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Emergency Evacuation Route Choice Based on Improved Ant Colony Algorithm

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In order to explore the optimal route choice for emergency evacuation in the campus, we propose a novel route choice method based on brittle characteristics of campus system and improved ant colony algorithm. Both optimal and worst-case emergency evacuation routes are simulated in the campus of Ningbo University of Technology. From the simulation, the length of optimal and worse-case evacuation routes between the starting point and eight exits can be obtained by adjusting the importance value of trip distance and the degree of conformity, under the condition of static relative importance of pheromone concentration to graph G. The optimal route of emergency evacuation in the campus can be obtained when the importance of trip distance is above 5 and the degree of conformity is above 0.3; while the worse-case route is obtained with the importance of trip distance above 5 and the degree of conformity below 0.5.

Keywords: route choice; ant colony algorithm; brittleness; emergency evacuation.

1. INTRODUCTION

With the increasing socialization of the university campus, the use of the school's site resources for holding large-scale and super large-scale activities has become the trend of social activities. Once accidents occur in large gatherings, the consequences are serious. It is very important to evacuate pedestrians rapidly and safely in emergency situations, strengthen the information management of pedestrian evacuation, prepare all kinds of contingency plans for emergency and improve the competence of emergency management. At the same time, it is a trend to plan the emergency route for pedestrians (Guo Ren-Yong, et al., 2012 and He Jian-fei, Liu Xiao, 2013) by solving the optimal path-planning problem.

In recent years, pedestrian safety emergency evacuation has become one of the hot topics. Four characteristics are vital in the safe evacuation, mainly including psychological and behavioural characteristics of pedestrians in large public places or buildings (such as cinemas, theatres, stadiums, railway stations, shopping malls, universities, civil aviation trainings centres, airports, etc.), crowd evacuation behaviour, characteristics of crowd evacuation in closed space in emergencies like fire, Pedestrian safety evacuation behaviour modelling (Pan X, et al., 2007 and Wang Ai-li, et al., 2012 and Zhang Qi, et al., 2008). With the development of computer technology, it is possible to simulate the pedestrian evacuation process. In the simulation, the pedestrian trajectory is simulated, pedestrian position at different time point can be recorded and total evacuation time for each pedestrian can be calculated. According to incomplete statistics, about 22 kinds of pedestrian evacuation model and network simulation software are available, of which EVACNET (Evacuation network simulation software), BUILDING EXODUS (Building environment evacuation simulation software), FIRECAM (Fire simulation software), SIMULEX (Evacuation software) etc. (Zheng Xiao-ping, et al., 2009 and Syed A T, Hassanain M A., 2013 and Yang Li-zhong, et al., 2012, Matas, M., Ristvej, J., et al. 2017, 2016, 2013) are the most prominent ones. With further study of pedestrian safety evacuation behaviour and the establishment of simulation platform, the researchers also take the psychological and physiological characteristics of pedestrians into consideration, and build a safe evacuation model; the representative models are social force model, cellular automata model and magnetic force model (Helbing D, Molnar P., 1995 and Seyfried A, et al., 2006 and Parisi D R, Dorso C O., 2005, Teknomo K., 2006 and Zagorecki, A.T., et al. 2013).

The study of safety emergency evacuation covers traffic engineering, evacuation dynamics, statistics, architecture, psychology, safety engineering, image processing, software development, and etc., which makes the study a multi-discipline research, but most of the researches done before are only considering a single factor or a single level, and some of the results are not practical. Also, few research results are conducted on the campus and most of them are without complexity theory and system method. To address the problem, we analysed campus safety emergency evacuation route choice, based on the brittle characteristics of the university campus, using the improved ant colony algorithm, which is a new exploration of campus safety emergency evacuation theory.

2. THE BRITTLE STRUCTURE CHARACTERISTICS OF UNIVERSITY CAMPUS – BRITTLENESS OF COMPLEX SYSTEM

Brittleness: under the combined action of internal and external factors, a subsystem of the complex system collapses due to collapses of a neighbouring subsystem. The other subsystems collapse like a chain reaction, eventually the whole complex system crashes down. This property of complex system is called brittleness (Li Qi, et al., 2005). The brittleness of complex system reflects the influence on the performance between subsystems, and the influence of subsystem on the performance of the whole system.

System crashes (Wang Song, Wang Ying, 2011): set a complex system with input x_i $(i=1,2,\cdots,m)$, output as y_j $(j=1,2,\cdots,n)$. When $\forall 1 \leqq j \leq n$, $y\_j=0$, the corresponding state is a safe state, which shows that the output of the system is normal; when $\exists y\_j=1$, $1 \leqq j \leq n$, the corresponding state is a collapsing state, which indicates that the output of the system is abnormal. For $\forall x\_i \in$, the state of the system is safe, as long as $\exists x\_i \notin$, the system will collapse.

2.1. BRITTLENESS ANALYSIS OF THE UNIVERSITY CAMPUS SYSTEM

The University campus system is a complex system. Generally speaking, the university campus system is mainly composed of the pedestrian subsystem, the export subsystem, the transportation subsystem, the channel subsystem and the management and control subsystem, but each subsystem contains a lot of elements, and the relationship between the elements is really complex. When an external factor disturbs a part of the subsystems in the university campus system, because of the correlation between the subsystems, it also affects other subsystems, causing the other subsystems to crash. If the collapse effect reaches a certain extent, the whole system crashes. So brittleness is one of the major characteristics of the university campus system.

The collapse of the university campus system is caused by the interaction of its subsystems. The mode of interaction between the subsystems has a great influence on the system crash. The main modes of the subsystems are as presented in Fig. 1.

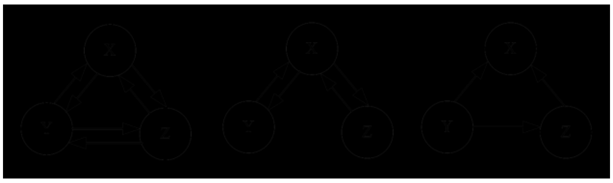

Fig. 1. The mode of interaction between the subsystems (a) complete brittleness (b) bilateral brittleness (c) level brittleness.

Complete brittleness is the collapse of any subsystem, which will affect the other two subsystems; bilateral brittleness means that there is no brittle connection between two subsystems in a system composed of three subsystems, but the other subsystem has brittle relation with them; hierarchical brittle relation refers to the crash that occurred under the subsystems, and that will not affect the upper subsystem, while the upper subsystem collapse will affect the lower subsystems.

3. SELECTION OF SAFETY EMERGENCY EVACUATION PATH BASED ON IMPROVED ANT COLONY ALGORITHM

The brittle nature of the university campus makes it a collapse tending system. The trend can be delayed through a certain technical measures.

The brittleness of the system can be represented by a weighted directed graph G, whose subsystem is abstracted as the vertex of G, a path that connecting all the culminated vertices is the collapse path of the system. The brittleness of the system leads to the inevitability of the existence of the collapse path.

3.1. CONCEPT DEFINITION

1. Hamilton path. Let G be a directed graph, where V1 and V2 are the two vertices of G, and if there is a directed edge H starting from V1 to V2 and passing through the other vertices of the directed graph G once and only once. H is then called a Hamilton path with directed edge from V1 to V2 in directed graph G.
2. Collapse path H. Since the Hamilton path of directed graph G is a starting point from one of its vertices, the collapse effect is transmitted through the directed edge H, then, chain reaction, and the other subsystem collapses under the influence factor. Finally, the whole system collapses. The Hamilton path H is called a crash path of the directed graph G.
3. Collapse path H. If the Hamilton path transmits the collapse effect from a starting vertex in the directed graph G to other subsystems through chain reaction, resulting a whole system collapse, then the Hamilton path H is called a crash path of the directed graph G.
4. The weight of the crash path H. The weight of the crash path H is denoted as WH, which is the product of all the edge weights in a path H = Vi1 Vi2 ... Vin. WH is the occur probability of the path H due to the collapse of the starting point. Let Vi1 → Vi2 → ... → Vin be the direction of the system crash process, assuming that the collapse of the vertices only affect the adjacent vertices. Here:

$$W_H = P\left(B_{i_n} B_{i_{n-1}} \cdots B_{i_1} \vee B_{i_1}\right) \tag{1}$$

where:

Bi represents the crash of event i. From (1), it can be derived as follows:

$$W_H = P\left(B_{i_n} B_{i_{n-1}} \cdots B_{i_1} \vee B_{i_1}\right) = \frac{P\left(B_{i_n} B_{i_{n-1}} \cdots B_{i_1}\right)}{P\left(B_{i_1}\right)}$$

$$\frac{P\left(B_{i_2} B_{i_1}\right)}{P\left(B_{i_1}\right)} \frac{P\left(B_{i_3} B_{i_2} B_{i_1}\right)}{P\left(B_{i_2} B_{i_1}\right)} \cdots \frac{P\left(B_{i_n} B_{i_{n-1}} \cdots B_{i_1}\right)}{P\left(B_{i_{n-1}} \cdots B_{i_1}\right)}$$

$$P\left(B_{i_2} \vee B_{i_1}\right) P\left(B_{i_3} \vee B_{i_2} B_{i_1}\right) \cdots P\left(B_{i_n} \vee B_{i_{n-1}} \cdots B_{i_1}\right)$$

$$P\left(B_{i_2} \vee B_{i_1}\right) P\left(B_{i_3} \vee B_{i_2}\right) \cdots P\left(B_{i_n} \vee B_{i_{n-1}}\right)$$

$$W_{i1i2} W_{i2i3} \cdots W_i \tag{2}$$

It can be concluded, WH is the product of all the edge weights in the path.

5. Maximum crash path and minimum crash path. In all the crash paths H in graph G, the maximum weight is called the maximum crash path, is denoted as Hmax, and the minimum crash path, is denoted as Hmin. In the case of path choice for university campus emergency evacuation, the maximum crash path is the worst path, which is the most likely to cause the system to be paralyzed. The minimum crash path is the optimal path, which can effectively guide the pedestrian to evacuate safely.

Mathematical Description: the graph G has n vertices, e = <i, j> is any edge, the weight is w (e) = wij, then traverse the path H of all vertices:

$$\max_{H \in E(h)} \left(\prod\nolimits_{e \in H} w(e)\right) \text{ or } \min_{H \in E(h)} \left(\prod\nolimits_{e \in H} w(e)\right) \tag{3}$$

where:

E (H) is a collection of all the crash paths in the university campus system.

3.2.IMPROVED ANT COLONY ALGORITHM

Traditional ant colony algorithm is slow in convergence and easy to fall into the local optimal, it is not suitable to apply to the actual operation of the university campus, where the traffic information is in dynamic changes, pedestrian path selection has a certain purpose of randomness. Therefore, based on the traditional ant colony algorithm, and combined with the university actual situation of pedestrian movement in campus evacuation, we propose an improved ant colony algorithm, which determines the starting point S and the ending point of the ant colony (assuming it as pedestrian). In the initial state, all ant colonies are arranged at the starting point. Reaching the end is the final goal of ant colony, and this point is different from the traditional ant colony algorithm, in which the final goal is traversing the key point.

At the beginning of the algorithm, m ants are placed at the specified starting point S. At the same time, each ant can go to the target pixel number stored in the taboo table. At this time, the amount of pheromone on each path is equal, and the pheromone concentration *τ (i, j) = C (C* is a smaller constant). Then, each ant selects the next pixel independently, according to the amount of residual information on the path and the heuristic information (the reciprocal of the distance between two pixels). The probability *pk (i, j)* of the ant whose order number is m moving from pixel i to pixel j is:

$$p_k(i,j) = \begin{cases} \frac{[\tau(i,j)]^{\alpha}\cdot[\eta(i,j)]^{\beta}}{\sum_{l\in J_k(i)}[\tau(i,j)]^{\alpha}\cdot[\eta(i,j)]^{\beta}}, & \text{IF} j \in J_k(i) \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

where:

Jk (i) is the set of optional vertices selected by the m-th ant; τ(i, j) is the pheromone concentration in <i, j> side, a constant can be chosen as an initial value; the importance of pheromone concentration to G directed-graph in the system is reflected by parameter α, let α>0; the importance of heuristic information to G directed-graph in the system is reflected by parameter β, letβ>0; η(i, j) the heuristic information (also referred as heuristic factor), is the expectation from pixel i to pixel j. It can be obtained from formula (5).

$$\eta(i,j) = 1/d\,(i,j) \quad (5)$$

where:

d(i, j) is the distance from pixel i to pixel j.

A controllable randomly- selected route rule is applied in the process of ant choosing target pixels to ensure the correctness of selection results. That is: set controlled variable *q0 (0≤q0≤1),* before each ant choosing next pixel, a figure *q∈[0.1]* will be generated at random, then the route-choosing rule will be forwarded after the comparison between q and parameter q0:

$$j = \begin{cases} \arg\max\limits_{j\in J_k(i)} [\tau(i,j)]^{\alpha}\left[w_{\text{ij}}\right]^{\beta} & q < q_0 \\ J & \text{otherwise} \end{cases} \quad (6)$$

where:

J is a constant, selected according to the state transition rules (6).

If the m-th ant reaches the set ending point E or goes through all reachable target pixels in the taboo list, it is called the m-th ant finishes the first travel, and use the cell array *R{k, m}* to record the travel route and the two dimensional array PL[k, m] to record the travel length. When all m ants finish a travel, this iteration ends. Update the pheromones in all sides at the same time. There into, the pheromones in every side will volatilize and reduce, so let variable *1-ρ (0<ρ<1)* be the volatilization coefficient. When all ants finish their travel, the global update rule (7) is applied into pheromones update in all sides. (The increase of pheromones in side *e = <i, j>* is controlled by heuristic value):

$$\tau(i,j) = (1-\rho)\cdot\tau(i,j) + \rho\cdot\prod_{k=1}^{m}\Delta\tau_k(i,j) \quad (7)$$

(4)

$$\Delta\tau_k(i,j) = \begin{cases} w_{\text{ij}} & \langle i,j\rangle \in H_m \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

where:

△τk (i, j) is the pheromone concentration variation. The pheromone concentration variation should be counted after each round of iteration ends; wij = Q/Lk,Lk is the travel distance of the k-th ant at this time; Q is intensity coefficient of pheromone increase; Hm is the optimum route of the m-th ant at last round.

When all K rounds of iterations end, the optimal (worst) route from start point S to ending point E as well as its length can be obtained through the analysis of ant colony structure array R{k, m} and two dimensional array PL{k, m}.

The improved algorithm is applied into the process of emergency evacuation route optimization in the campus through simulation methods. That is: the obstacles will be generated with certain probability when producing maps in complex brittleness systems, to simulate the contingency in evacuation, which will be more likely to present the real circumstances of emergency evacuation in campus.

3.3. ROUTE SOLUTION FOR SAFETY EVACUATION

(6)

Matlab is applied to the programing of ant colony algorithm to work out the average length, the optimum and the worst length of emergency evacuation in the campus. Following are the specific computing processes.

Algorithm steps are given campus network with n exits.

Step 1: Parameter initialization, make sure the start point S and ending point E of the ant and convert map data to adjacency matrix, then set the initial pheromone concentration $\tau(i, j)$;

Step 2: Start K rounds of iterations;

Step 3: Put m ants at the start point S. Deposit the reachable pixels in the taboo list based on the adjacency matrix.

Step 4: Each ant moves to the next node according to formula (5), and its travel route is recorded;

Step 5: If m ants finish the travel respectively, carry out Step 6, or carry out Step 4;

Step 6: Update the pheromones in all branches using global update rules;

Step 7: If all the K rounds of iterations are finished, end the algorithm; or back to Step 3 and start the next round of iteration.

The flow chart of the improved ant colony algorithm is shown as follows Fig. 2.

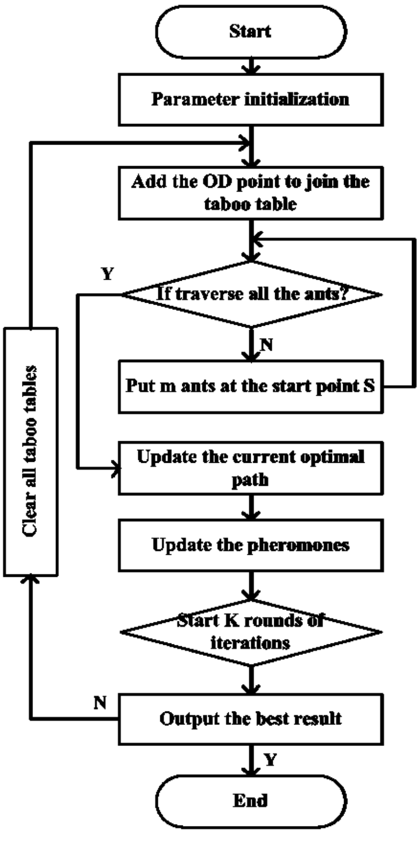

Fig 2. Flow chart of the improved ant colony algorithm.

4. CONCLUSIONS

By comparing the optimal path with the worst path, we can see that in the case where the relatively important degree of the heuristic information to the directed graph G is fixed, the walking distance attention degree and the degree of conformity have a great influence on the path selection. When the walking distance attention degree is less than 5 and the degree of conformity is greater than 0.3, the university campus safety emergency evacuation path is easy to become the optimal path; when the walking distance attention degree is less than 5, and the degree of conformity is less than 0.5, the university campus emergency evacuation path easily mutated into the worst path.

When making a selection of the university campus security safety emergency evacuation path, the optimal path is preferred as the worst path can stimulate the brittleness of system and accelerate the collapse trend of the system, resulting in paralysis of the university campus system and causing accidents.

In future studies, the factors that lead to the worst path of the university campus will be identified, clustered and analysed via case studies and use cases, e.g. shortest passenger evacuation route simulation based on improved ant colony algorithm in the scenario of Ningbo University of Technology (NBUT), shortest passenger evacuation route simulation based on improved ant colony algorithm in the scenario of University of Žilina (UNIZA), Slovak Republic and scenario of the International University of Logistics and Transport in Wrocław, Wroclaw, Poland, especially in large public places and in buildings such as cinemas, theatres, stadiums, railway stations, shopping malls, universities, civil aviation trainings centres, airports, etc.

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