Modeling Pedestrian Group Behavior in Crowd Evacuations

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Abstract. In the process of evacuation, individuals will group according to the close relationship, so grouping behavior is a factor that cannot be ignored in crowd evacuation simulation. At present, the method for crowd simulation is considered grouping only based on distance, without considering the relationship between individuals. Because of the above shortcomings, this paper considers the influence of location similarity, velocity similarity, and motion direction similarity on evacuation, and proposes an improved K-Medoids algorithm, which considers three different eigenvalues. After the crowd is clustered, the intra-group attraction is added to improve the social force model. In order to verify the effectiveness of the proposed method, multiple sets of experiments are designed. The results illustrate that the proposed method can improve evacuation efficiency. It is more in line with the crowd evacuation behavior in the real environment.

Keywords: Crowd evacuation · Grouping behavior · Social Force Model · K-Medoids

1 Introduction

Most of the individuals in the group have a 'herd mentality' [1]. Due to the existence of 'herd mentality', pedestrians who are closely related will show a trend of aggregation during the evacuation. This phenomenon is called 'group behavior' in this paper (see Fig. 1). The crowd is often composed of several small groups under the influence of specific factors such as egress location and evacuation path [2].

At present, among the models of evacuation, the social force model [3] is more typical. It is simple to model, and can simulate the phenomena of 'egress arching' and 'fast is slow'. However, it cannot simulate the group movement based on social relations in emergencies.

To truly simulate the group behavior, this paper uses the clustering method in the field of data mining to group individuals. The grouping information is provided to the improved social force model (ISFM) to simulate the group movement. To obtain the simulation results of real crowd behavior, people usually think of a method to obtain various parameters in the crowd movement through real-person simulation exercises

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Fig. 1. Screenshots of evacuated small groups

[4], and then apply them to the simulation algorithm. However, this method requires a lot of manpower and resources [5], and it is difficult to fully guarantee the safety of participants, so it is not suitable for the simulation of large-scale crowds. In this paper, computer simulation technology is used as an effective means to study crowd behavior, which overcomes the deficiencies of the real-person exercise method [6]. It is an effective way to prevent and solve the frequent public safety problems in the current society by simulating the individual behavior characteristics and movement rules of the evacuation crowd during the emergency [7].

The following of this paper is organized as follows. Section 2 is the method for pedestrian groups based on the K-Medoids algorithm and improved social force model (ISFM). In Sect. 3, we evaluate the proposed method to demonstrate its performance. Next, the social force model (SFM) and its improvement are simulated and compared. The conclusions are drawn in Sect. 4.

2 Methodology

2.1 Group Division

It is generally believed that the higher the similarity of individual behavior, the easier it is for pedestrians to gather [8]. Therefore, we quantify the pedestrian consistency from three aspects: position, speed size and speed direction.

1. Positation: Distance is used to calculate the position of individuals i and j. The smaller the value, the more similar.

$$dist(i,j) = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{1}$$

2. Speed size: A function is defined to represent the speed similarity between individual i and individual j.

$$vel(i,j) = \frac{1}{1 + e^{-\left(v_i - v_j\right)^2}} \tag{2}$$

   where $\left(v_i - v_j\right)$ denotes the speed difference between individuals i and j. In order to make the difference more significant, the square difference is calculated. At the same time, we use the Sigmoid function to map the value to [0, 1]. The smaller the value, the more similar.

3. Speed direction: The function is defined to represent the direction similarity between individual i and individual j.

$$ori(i,j) = \frac{o_i \cdot o_j}{|o_i||o_j|} \tag{3}$$

where o_i and o_j are the direction vectors of individuals i and j, respectively. The larger the value, the more similar.

Reference [6] proposed an algorithm to calculate the dissimilarity between individuals. Based on the social comparison theory in the literature, this paper considers the influence of location, speed, and direction on the clustering results to calculate the dissimilarity between individuals. The magnitudes of distance, velocity, and direction are different, and the three factors need to be normalized. Therefore, the improved dissimilarity is defined as:

$$dif = k_1 \times \frac{1}{dist(i,j)} + k_2 \times \frac{1}{vel(i,j)} + k_3 \times ori(i,j) \tag{4}$$

where k_1, k_2, k_3 denote the weight of position, velocity, and direction respectively. $k_1 + k_2 + k_3 = 1$.

We use an improved K-Medoids algorithm to group the population. The influence of position, velocity, and direction between individuals on the movement is considered. The improved K-Medoids algorithm weights three different types of values.

2.2 ISFM

The original SFM takes into account the individuals' self-driven force, the interactive force with other individuals, and the interactive force with the obstacles during individuals' movement. The SFM is defined as below:

$$\frac{md^2\overrightarrow{r}}{dt^2} = \overrightarrow{F}_i^0 + \overrightarrow{F}_{ij} + \overrightarrow{F}_{iw} \tag{5}$$

where $\overrightarrow{F}_i^0$ represents the self-driven force of individual i; $\overrightarrow{F}_{ij}$ is the interactive force that pedestrian j exerts on i; $\overrightarrow{F}_{iw}$ is the interactive force that obstacle w exerts on pedestrian i.

In the crowd evacuation model, individuals can usually be abstracted as particle model, ellipse model, circular model, square cell, and so on without considering the radius [9]. Considering the complexity of the agent's behavior and the accuracy of the model, this paper adopts the individual fan vision model, as shown in Fig. 2.

1. Self-driving force

Individuals are driven by self-driving forces to evacuate to the target location at the desired speed. The self-driving force is given,

$$\overrightarrow{F}_i^0 = \frac{m\left(v^d \overrightarrow{e}_i^d - \overrightarrow{v}_i\right)}{\tau} \tag{6}$$

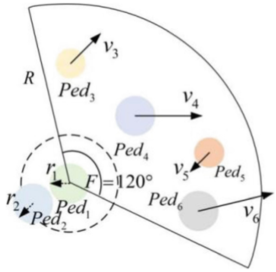

Fig. 2. Fan vision.

where m is the mass of people and equals 50–80 kg;v^d is the desired velocity; $\overrightarrow{v}_i$ is the actual speed; $\overrightarrow{e}_i^d$ is the desired direction; τ is the response time and equals 0.5 s.

2. Interaction force among evacuees

Evacuees will keep a certain distance from their neighbors, representing a psychological repulsion in the SFM.

$$\vec{F}_{ij} = \vec{F}_{ij}^{avoidance} + \vec{F}_{ij}^{compression} + \vec{F}_{ij}^{friction} = A_{ij} \cdot exp\left(\frac{(r_{ij} - d_{ij})}{B_{ij}}\right)\vec{n}_{ij} + k_c g(r_{ij} - d_{ij})\vec{n}_{ij} + k_f g(r_{ij} - d_{ij})\Delta v_{ij}^t \vec{t}_{ij} \quad (7)$$

where A_{ij} strength of the force between the rows and equals 2 KN;B_{ij} is the range of force between rows and equals 0.08 m; k_c and k_f are the coefficient of positive pressure and the coefficient of friction, respectively; r_{ij} is the mean diameter of individual i versus individual j; d_{ij} is the distance between individual i and individual j;$g(x)$ is the slope function and equals 1 when x is not less than 0, otherwise equals 0; $\overrightarrow{n}_{ij}$ and $\overrightarrow{t}_{ij}$ are the velocity difference in the tangential direction of the individual i contact point with individual j.

3. Interaction forces between individual and obstacle

Evacuee's walking will inevitably interfere with obstacles, and the physical repulsive force denotes the behavior of an individual who tries to avoid dodging obstacles,

$$\vec{F}_{iw} = \vec{F}_{iw}^{avoidance} + \vec{F}_{iw}^{compression} + \vec{F}_{iw}^{friction} = A_{iw} \cdot exp\left(\frac{(r_i - d_{iw})}{B_{iw}}\right)\vec{n}_{iw} + k_{cw} g(r_i - d_{iw})\vec{n}_{iw} + k_{fw} g(r_i - d_{iw})|\vec{v}_i| cos(\vec{v}_i, \vec{t}_{iw})\vec{t}_{iw} \quad (8)$$

where A_{iw} is the strength of force with obstacle and equals 10 m/s^2; B_{iw} is the range of action with obstacles and equals 0.4 m; k_{cw} and k_{fw} are the coefficient of positive pressure and the coefficient of friction; r_i is the radius of individual i and equals 0.23–0.25 m; d_{iw} is the shortest distance from individual i to obstacle w; $\overrightarrow{n}_{iw}$ and $\overrightarrow{t}_{iw}$ are unit vectors mutually perpendicular.

4. Group attractiveness

In the original SFM, all individuals are isolated. But in fact, there are different social relations between individuals. They always walk with people they are close to [10]. By adding a cohesive force, pedestrians in the same group will attract each other. Group attractiveness is shown as,

$$F_{ij}^{\overrightarrow{rel}} = p_{ij}c_{ij}exp\left[\frac{\left(p_{ij} - d_{ij}\right)}{D_{ij}}\right]\overrightarrow{n}_{ij} \tag{9}$$

where c_{ij} and D_{ij} are the aggregation force parameters. p_{ij} is the aggregation probability between pedestrian i and pedestrian j. The aggregation force is calculated by the aggregation probability weighting. The ISFM formula is as follows:

$$m_i\frac{d\overrightarrow{v}_i(t)}{dt} = \overrightarrow{F}_i^0 + \overrightarrow{F}_{ij} + \overrightarrow{F}_{i\omega} + F_{ij}^{\overrightarrow{rel}} \tag{10}$$

$$v_{i'}(t) = \frac{\overrightarrow{F}_i}{m_i} \cdot \Delta t + v_i(t) \tag{11}$$

where $v_i(t)$ is the initial velocity; $v_{i'}(t)$ is the moving speed; Δt is the time span.

3 Results

3.1 Crowd Evacuation After Clustering Grouping

In this paper, the evacuation is simulated in a room with a regional size of 300 * 200pix. The number of particles is 270, and the improved K-Medoids clustering algorithm is used to group clustering. After clustering, the social force of individual attraction in the same group is added.

Figure 3 shows the grouping results of 270 individuals. Points with different colors represent different particle groups. In the process of crowd evacuation, the crowd can be divided into several groups according to the position, speed, and direction between individuals.

Figure 3a is the result of clustering grouping, and the particles of the same color after clustering are a group. Figure 3b–d represent the evacuation states of particles at different times. It shows that during the evacuation process, people of the same color gradually gathered together, that is, individuals in the same group gradually gathered while constantly moving to the egress and escaped from the same egress; at the same time, the effect of 'export arching' and 'fast is slow' appeared at the egress. Using this algorithm to group, the group behavior can be simulated more realistically.

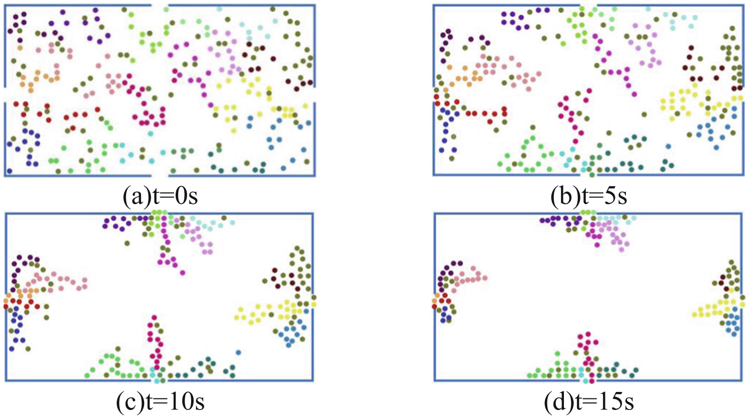

Fig. 3. Crowd evacuation at different times after clustering.

3.2 Model Evaluation

ISFM and SFM in barrier-free scenes are compared.

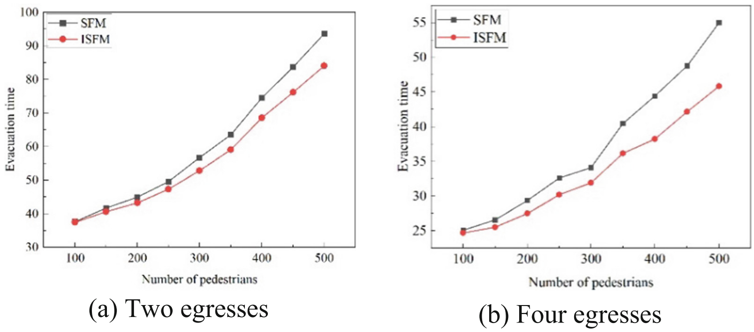

Fig. 4. The evacuation time comparison chart of SFM and ISFM.

An average of 50 comparative experiments was taken to obtain the average evacuation time of the two models. The formation of two egresses (Table 1 and Fig. 4a) and four egresses (Table 2 and Fig. 4b) groups improve evacuation efficiency because individuals are attracted by other individuals in the group, and are also affected by self-motivation. This situation increases the individual's collaboration, thereby increasing the individual's movement speed and reducing the overall evacuation time.

4 Conclusions

This paper considers the influence of distance and pedestrian relationships on the phenomenon of crowd clustering and grouping under emergencies and considers the influence of group force and guidance on crowd evacuation. The experimental results show

Table 1. Evacuation time of two egresses scenarios

Number of individuals	SFM	ISFM
100	37.6	37.4
150	41.7	40.6
200	44.9	43.25
250	49.53	47.32
300	56.74	52.85
350	63.47	59.05
400	74.52	68.59
450	83.7	76.15
500	93.62	84.08

Table 2. Evacuation time of four egresses scenarios

Number of individuals	SFM	ISFM
100	25.09	24.68
150	26.56	25.54
200	29.36	27.48
250	32.62	30.21
300	34.10	31.91
350	40.47	36.15
400	44.43	38..22
450	48.79	42.16
500	55.02	45.86

that the proposed method can improve evacuation efficiency. It is more in line with the crowd evacuation behavior in the real environment. However, in the actual situation, there are still many factors affecting the evacuation of the crowd, such as the scope of vision, the size of the pedestrian, the location and shape of the obstacle, the individual's situation, the emotional infection status, the number, size, and location of the scene exit. Therefore, the influence of the above factors on evacuation efficiency will be further studied in future work. At the same time, it will also study how to guide and utilize the phenomenon of crowd clustering and formulate corresponding crowd evacuation mechanisms to improve the evacuation efficiency of the crowd.

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