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RESEARCH ARTICLE

Research of Crowd Evacuation Simulation Based on the Machine Learning

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A majority of existing evacuation models overlooked the pedestrian's social relationship and their learning ability. In this paper, we made two improvements base on the social force model. First, a new force called group relationship force was added to the social force model. Pedestrians who have close relationship could gather into a group and walk together. Second, the machine learning was introduced to the improved social force model to represent pedestrian's learning and cognitive ability. In the improved model, pedestrians could store the evacuation route to the knowledge base, and next time they can choose a best path to evacuate according to their knowledge. Simulation results show that the new method could better to avoid obstacles and save evacuation time. Furthermore, this improved model is applied to the simulation system of Ji'nan Springs Plaza for predictive evacuation experiments.

Keywords: Social Force Model, Crowd Evacuation, Social Relationship, Machine Learning.

1. INTRODUCTION

Recently, the development of crowd evacuation simulation has been a pop research area in traffic science and engineering. A research report has shown the significance of this issue in Ref. [1]. In public places, such as supermarkets and subway stations, a proper evacuation method can save many lives in emergencies. Therefore, planning emergency evacuation as designing buildings is crucial aspect of public security. To solve the problem of crowd emergent evacuation in complex buildings, many methods have been proposed. However, there are still many shortcomings. Pedestrians are not discrete particles. Their complex relationships will affect their movement. Moreover, pedestrian's cognitive and learning ability has been neglected in most of the evacuation model.

To make the evacuation simulation more realistic, an improved method based on the social force model was proposed in this paper. First, describing the relationship between pedestrians by a matrix, and the relationship is quantified to value between 0–1. The group relationship force was added to primary model, which means pedestrians who have a large relationship values will gather into one group. Furthermore, pedestrians who are in same group are leaded by the team leader, and the team leader has the largest summation relationship values with other pedestrians. Second, the machine learning was introduced to the social force model to perform pedestrians' cognitive and learning ability. In the improved evacuation model, pedestrians were able to avoid obstacles ahead. Simulation results also show that the new method could save evacuation time.

2. RELATED WORK

Currently, there are two types of the crowd evacuation models, macroscopic model and microscopic model.[2] One of the classical macroscopic model is the fluid dynamics model.[3] Pedestrians are treated as fluid with the use of partial differential equation, and their dynamic characteristics are described by average speed, density, etc. Therefore, detailed behaviors and interactions of the crowd will be overlooked in the macroscopic model. This is the reason why we chose microscopic model to improve. Unlike macroscopic model, microscopic model could batter reflect the details of the evacuation. The cellular automaton model[4] and the lattice gas model are famous microscopic discrete model. The social force model is the continuous model which was proposed by Helbing.[5] Social force model could describe the movement real because it considers both psychological and physical forces. We can also use the Newton's second law to analyze the pedestrians' movement.

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Some related studies of scholars concentrated on the individual in social force model. In Ref. [6], Yuan investigated the effect of the visibility range and the guiders in the panic evacuation process, and they found that leaders could accelerate the dynamic efficiently. In Ref. [7], Hou studied the influence of the number and location of evacuation leaders, and they concluded that we should set as many leaders as the number of exits in the center of the multi-exits. In Ref. [8], Yang improved the social force model, and a leader was added into the model. Pedestrians will be attracted by leader and follow the leader. In Ref. [9], Helbing introduced the vision field by defining a term to the socio-psychological force in the original social force model that could reflect the anisotropic character of pedestrian interaction. In Ref. [10], Hughes investigated how to choice a route by using a continuum model based on well-defined observations of pedestrian behavior. In Ref. [11], pelechano studied the process of way-finding in a complex building with limited visibility where normal pedestrians could communicate with some trained leaders who definitely knew where the exits were. In Ref. [12], Parisi introduced a self-stop mechanism to prevent a simulated pedestrians from continuously pushing over other pedestrians. In Ref. [13], Lv improved the model by adding a relationship attractive force.

The rest of this paper is as follows. A modified social force model is proposed in Section 3, which considers that pedestrians who have close social relationship will form groups. Section 4, we combined the machine learning with the improved social force model. Pedestrians could learn knowledge from the evacuation and choose a best path to leave. Section 5 verifies the improved model by comparing its pedestrians formation diagrams with fundamental diagrams and studies the effects of the group relationship force for the evacuation crowd, as well as analyzes the effect of machine learning on the evacuation time and pedestrians evacuate formation through simulations. In the end, evacuation experiments with improved social force model are done based on the simulation system of Ji'nan Spring City Square.

3. MODEL AND MODIFICATION

3.1. Social Force Model

The social force model is proposed by Helbing. To describe the pedestrians' movement, three forces were added to the model. The three forces were the desire force f_i^0, the interaction force f_{ij} in pedestrians, the interaction force f_{iw} between pedestrians and obstruction. After quantifying the three force, the corresponding mathematical expression of each pedestrian i is

$$m_i \frac{dv_i(t)}{dt} = f_i^0 + \sum f_{ij} + \sum f_{iw} \tag{1}$$

m_i means the mass of pedestrian i, and $v_i(t)$ is the pedestrian i velocity.

Desire force reflects pedestrians willingness to a target position. This force is expressed as follow:

$$f_i^0 = m_i \frac{v_i^0 e_i^0 - v_i(t)}{t_i} \tag{2}$$

Each pedestrian moves with a certain desired speed v_i^0 and a certain desire direction e_i^0. Pedestrian adapt real velocity v_i to the desired velocity v_i^0 in time t_i.

Interaction force between pedestrians contains soci-psychological force f_{ij}^s and physical force f_{ij}^p. Pedestrians have tendency to stay away from each other to avoid collision when they walk. We express the soci-psychological force by f_{ij}^s. The physical force means when the distance of two pedestrian i and j is too close, they have a extrusion force f_{ij}^{p1} and friction force f_{ij}^{p2} between them. So the soci-psychological force expression f_{ij}^s has the following form:

$$f_{ij} = f_{ij}^s + f_{ij}^p \tag{3}$$

$$f_{ij}^s = A_i \exp[r_{ij} - d_{ij}/B_{ij}]n_{ij} \tag{4}$$

$$f_{ij}^p = f_{ij}^{p1} + f_{ij}^{p2} \tag{5}$$

Interaction force between pedestrian i and walls were f_{iw}, can be given by

$$f_{iw} = A_i \exp[(r_i - d_{iw})/b_i]n_{ij} + kg(r_i - d_{iw})n_{iw} + kg(r_i - d_{iw})\Delta v_{iw}^t t_{iw}$$

3.2. Modification

The primary social force model ignored social contact between pedestrians, and considered pedestrians are independent. Only a repulsive force is set for maintain a safe distance. Moreover, the pedestrians are regard as exactly same individual when we calculate the force between pedestrians. Actually, pedestrians speed is influenced by their nervousness and neighbors' speed. The force between individuals is certainly different in real life. For example, pedestrians are more likely to be influenced by family and friends. Therefore, the primary model has been improved from the following aspect.

3.2.1. The Team Leader and Pedestrians' Relationship

The pedestrian's relationships were quantified to a value between 0–1, and stored in a two-dimensional array g_{ij}. A larger g_{ij} value means pedestrian i and j have a closer relationship. They may be friends or family. We assume that the leader have the largest summation relationship values with other pedestrian. Leaders could gather the pedestrians into one group and leaders evacuation paths could almost represent other pedestrians.

3.2.2. The Improvement of Desire Velocity

In primary social force model, pedestrians' desire velocity v_i^0 is determined by the force that they suffered. But in the real situation, pedestrians' desire velocity may be affected by their nervousness and the average speed of the group which they belong to. According to Ref. [14], pedestrian's desired velocity often changes based on his or her nervousness. The parameter:

$$n_i(t) = 1 - \frac{v_{id}(t)}{v_i^0(0)} \tag{6}$$

is used to reflect the nervousness, where $v_{id}(t)$ is the projection value of the velocity at the desire direction, and $v_i^0(0)$ is the original desired velocity. Then, the desired velocity $v_i^0(t)$ is updated by

$$\begin{gathered} v_i^0(t) = \alpha v_i^0(0) + \beta\{\overline{v_g(t)}\} + n_i(t)v_i^{\max} \\ \alpha + \beta + n_i(t) = 1 \end{gathered} \tag{7}$$

In the formula (7), the desired velocity is updated by $v_i^0(0)$, $\{\overline{v_g(t)}\}$ and $n_i(t)v_i^{\max}$. $v_i^{\max}$ is the maximum desired velocity, $\{\overline{v_g(t)}\}$ is the average speed around the pedestrian i. α, β is parameter to adjust their weights.

3.2.3. The Improvement of Group Force

There are complex social relationships between pedestrians, and people who have a more intimate relationship will form groups. To make the simulation truly, we add a group relationship force to the primary social force model. The group force could assemble the pedestrians. In mathematical, the group force is given as:

$$f_{ij}^g = g_{ij}\exp[(r_{ij} - d_{ij})/D_i]n_{ij} \tag{8}$$

Where g_{ij} describe the weights of the pedestrian i and pedestrian j relationship, D_i is the minimum safe distance, and n_{ij} is a direction which point to leader. So the improved social force model is given by the equation:

$$m_i\frac{dv_i(t)}{dt} = f_i^j + \sum f_{ij} + \sum f_{iw} + f_{ij}^g$$

In the improved model, pedestrians who have a closer relationship will form a group and walk together. Group members will adjust their speed to suit group speed, and group members will be leaded by the group leader. The evacuation simulation is more real than before.

4. ROTE LEARNING

The rote learning model is used to represent the learning ability of pedestrians. As part of the actuator could solve the problem, the system is simply records the solution of the problem in the memory, when faced with a similar problem again, the actuator part directly retrieves the problem from the memory and solved it. The ultimate goal of crowd evacuation simulation is to avoid collision with obstacles, and evacuate to safe area in certain scenarios finally. In the same scene, if the pedestrians have evacuated before, they will choose the best path according to their past experience. The evacuation route is recorded, and then the results are retrieved at the time of need. At this point, the rote learning is completely able to meet. Therefore, this paper chose the rote learning as the basic model. The process of rote learning is shown in Figure 1.

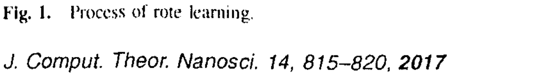


Fig. 1. Process of rote learning.

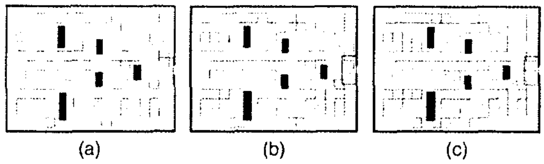


Fig. 2. The learner learn evacuation path.

4.1. The Learner

In the primary social force model, the previous evacuation process has not any help to the subsequent evacuation even in the same scene. In reality, with the number of evacuation times increased, people will gradually accumulate experience and knowledge of the evacuation. They could avoid obstacles in advance, and choose a closer evacuation route according to past experience and knowledge. Therefore, each time we finished an evacuation simulation. The learner will storage follow information as knowledge for subsequent use: the group leaders' evacuation path, the initial coordinates of the leader, the evacuation time, the number of pedestrians in evacuation.

Figure 2 shows the evacuation path that learner have learned. The evacuation path which learner learned almost covers the whole scene as shows in Figure 2(c).

4.2. Knowledge Base

Knowledge Base is used to store the pedestrians' evacuation experience and knowledge learned from learner. The knowledge is actual an evacuation path in the specific environment. It is considered that the pedestrians in the same group, the movement process is basically similar. Furthermore, the leaders' evacuation path were chosen to represent the groups evacuation experience and record it. The data structure of pedestrian knowledge is shown in Table 1.

Table 1. The data structure of pedestrians knowledge.

Variable names	Variable type	Variable description
P	point	The leader's coordinates
N	int	The number of evacuated people
T	int	Evacuation time
Path	txt	The leader evacuation path

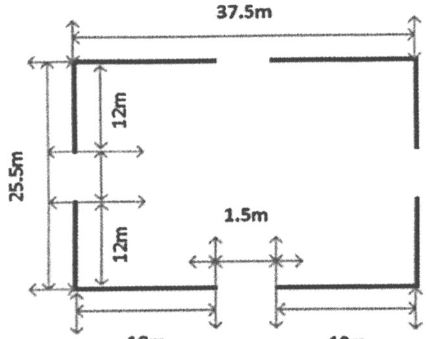


Fig. 3. A scene of simulation: four-exits room.

These information was used to measure which path should be chosen. Variable P is the first point in the leaders' path. The path we chose in the knowledge base should has the nearest start position. N is the number of person in the group. T is the evacuation time. Path is a txt file which stored the coordinates of evacuation routes.

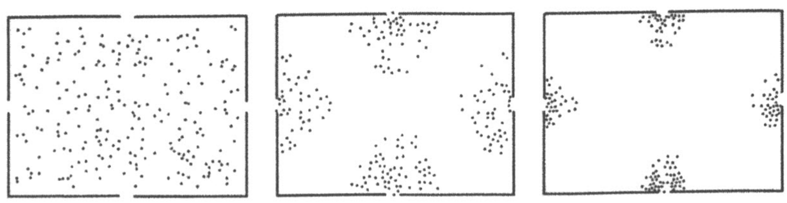
4.3. The Actuator

Each time the learner has to recalculate the pedestrian's evacuation routes and store the leader path in knowledge base. Unlike the learner, the actuator chose the leading path from knowledge base directly. The working process of the actuator is as follows: first, the pedestrians are divided into groups according to relationship value, and each group has a leader. Second, choosing the most appropriate evacuation path from the knowledge base. The path should have approximate starting point with the group leader, and evacuation time is as short as possible. Then, the pedestrians are directed to the safe area along the path.

5. SIMULATION

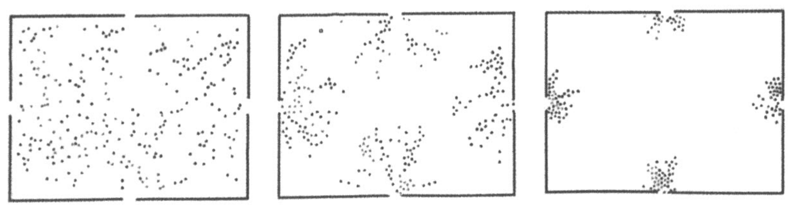
These experiments build a crowd evacuation simulation system by using Visual Studio 2012 as platform. Experiment environment is shown in the Figure 3. The room has four exits, and each exit has the same width, 1.5 m. In our simulations, the parameters are set as follows: the Individual radius: $r = 0.25$ m, Individual quality: $m = 80$ kg, Individual expectations velocity: $v_i^0 = 0.8\ \text{m}\cdot\text{s}^{-1}$, Social Force model constants: $k = 1.2 \times 10^5\ \text{kg}\cdot\text{s}^{-2}, k = 2.4 \times 10^5\ \text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$, $A = 2000$ N, $B = 0.08$ m, $C = 2000$ N, $D = 0.05$ m, $\alpha = 0.7$.

In order to show the influence of crowd including a certain number of people having relationships with others, following experiments would be made. The number of evacuation pedestrians was set from 100 to 500. To display different crowd evacuation effect by using social force model and improved model, we make a comparison experiment with 300 people. The layout of the simulation scenario is illustrated by Figures 4 and 5. Pedestrians show in Figure 4(a) without social relationship and they are discrete, independent. Figure 5(a) show that pedestrians who have closer relationships are set same colors. The evacuation effect graph is shown as Figures 4(b) and 5(b) when $t = 30$ s. Figure 4(b) shows that pedestrians would occur aggregation and jams more earlier than pedestrians with relationship. As is illustrated in Figure 5(b), the



(a) Snapshot of initialization of crowd simulation (b) Snapshot of crowd simulation when t=30s (c) Snapshot of crowd simulation when t=50s

Fig. 4. Snapshot of the simulation by using original social force model in four exits room.



(a) Snapshot of initialization of crowd simulation (b) Snapshot of crowd simulation when t=30s (c) Snapshot of crowd simulation when t=50s

Fig. 5. Snapshot of the simulation by using crowd evacuation model based on grouping and guiding in the single.

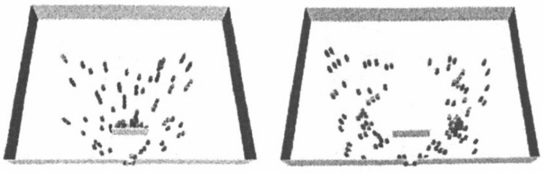


Fig. 6. The contrast of evacuation with machine learning and without machine learning.

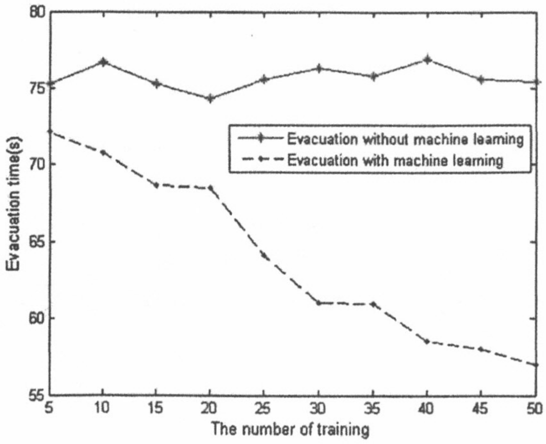


Fig. 7. The experimental results of evacuation time in single-exit room.

movement trend of pedestrians of the same color is getting together gradually. Besides, pedestrians in same group would stay away from other groups and they would move together as a group. The evacuation effect graph is shown as Figures 4(c) and 5(c) when $t = 50$ s. Arching effect is formed nearby the exit of environment in both graphs. It can be seen that the new model have no influence on the characteristic of social force model.

In Figure 6, the size of the room is as same as room show in Figure 3, length 37.5 m, width 25.5 m, gate width 1.5 m. Other parameters are also same as above. The difference is that room in Figure 5 has one exit, and a obstacle is set at a distance of 5 m at the exit. Pedestrians showed in Figure 6(a) does not have evacuation experience. Some of them are blocked in the outside. Some pedestrians take a long time to evacuate, and even some of the pedestrians' evacuation is not successful. This is because the three forces: desired force f_i^0; the interaction force between pedestrians i and jf_{ij}; the interaction force between pedestrian i and walls f_{iw}, have reached a balance state. In other word, pedestrians could not move. Figure 6(b) showed the pedestrian's evacuation results after 20 times machine learning training. As is shown in graph, leaders have already known there are obstacles in the scene. Therefore, pedestrians could avoid obstacles smoothly, and shorten the evacuation time.

Figure 7 shows the relationship between the evacuation time and the number of training times. Here, we can see the evacuation process without machine learning, the evacuation time tends to be stable. It can be comprehended that training times has no effect on it. It is obviously that evacuation process with machine learning is influenced by the training times. With the increase of the number of training, the evacuation time was shortened. This is because leader could find an optimal evacuation path from the past experience. It is worth noting that evacuation with machine learning save 19 s than evacuation without machine learning at 50 training times. In case of emergency, many people could save their lives in 19 s.

Using the modificate social force model which leaders have the ability to learn and accumulated evacuation

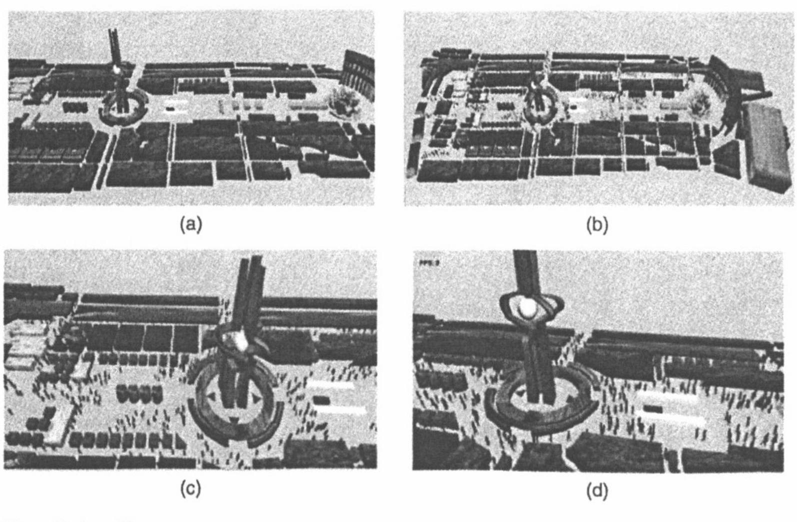


Fig. 8. Evacuation in Ji'nan Springs Plaza.

experience, we do evacuation experiments based on the simulation of Ji'nan Springs City Square for multiple pedestrian groups as Figure 8 shows. Figure 8(a) is the scene of simulation. Figure 8(b) shows the initialization state of the crowd. People's location includes all roads and exits of teaching building. The evacuation effect graph is shown as Figure 8(c) at some time. A close angle graph in process is shown in Figure 8(d).

In this scene, 26 s can be save when we evacuate pedestrians 50 times. The results of simulation experiments indicated that the improved model is feasible and effective. The research provides a fundamental theoretical for making emergency plan.

6. CONCLUSION

A modification method of pedestrian dynamics based on the social force model is introduced in this paper aiming at making pedestrian dynamics more realistic. Then, the modified model is applied for modeling the guided pedestrian by defining the leader's knowledge. The superiority of the leader's knowledge is validated by comparing its evacuation time and the ability of avoid obstacles with fundamental diagrams. Pedestrians would consume less evacuation time and be easier to avoid obstacles. Moreover, the more complex scenes, the less time it takes to evacuation. Finally, we found that leaders with knowledge would play essential roles for efficient and orderly pedestrians' evacuation through doing evacuation experiments based on the simulation system of Ji'nan Springs City Square.

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References

1. P. Kachroo, S. J. Al-Nasur, S. A. Wadoo, et al., Pedestrian dynamics: Feedback control of crowd evacuation, Springer Science and Business Media, New York **(2008)**, pp. 5–9.
2. X. Zheng, T. Zhong, and M. Liu, *Building and Environment* 44, 437 **(2009)**.
3. R. L. Hughes, *Annual Review of Fluid Mechanics* 35, 169 **(2003)**.
4. W. Song, Y. Yu, and W. Fan, *Science in China Ser. E Engineering and Materials Science* 48, 403 **(2005)**.
5. D. Helbing, I. Farkas, and T. Vicsek, *Nature* 407, 487 **(2000)**.
6. W. Yuan and K. H. Tan, *Current Applied Physics* 9, 1014 **(2009)**.
7. L. Hou, J. G. Liu, and X. Pan, *Physica A Statistical Mechanics and Its Applications* 400, 93 **(2014)**.
8. X. Yang, H. Dong, and Q. Wang, *Physica A: Statistical Mechanics and Its Applications* 411, 63 **(2014)**.
9. D. Helbing, I. J. Farkas, and P. Molnár, *Pedestrian and Evacuation Dynamics* 21, 21 **(2002)**.
10. R. L. Hughes, *Mathematics and Computers in Simulation* 53, 367 **(2000)**.
11. N. Pelechano and N. I. Badler, *IEEE Computer Graphics and Applications* 26, 80 **(2006)**.
12. D. R. Parisi, M. Gilman, and H. Moldovan, *Physica A: Statistical Mechanics and Its Applications* 388, 3600 **(2009)**.
13. Y. Y. Lv, H. Liu, and D. J. Lu, *Journal of Computational Information Systems* 11, 7553 **(2015)**.
14. D. Helbing, L. Buzna, and A. Johansson, *Transportation Science* 39, 1 **(2005)**.

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