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Optimization of social force model in subway station aisle

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Abstract: According to the research on pedestrian collision avoidance in Xizhimen subway station of Beijing, This paper gives some optimizations about existing pedestrian collision avoidance model in subway station aisle. Through analysis and observation of survey data, find that the psychological repulsion force intensity is not a fixed vlaue, but varies with the distance between pedestrians, and give its fitting formula. Besides, this paper changes the phenomenon that one pedestrian would walk through another pedestrian when the longitudinal distance of two people is zero. It achieves a reasonable collison avoidance by designning the deflection angle. Establishing the simulation software of optimized model based on MATLAB, the process verified the validity of the optimized social force simulation model.

1 Introduction

Since Helbing presented the social force model, many scholars make use of it to research pedestrian's walking behavior on different situations. Besides, some of them optimize the existing model. In the aspect of collision avoidance simulation model, Daniel R. Parisi [1,2] and some scholars(2009) put forward the automatic stop mechanism that make pedestrian's expect speed become zero, which could change the phenomenon that pedestrian suddenly stop in traditional social force model. As a result, pedestrians' walking speed would slow down and avoid the collision. Yuan Gao(2014) [3] studied the effect of pedestrian's walking speed on collision avoidance. Aiming at the trajectory of pedestrian's collision avoidance both at normal speed and high speed in the experiment. Get a conclusion that pedestrian's walking speed has a significant effect on collision avoidance. Compared to pedestrian who walk at normal speed, when a pedestrian walk at higher speed wants to stop in order to avoid collision, they need a larger deceleration and more space. The experimental results were used to improve the pedestrian motion model. Wang Qian-lian （2015）[4] proposed an optimized model to avoid collision, this model eliminates pedestrian repulsion force, it is advantageous for pedestrian to look for the fastest way to reach their destinations. However, there are still some shortcomings about pedestrian avoidance social force model in subway station aisle, such as overlap and collision in the process of simulation. This article is mainly research on these respects.

2 Optimization of psychological repulsion force intensity

When other people appear in the scope of pedestrian's avoidance, pedestrian would automatically avoid the collision under the efect of psychological repulsion force. As a important factor in the calculation of pedestrian psychological repulsion force, we use A_i to represent the psychological repulsion force intensity. In the traditional social force model, Helbing [5, 6] put forward that the psychological repulsion force intensity is a fixed value. Besides, he gave the formula of calculation of psychological repulsion force, which is shown in formula (1).

$$\vec{F}_{ij}^{r} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right)\vec{n}_{ij} \quad (1)$$

r_{ij}——Sum of the radii of two pedestrians;

d_{ij}——Distance between two pedestrians;

A_i——Psychological repulsion intensity, which is a model parameter;

B_i——Action area of psychological repulsion, which a model parameter;

$\vec{n}_{ij}$——Unit vector pedestrian j points to the pedestrian i.

2.1 Description of the original model

Helbing and other scholars used $A_i exp((r_{ij} - d_{ij})/B_i)$ to show how the distance between two pedestrians affect psychological repulsion force. In the formula, A_i and B_i are both fixed value.

During the simulation, it cause that two pedestrians with smaller longitudinal distances collide because of the lack of psychological repulsion force. Because of oversized psychological repulsion force, two pedestrians with larger longitudinal distance would avoid a unrealistic displacement, This paper takes pedestrian's psychological repulsion force as 200N to show the defect. Simulating two cases which two pedestrian's longitudinal distance is 0.02 and 0.1m, get pedestrian's collision avoidance process and trajectory, which is shown in figure1 and 2.

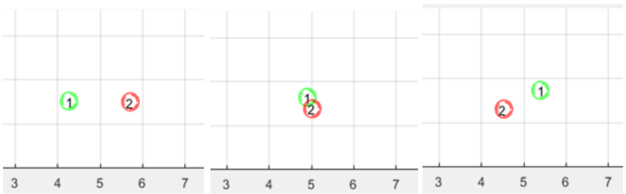

Figure 1 Process of pedestrian's collision avoidance at 0.02m vertical distance

In the figure 1, pedestrian1 enters from the left side of at an ordinate of 1.52m, Pedestrian 2 enters from the right side at an ordinate of 1.5m. As is shown in the figure 1, there is a collision between two pedestrians in the walking process. It indicates that when two pedestrians' longitudinal distance is 0.02m, 200N of psychological repulsion force intensity is insufficient.

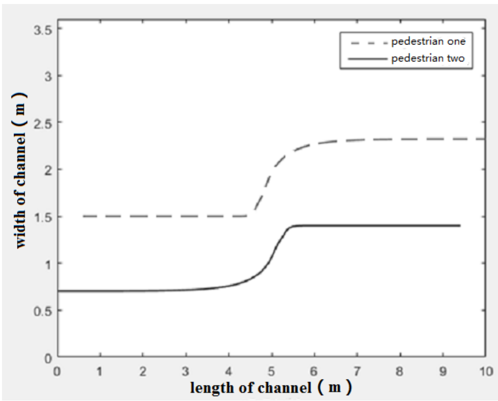

Figure 2 Trajectory of pedestrian's collision avoidance at 0.1m vertical distance

In the figure 2, Pedestrian 1 enters from the left side at an ordinate of 1.5m, Pedestrian 2 enters from the right side at an ordinate of 1.4m. As is shown in the figure 2, after the collision avoidance, two pedestrians' longitudinal distance gradually increase, which is not consistent with reality. It indicates that when two pedestrians' longitudinal distance is 0.1m, 200N of the psychological repulsion force intensity is too large. Experimental result shows that the psychological repulsion force intensity should not be a fixed value, but varies with the distance between pedestrians.

2.2 Analysis and optimization

The psychological repulsion force intensity is related to the longitudinal distance between two pedestrians. When two pedestrians' longitudinal distance is small, Pedestrian need a larger psychological repulsion force intensity to avoid collision with the other pedestrian. When two pedestrians' longitudinal distance is large, Pedestrians need a smaller psychological repulsion force intensity to avoid excessive avoidance phenomenon. According to the the relationship between the psychological repulsion force intensity and the longitudinal distance, fitting the mathematical formula between two variables, which is shown in formula(2).

$$A_i(d) = a_0 + \sum_{i=1}^{3}\left(a_i \cos i\omega d + b_i \sin i\omega d\right) \tag{2}$$

$a_0 = -1.432 \times 10^{11}$; $a_1 = 2.144 \times 10^{11}$; $a_2 = -8.529 \times 10^{10}$; $a_3 = 1.408 \times 10^{10}$; $b_1 = 1.351 \times 10^{10}$; $b_2 = -1.079 \times 10^{10}$; $b_3 = 2.691 \times 10^{9}$; $\omega = 0.2428$;

i——pedestrian number;

d——Longitudinal distance between pedestrians, must be above zero.

Using the fitted A_i value in the scope of Pedestrian avoidance mechanism, simulate two cases which two pedestrian's longitudinal distance is 0.02 and 0.1m. From the simulation, pedestrians' trajectory can be seen in Figure 3 and figure 4.

In the figure 3 and figure 4, the trajectory of pedestrian 1 is shown by the dotted line while the trajectory of pedestrian 2 is shown by the solid line. Pedestrian 1 enters the channel from left side while pedestrian 2 enters the channel from right side. As it formula (2) shows, pedestrians' psychological repulsion force intensity is determined according to the longitudinal distance between the two pedestrians.

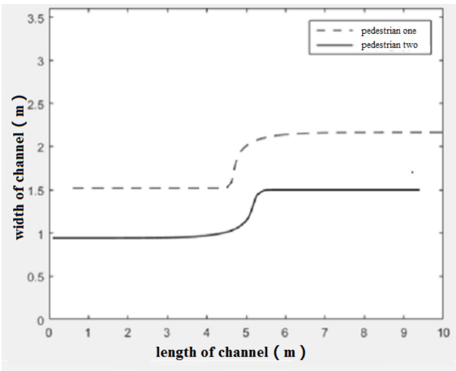

Figure 3 Trajectory of pedestrian's collision avoidance at 0.02m vertical distance

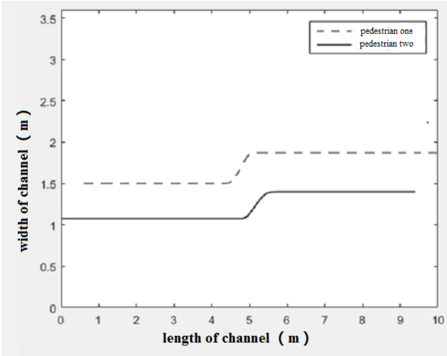

Figure 4 Trajectory of pedestrian's collision avoidance at 0.1m vertical distance

As is shown in the trajectory, there is no collision in the walking process on two situations. After the process, there also is no excessive increase in the longitudinal distance between two pedestrians, which is consistent with reality. The result shows that 205N psychological repulsive force was reasonable when two pedestrians' longitudinal distance is 0.02m, when the longitudinal distance of two pedestrians is 0.1m, the 170N psychological repulsion force which calculated by new psychological repulsion force intensity is appropriate. In summary, after optimizing the pedestrian psychological repulsion force intensity, Pedestrian psychological repulsion force can better sense the impact of changes in longitudinal distance, so it makes pedestrian's avoiding trajectory more realistic.

3 Optimization of collision avoidance when two pedestrians' longitudinal distance is zero

In the subway station aisle, there are many situations that two pedestrians walk in opposite direction and their longitudinal distance is zero, which can be seen in figure 5. But in the traditional social force model, phenomenon of pedestrians' collision avoidance simulation is not consistent with reality under this situation.

Figure 5 realistic phenomenon of pedestrians' collision avoidance in subway station aisle

3.1 Description of the original model

In traditional social force model， pedestrians complete collision avoidance by pedestrian repulsion force. The repulsion force between pedestrians can explain the avoidance behavior between two pedestrians whose longitudinal distance is not zero. But it can't explain the avoidance behavior when two pedestrians' longitudinal distance is zero. Specific reasons include: when two pedestrians walk in opposite direction, they only effected by the role of psychological repulsion. At the same time, $\delta_{ij} = 0°$, which represent the direction angle that pedestrian j point to pedestrian i.

From the formula (3), we know that $\vec{n}_{ij} = \left(\cos 0°, \sin 0°\right) = \left(1, 0\right)$, which represent the direction vector that pedestrian j point to pedestrian i. Formula (1) shows that the psychological repulsion force between two pedestrians point to the horizontal direction, the longitudinal component of psychological repulsion force is zero.

$$\vec{n}_{ij} = \left(\cos \delta_{ij}, \sin \delta_{ij}\right) \qquad (3)$$

$\vec{n}_{ij}$——Unit vector that pedestrian j points to the pedestrian i;

δ_{ij}——direction angle that pedestrian j points to pedestrian i.

When two pedestrians walk in opposite and get physical touch, in addition to psychological repulsion force, pedestrian is also subjected to the effect of physical repulsion force. The physical force of the pedestrian is a contact force. It is divided into body positive pressure force $\vec{f}_{ij}^{p}$ and sliding friction force $\vec{f}_{ij}^{f}$. The specific calculation is shown in formula (4), (5) and (6). Similar to the process of calculation of pedestrian psychological repulsion force, the longitudinal component of pedestrian's body positive pressure force is also zero. In addition, the speed difference between the two pedestrians who walk in opposite direction, certainly point to two pedestrians' contact surface's normal vector direction. So the projection value of the velocity difference in tangential vector direction is zero. As is shown in the equation (6), Pedestrian's sliding friction force is zero.

$$\vec{F}_{ij}^{p} = \vec{f}_{ij}^{p} + \vec{f}_{ij}^{f} \quad (4)$$

1) The calculation of body positive pressure force is given by formula (5).

$$\vec{f}_{ij}^{p} = k\tau\left(r_{ij} - d_{ij}\right)\vec{n}_{ij} \quad (5)$$

k——Positive pressure coefficient between pedestrians;

$\vec{n}_{ij}$——Unit vector pedestrian j point to pedestrian i.

2) The calculation of the sliding frictional force is given by formula (6).

$$\vec{f}_{ij}^{f} = K\tau\left(r_{ij} - d_{ij}\right)\Delta v_{ji}^{t}\vec{t}_{ij} \quad (6)$$

K——Sliding friction force coefficient;

$\vec{t}_{ij}$——Unit tangent vector;

Δv_{ji}^{t}——Projection of velocity difference between two pedestrians in the direction of $\vec{t}_{ij}$.

In summary, when two pedestrians walk in opposite direction and their longitudinal distance is zero, whether they touch or not, the longitudinal force of the two pedestrians is zero. At this time, there is no longitudinal force or speed that makes pedestrian to stagger each other. Original model will make the one pedestrian cross the other and move on, which is not consistent with reality.

3.2 Analysis and optimization

Based on the investigation of pedestrian walking characteristics in Xizhimen subway station aisle, if two pedestrians walk in opposite direction and their longitudinal distance is zero, when they will collide, two pedestrians would both choose to avoid in most cases. In order to make up for the traditional social force model, give each pedestrian a deflection speed to make them move from flank before two pedestrians collide. As is shown in figure 6, pedestrian A and pedestrian B walk in opposite direction. When the distance between A and B is less than the horizontal action range of avoidance mechanism, pedestrian A and B are both affected by the role of the longitudinal speed ΔV, so that two pedestrians who will soon collide would stagger. The specific deflection speed algorithm is shown in equation (7).

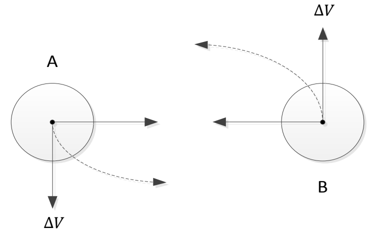

Figure 6 Combined speeds after designing a deflection speed

$$\Delta V = \tan\theta \times V_{水平} \quad (7)$$

θ——Deflection angle, it is shown in formula (8)

$$\theta = \arctan\left[\left(Chjx - \left|y_j - y_i\right|\right) / \left|x_j - x_i\right|\right] \quad (8)$$

$Chjx$——Pedestrian vertical scope boundary，indicate that the avoidance destination is the boundary of the vertical range of another pedestrian avoidance mechanism. Without considering other disturbances, Pedestrians will choose the shortest avoidance path which another pedestrian interference outside the range. Figure 7 shows the deflection speed of two pedestrians whose longitudinal distance is zero.

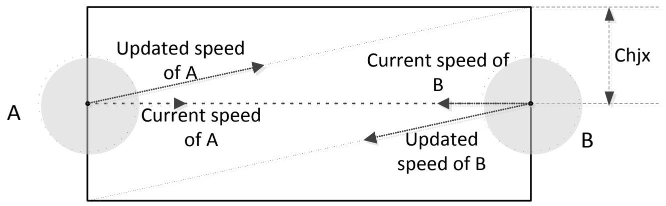

Figure 7 Deflection speed of two pedestrian when their longitudinal distance is 0m

After optimizing the model, simulate the phenomenon that two pedestrians walk in opposite direction whose longitudinal distance is zero, which can be seen in figure 8.

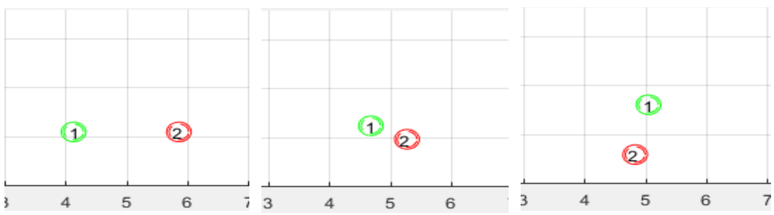

Figure 8 Trajectory of two pedestrians in opposite direction when their longitudinal distance is 0m

As is shown in figure 8, in the optimized model, under the effect of deflection speed, two pedestrians who walk in opposite direction and longitudinal distance is zero would avoid colliding. Optimized model change the phenomenon that two pedestrian who walk in opposite direction and longitudinal distance is zero would still walk through each other.

4 The Conclusion

In this paper, based on the social force model of pedestrian collision avoidance in subway station aisle, optimizing that strength of psychological repulsion force varies with the distance between pedestrians rather than a fixed value. Changing the phenomenon that one pedestrian would walk through another pedestrian when two pedestrians' longitudinal distance is zero. Compiling a simulate software with MATLAB and carry out analysis before and after the optimization. In conclusion, the effectiveness of the optimized model is verified by simulation.

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