method, thus they are not considered in this section.

4. The Results of the Model

The simulation of the optimized evacuation path planning is based on the evacuation model, which is divide into the following steps:

4.1 Establish a Topology for the Internal Structure of the Louvre

According to the obtained internal structure diagram of the Louvre, most of the open areas whose environmental factors are unchanged are simplified into nodes and are labeled. Set the exit nodes and simplify the passages, the stairs and the escalators connecting the nodes into lines between the nodes. The structural map with topology and structural topology of the Louvre is as Figure A1 & A2 in the appendixes.

4.2 Digital Abstraction of the Topology

Establish a node set $V_{node} = \{1,2,3,...,168\}$. In the structural map with topology, the position of the nodes are similar to those of the actual areas, thus the two-dimensional pixel coordinate of each node is extracted from the structural map with topology. By comparing distances between the node pixels and between the actual areas, assume the scale of the topology is $\mu = 1.5 pixel/m$.

Assume that the actual length of the stairs between the floors is 10 meters, and the pixel distance between the floors is 15 pixels. Obtain the three-dimensional pixel coordinates of the nodes using the layer 0 as the reference height and construct the node coordinate matrix C. Thus the pixel distance l_{ij} between any of the connected nodes i and j is determined. The connectivity matrix F is established according to the node connectivity of the topology map. If the nodes i and j are connected, $F_{ij} = Fji = 1$, otherwise $F_{ij} = Fji = 0$. The node is not connected with itself, i.e. $F_{ii} = 0$.

4.3 The Parameter Setting of the Ant Colony Algorithm

- The order of the nodes the ant k has passed is recorded in the iteration N_c on the tabu list $Tabu_{kN_c}$. It is assumed that $m = 100$ and $N_{c_{max}} = 500$.
- Establish the initial pheromone matrix τ. Assume that all initial pheromones in the matrix are 1 and establish a pheromone update matrix. The total pheromone increment in the iteration N_c is recorded in $\Delta\tau$. In the iteration N_c, if the ant k can reach the destination, the pheromone increment that it releases at the points i and j is $\Delta\tau_{ij}^k = \frac{Q}{L_k}$, in which $Q = 100$. Assume that the pheromone evaporation coefficient $\rho = 0.3$, thus in the iteration N_{c+1}, $\tau_{ij}N_{c+1} - (1-\rho)\tau_{ij}N_c + \Delta\tau_{ij}$.
- Establish a heuristic factor matrix η, wherein $\eta_{ij} = \frac{1}{d_{ij}}$ and d_{ij} represents weight between the nodes i and j. In the previous section, $d_{ij} = \frac{\varphi\gamma l_{ij}}{V}$ is specified, in which l_{ij} is the distance between i and j.
- Quote Formula 4-1. Assume that $\alpha = 1$ and $\beta = 5$. To prevent the occurrence of local optimal solutions, set a random number $0 < r < 1$. If $r < P_{ij}$ in a certain node, select it.

4.4 The Ant Colony Algorithm Path Planning Simulation

The modified distance $D = L\varphi\gamma\theta$, in which L is the total evacuation distance, φ is the passage condition modification coefficient, γ is the area condition coefficient and θ is the individual type modification coefficient. The modified evacuation time $T = \frac{D}{V}$, in which the speed of ordinary people $V = 1m/s$.

Therefore, the modification of the evacuation time is equivalent to that of D, of which the main influencing factor is L. The total time of the entire evacuation process is the evacuation time of the last evacuator. Thus, the evacuation condition for the last evacuator is set to be difficult that it is one with limited mobility and the passage environment is poor that the average degree of congestion of the whole path is 60% of that of the bottleneck and three random passages are unavailable, so the evacuation time of this evacuator can be approximated as the total time of the evacuation process.

According to the analysis above, the starting point is set to be the node 1(Room 864) and the single destinations are set to be the node 94 & 95(Passage Richelieu), 106(Pyramid Main Entrance/Exit), 130(Porte Des Lions) and 165(Carroussel du Louvre). The three random passages unavailable is 2/28, 70/71 and 95/96, the average degree of congestion of the whole path is 60% of that of the bottleneck that $\varphi = 1.5$, the evacuator type is the person with limited mobility that $\theta = 2.5$ and severe disasters or extra exits are not considered that $\gamma = 1$. The simulation path is shown as below:

TABLE I. The Single-exit Path Planning Simulation of the Ant Colony Algorithm

Starting Point	Destination	Modified Path Length/pixel	Optimal Solution
1	94	2450.7945	1-2-7-8-9-36-35-34-33-28-80-79-86-92-93-94
1	95	1554.726	1-2-7-8-9-36-96-89-83-82-88-95
1	106	1994.874	1-2-7-8-9-36-96-140-139-141-166-106
1	130	/	Unable to evacuate due to the passage 70/71 closed
1	165	3551.17525	1-2-7-8-9-36-96-140-139-141-166-165

TABLE II. The Multi-exit Path Planning Simulation of the Ant Colony Algorithm

Starting Point	Destination	Modified Path Length/pixel	Optimal Solution
1	94, 95, 106, 130, 165	1554.726	1-2-7-8-9-36-96-89-83-82-88-95

Therefore, the optimal evacuation path can be obtained through the multi-target Ant Colony Algorithm.

The total evacuation time after conversion is:

$$T = \frac{\frac{D}{\mu}}{V} = \frac{1554.726pixel}{1.5pixel/s} = 1036.484s \approx 17.27min$$

The total evacuation time is reasonable so that the evacuation model based on the Ant Colony Algorithm is reliable.

The emergency personnel path planning simulation is similar to the above so it is not shown.

5. Conclusion

In this paper, in order to solve the problem of evacuation when the Louvre is under potential threat, the floor topology and the evacuation node map are established and the Ant Colony Algorithm is applied to construct the preliminary model. In the analysis, the actual situations are considered to modify the primary evacuation model and a comprehensive three-dimensional multi-layer building dynamic evacuation model that can handle a variety of emergency situations. Furthermore, the evacuation model in the background of the Louvre is simulated on the Matlab to find the best path and the shortest time of the evacuation, which verifies the feasibility of the evacuation model. In order to update the real-time path planning, the WSN is applied to monitor and update the data in real time and develop the latest evacuation plan.

In addition, to solve the bottleneck problem in the evacuation process, the bottleneck solving model was established with the Queuing Theory, which can identify the bottleneck areas that reduce evacuation efficiency. The Simulated Annealing Algorithm is used to solve the problem by comparing with the set prime escape time, discussing the increase of additional passages and emergency personnel and quantifying the quantity of additional passages, which makes the model highly versatile. At last, the specific application of the model in the real scene of the Louvre is discussed, which provides a reasonable reference for the change of the evacuation caused by the change of visitor quantity.

6. Strengths and Weaknesses

6.1 Strengths

The model can be generally applied with a comprehensive discussion.

The model is combined with high technology to update the real-time evacuation plan with intelligence and timeliness.

The different attributes of evacuators and emergency personnel are modified providing information for both the evacuators and emergency personnel in order to link the evacuation and the rescue.

The bottleneck problem is solved by identifying the congestion areas to improve evacuation efficiency and reduce evacuation time, thus the actual problem can be properly solved.

The model simulation results are ideal, indicating that the model is reliable.

6.2 Weaknesses

Some of the actual conditions are ideally assumed that the true situation of the interior or surrounding environment of the Louvre are not completely reflected.

The influence of human’s emotion is not considered in this model.

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