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Optimization of Emergency Evacuation Strategy Based on Social Force Model

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Abstract. In order to deal with the possible terrorist attacks and other emergencies, it is particularly important to develop a reasonable evacuation plan. We develop an evacuation model to solve this problem. The evacuation model is based on social force and bottleneck evacuation model. The simulation experiments show that the social force model proposed in this paper can reproduce the evacuation behavior of the crowd in emergency situations, and the bottleneck after the transformation greatly eases the congestion of pedestrians here. The passability of pedestrians at the bottleneck and the overall speed of travel have greatly improved.

Keywords: *social force model, bottleneck evacuation model, fluid theory*

1. Introduction

In recent years, the world economy has developed rapidly and the population has grown rapidly. With the increase in the scale and structural complexity of public buildings, people pay more and more attention to the evacuation efficiency of people in the event of an emergency. Efficiency is an important part of a large security system. When there are terrorist attacks or some emergencies such as fire, earthquake, explosion and other accidents in large public buildings, if there is no corresponding plan for emergency evacuation of people, it will seriously threaten the public interest and life safety of the people. In order to respond to the above-mentioned sudden accidents scientifically, quickly and efficiently, to avoid major casualties and economic losses, and to evacuate personnel quickly and efficiently, it has become an urgent problem to be solved. At present, domestic and foreign scholars have done some significant analysis and research. This paper comprehensively improves the emergency evacuation efficiency by using the improved social force model and bottleneck evacuation model.

2. Social Force Model based on Obstacle Avoidance Strategy

In general, no matter how complex the behavior of pedestrians is in an emergency, the purpose of movement is unique, that is, to constantly adjust the evacuation strategy to evacuate the scene with the minimum cost. But pedestrian evacuation slightly planning and adjustment depends largely on the traveler's own factors, synergy between pedestrians and the adequacy of the cognition of evacuation surroundings, so the analysis of the factors that influence efficiency of pedestrian evacuation, and build the relationship between people is key to the study of emergency evacuation behavior, here we consider a kind of social force model based on the strategy of obstacle avoidance[1].

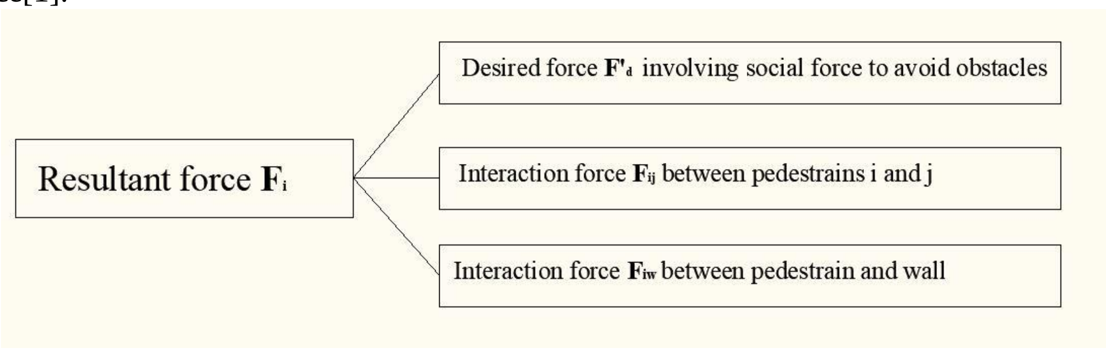

Fig 1. Parts of resultant force

In this model, pedestrians are drived mainly by three forces, namely, desired force $F_d^{'}$, interaction force F_{ij} between pedestrians i and j, and interaction force F_{iw} between pedestrian and wall. According to Newton's second law of motion, the resultant force F_i [2]is expressed as below:

$$F_i = F_d^{'} + F_{ij} + F_{iw}$$

2.1 Desired Force F' d Involving Social Force to Avoid Obstacles

The desired drive is the force that moves people toward the desired exit. Considering the presence of complex obstacles in the evacuation process, the desired force is improved and we get equality of desired force involving social force to avoid obstacles[3].

$$F_d = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{T_i}$$

Where m_i is the weight of pedestrian i. v_i^0 (t) is the desired speed, e_i^0 (t) is the desired , and T_i is the time it takes for pedestrians i to accelerate from v_i to v_i^0 .

$$F_d^{'} = g(ds)(e^{-ds}F_d + (1-e^{-ds})\|F_d\|P_d) + (1-g(ds))F_d$$

In the formula, ds refers to the distance from the pedestrian to the first obstacle in the direction of movement. When there is no obstacles in the direction of movement, ds is 0. And Pd is the tangent direction for pedestrians to avoid obstacles.

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$$P_d = (\cos(\theta + \alpha\frac{\pi}{2}), \sin(\theta + \alpha\frac{\pi}{2}))$$

$$g(ds) = \begin{cases} 1, & ds \neq 0 \\ 0, & ds = 0 \end{cases}$$

Where θ refers to the angle between the pedestrian's position and the first obstacle encountered in the direction of motion and α is tangent to θ.

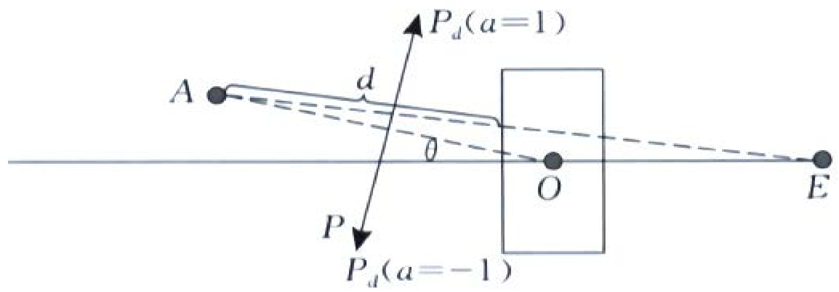

Fig 2. Schematic diagram of pedestrian obstacle avoidance process parameters

A is the position of the pedestrian, O is the center of the obstacle, E is the exit, and the straight line P is perpendicular to the straight line AO. a indicates the direction of pedestrians bypassing obstacles. Pd indicates the direction of the bypass, and a takes a value of 1 or -1, indicating that the pedestrian will bypass the obstacle from the left or right side.

2.2 Interaction Force F_{ij} Between Pedestrians i and j

The psychological tendency of two pedestrians to move away from each other can be described by repulsive forces. If pedestrians collide with each other in the case of emergency evacuation, two additional forces need to be further considered: the body force against other pedestrians and the sliding friction force to prevent relative tangential motion. Therefore, the interaction force between pedestrian i and pedestrian j can be express as below[4]:

$$F_{ij} = A_i e^{(r_{ij}-d_{ij})/B_i} n_{ij} + kg(r_{ij}-d_{ij})n_{ij} + \kappa g(r_{ij}-d_{ij})\Delta v_{ji}^t t_{ij}$$

Where A_i,B_i, k, κ are contants, d_{ij} is the distance between pedestrian i and pedestrian j, r_{ij} is the radius sum between two interacting pedestrians, n_{ij} represents the unit vector from pedestrian j to pedestrian i, t_{ij} represents the tangential vector from pedestrian i to pedestrian j, and Δv_{ji}^t is the tangential relative velocity. When there is no contact between pedestrians, the value of function g(x) is 0.

2.3 Interaction Force F_{iw} Between Pedestrian and Wall

Interaction force between pedestrian and wall F_{iw} is similar to F_{ij} . We can get similar equality as follows:

$$F_{iw} = A_i e^{(r_i-d_{iw})/B_i} n_{iw} + kg(r_i-d_{iw})n_{iw} + \kappa g(r_i-d_{iw})(-v\, t_{iw})t_{iw}$$

Where d_{iw} is the distance between pedestrian i and wall, n_{iw} is the unit vector perpendicular to the wall and t_{iw} is the direction tangent to the wall. The above analysis is based on a two-dimensional space in which the velocity v has components in the X-axis and Y-axis directions.

$$|v_i| = \sqrt{v_x{}^2 + v_y{}^2}$$

3. Bottleneck Competitive Evacuation Model

When there are disabled tourists or there is a conflict between tourists, it is easy for bottleneck effect to occur at the gate during emergency evacuation. The most significant sign of bottleneck in the process of evacuation is the increase of pedestrian density and the decrease of evacuation speed. The schematic is as follows:

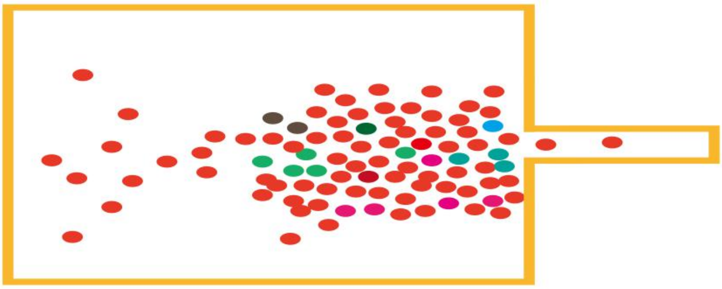

Fig 3. Diagram of competitive behavior at the bottleneck

We conclude that the emergency evacuation ability of the bottleneck competitive behavior is closely related to the daily emergency evacuation training of pedestrians and the rationality of the bottleneck design.

Based on the relevant fluid theory knowledge, we transform the bottleneck as shown in the figure below[5]:

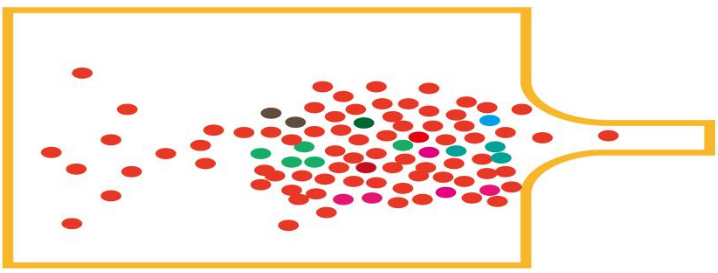

Fig 4. The bottleneck diagram after transformation

4. Simulation and Results Analysis

With the help of anylogic software, the basic scene evacuation simulation is carried out, taking the two evacuation models introduced in this paper into account, and then combining with queuing theory, the simulation of pedestrian at 90%, 80% and 70% of the maximum flow and the maximum flow is carried out, and the process data of evacuation simulation is collected and analyzed. By comparing the original evacuation time and the optimized evacuation time, the optimized evacuation effect is found. The rate has improved significantly. Therefore, the optimized evacuation model provides effective suggestions for evacuation strategy in emergency.

5. Conclusion and Prospects

5.1 Conclusion

This paper improves the evacuation efficiency of pedestrian flow when considering the social evacuation model and the bottleneck evacuation model established by considering various factors affecting pedestrian route selection, and provides a reference for evacuation strategies in emergencies.

5.2 Prospects

(1)In the simulation study of pedestrian complex movements, it did not take into account that pedestrians may fall to form new bottlenecks. In further studies, the probability of an individual having an accident such as a fall is judged by comparing the individual's stay time with the average length of stay of the person[3].

(2)In the process of model building, the guiding role of the evacuation staff was not taken into account, so that the simulation scenario did not fully meet the actual situation.

Further development of these tasks will help to study the internal relationship between evacuation scenarios, evacuation strategies and evacuation efficiency in emergencies, and provide evacuation plans for improving evacuation efficiency and reducing losses under emergencies.

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