Simulation of Bi-Direction Pedestrian Movement in Corridor Based on Crowd Space

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Abstract

Focusing on bi-direction pedestrian movement in corridor, this paper presents the definition of crowd space which is divided into personal space and information processing space. Pedestrian movement is caused by the synthetically actions of personal space as a repulsive field and information processing space as a gravitational field. A cellular automata model has been developed to simulate and evaluate the features of evolution process about pedestrian movement in corridor. It is demonstrated that pedestrian density and system scale have significant effects on evacuation time. And pedestrian movement in one direction would form the line in a sufficiently high pedestrian density. Furthermore, this process spontaneous separates bi-directional pedestrians. The approach can be used for analyzing pedestrian movement in various corridors, such as subway tracks, underground passage, etc.

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1. Introduction

Pedestrian flow simulation is an effective way to design multi-modal transport hubs as well as evaluate and optimize manage alternatives (Wolf et al., 1996). In recent years, there has been a steady growth of interest in concern about pedestrian flow in order to aid the design of transportation infrastructure and to optimize the allocation of resources. We carry on the reasonable plan and the design for pedestrian facilities and traffic rules based on mastering and understanding the microscopic and macroscopic characteristics of pedestrian flow. Consequently, simulation on the macroscopic pedestrian flow to explore the movement mechanism and features of...
Macroscopic pedestrian flow in different environments, based on studying microscopic characteristics of pedestrians, is the hot and focus of the research on pedestrian flow (Helbing et al., 1998, 2000). Pedestrians are different from vehicles, because the pedestrian movement is more complex than vehicular flow. Firstly, pedestrians are more intelligent than vehicles and they can choose an optimum route according to the environment around. Secondly, pedestrians are more flexible in changing directions and not limited to the lanes as in vehicular flow. Thirdly, the slight bumping is acceptable and need not be absolutely avoided (see, e.g. Fang et al., 2003).

In studies of pedestrian flow simulation, the model of cellular automata (CA) has widely been used in different kinds of fields, such as pedestrian walkways, traffic intersections, transportation facilities, and other public buildings pedestrian flow. CA would be used to study the overall macroscopic behavior characteristics through definition and simulation of the microscopic behavior of individual in the system (see, e.g. Yang et al., 2002). In pedestrian flow simulation and research based on CA, there are many kinds model be used, such as two processes model, lattice gas model, two floors model, dynamic parameters model, multi-grid model, etc (see, e.g. Katsuhiro, 2006). However, human psychology has a considerable effect on his action and choice in real life. Pedestrian will not only appear to imitate others moving, but also try to keep a certain distance with others in the process of movement (Burstedde et al., 2001 and Nishinari et al., 2006), yet there have been few studies on this feature of human psychology.

This paper aims to define the crowd space which describes a kind of pedestrian psychology as imitating other's behavior and keeping the distance with the adjacent pedestrians. Furthermore, it uses direction force parameter and distance parameter to simulate bi-direction pedestrian movement in corridor, analyses the influence of pedestrian density and system scale on evacuation time, and observes the interaction among pedestrians.

2. Model

The model is described in the $L \times W$ two-dimensional discrete cellular grids system $\Omega^2$, where $L$ is the length of the system, $W$ is the width of the system, $\Omega^2$ is the two-dimensional system. The upper and lower boundaries of the system form the walls of simulation scene, and the exits of simulation scene are composed of the left and right boundaries. Each cellular can either be occupied only by one pedestrian or emptied. The size of a cellular corresponds to approximately 0.5m×0.5m. This is the typical space occupied by a pedestrian in crowd. Based on empirical statistics, the average velocity of a pedestrian is about 1.00m/s in normal circumstances (Isobe et al., 2004 and Li et al., 2005). Therefore, one time-step is approximately 0.5s in this model. Pedestrians are distributed randomly in the system according to the pedestrian density. Pedestrians are divided into left to walk and walking rightwards on the basis of a ratio as moving left and right proportion of pedestrian. They can not cross the walls, only through exits to leave the system. There is two ways of processing a pedestrian when he leaving system: first the pedestrian will no longer enter the system; second if the pedestrian in the left boundary, he will move to the right boundary and vice versa. The simulation model is shown in Fig 1, where 'o' indicates a pedestrian moving to the left, and '*' expresses a pedestrian moving to the right.

Every pedestrian can wait or move to 5 directions in each discrete time-step of the model's evolution. This hypothesis demonstrates that pedestrians can only wait or move forward, but not backward. It is consistent with the actual situation. So the field of pedestrian movement is displayed in Fig 2. When a pedestrian chooses one position in the next time-step, he will judge moving profit of each position in the field of pedestrian movement and select the position as his target position that has the largest profit value. Pedestrians moving to the left can choose the position occupied by pedestrian moving to the right, and vice versa. Therefore, pedestrians have a possibility to exchange their positions in process of the evolution model. At the same time-step, if and only if two pedestrians choose each other position as their target position, they will exchange their position in the next time-step.
The moving profit of every cellular in the system is divided into two kings: moving profit of left direction and moving profit of right direction. Each moving profit is obtained by direction force parameter and distance parameter added up. Direction force parameter reflects a moving direction of the pedestrian in the next step. And Distance parameter is used to describe the proximity from optional position to exits. The model assumes that pedestrians can calculate every moving profit of optional position and confirm their forward position in the process of movement. In the calculation of direction force parameter, we need to define two kinds of force field in the crowd space.

2.1. Crowd space

In the process of movement, a pedestrian will not only appear to imitate others moving, but also try to keep a certain distance with others in crowd space (Takimoto et al., 2003, Katsuhiro, 2006 and Nagai et al., 2006). This means that there are two forces in crowd space: first there has a repulsive field defined as personal space; second there has a gravitational field named as information processing space. As far as personal space is concerned, pedestrians will unconsciously to mark their territory. Once some ones close to them, it will make them to feel uncomfortable. Even if someone closes to the others, he also can avoid too close to each other. Therefore, there is a mutual repulsive force among pedestrians in personal space, and we can think that personal space is a repulsive range of pedestrians. In addition to personal space, pedestrians can also interact with others through the beyond visual range and more extensive information. Pedestrian tend to close to the others in this information space, who have similar characteristics with him. This space is defined as information processing space. Accordingly, information processing space is a gravitational force field, and it will also effect on direction selection of pedestrians in next time-step. The personal space and information processing space are demonstrated in Fig 3. Thereinto, small dotted circle represents personal space, and big dotted circle stands for information processing space. In empirical statistics, the scope of distance in personal space is about 2m, and the range of distance in information processing space is approximately 5m (Isobe et al., 2004 and Katsuhiro, 2006).
Pedestrians choose forward position through the effect of crowd space in the process of movement. In order to define personal space and information processing space in CA, we assume that pedestrians always orient to an exit, personal space and information space are composed of cellular grids. Supposing the model system having enough cellular grids, someone's personal space is composed of the cellular grids oriented exit's direction, which distance is within 2m from his position. And the cellular grids, which distance from his position is between 2m and 5m, constitute information processing space. When a pedestrian judging a certain direction, his angle of vision range is roughly 45 degrees based on empirical statistics (see, e.g., Katsuhiro, 2006). Therefore, Fig 4 shows the personal space and information processing space in CA. If a pedestrian near the wall, we assume that there are non-existent cellular grids occupied by virtual pedestrians. In personal space, this hypothesis demonstrates that walls have repulsive force to pedestrians, pedestrians do not like crowded near walls. In information processing space, this assumption shows that walls have gravitational force to pedestrians, and pedestrians think they will effectively reach the exit along the wall. Therefore, there have two kinds of interaction force fields to influence on the direction of pedestrian movement.

In personal space, a pedestrian will keep a distance with the adjacent pedestrians, so he will inclined to choice one direction for their next target which has the most number of void cellular grids. Consequently, we define the void density of every 5 direction's corresponding cellular grids in personal space to describe this repulsive force. These densities are expressed as $\rho^v_n$ ($n = 1, 2, \ldots, 5$).

In information processing space, a pedestrian will imitate crowd had the same features, so he will inclined to choice one direction, which has the most cellular grids occupied by the same direction's pedestrians. Therefore, we define the same direction's pedestrian's density of every 5 direction's corresponding cellular grids in information processing space to demonstrate this gravitational force. These densities are expressed as $\rho^g_n$ ($n = 1, 2, \ldots, 5$). And we assume the densities of current position are zero.

In order to synthesize the repulsive force of personal space and the gravitational force of information processing space, this paper defines the direction force parameter $F_{ij}$. If a pedestrian current position's coordinate is $(i, j)$, his
direction force parameter of every 6 optional positions as shown in Equation (1). where \((x, y)\) is a cellule's coordinate, \(F^L_w ((x, y) \in \{i-1, i\} \times \{j-1, j, j+1\})\) is the direction force parameter in his left neighborhood, thereinto, \([i-1, i] \times [j-1, j, j+1]\) is shown the set of Cartesian product between \([i-1, i]\) and \([j-1, j, j+1]\), \(F^R_w ((x, y) \in \{i, i+1\} \times \{j-1, j, j+1\})\) is the direction force parameter in his right neighborhood, \(\omega\) \((0 \leq \omega \leq 1)\) is the inertia weight, \(\xi\) and \(\eta\) are the random numbers extracted evenly in the range of \([0, 1]\).

\[
F^L_w = \begin{cases} 0 & \text{if } (x, y) = (i, j), \\ \omega \xi^L_x + (1 - \omega) \eta^L_x & \text{if } (x, y) \neq (i, j) \end{cases}, \quad F^R_w = \begin{cases} 0 & \text{if } (x, y) = (i, j), \\ \omega \xi^R_x + (1 - \omega) \eta^R_x & \text{if } (x, y) \neq (i, j) \end{cases}
\]  \hspace{1cm} (1)

2.2. Distance parameter

In addition to the direction of pedestrian movement, there is a certain purpose in the process of movement. Pedestrians have not walk through in the system without aim. The pedestrian's destination is exits of the system. So pedestrians select the neighbourhood's cellular grid as their target position that has the nearest distance to the exits.

This paper uses the shortest distance from a cellular to the exits to express the extent of this cellule's attraction for pedestrians. If cellular has closer distance to the left exits in the simulation system, it will have more attractive force to moving left pedestrians and vice versa.

This paper calculates the Euclidean distances from every cellular to the left and the right exits in the calculation of distance parameter, and stipulates the distances of left and right boundary cellular are zero. This calculation process is shown in Equation (2), where \((x, y)\) is a cellule's coordinate in the system, \(D^L_w\) is the shortest distance from a cellular \((x, y)\) to the left exits, \(D^R_w\) is the shortest distance to the right, \((x^L_w, y^L_w)\) is coordinate of the cellular \(w\) \((w=1, 2, \ldots, W)\) in the left exits, \((x^R_w, y^R_w)\) is coordinate of the cellular \(w\) in the right exits.

\[
D^L_w = \min_u \sqrt{(x - x^L_u)^2 + (y - y^L_u)^2}, \quad D^R_w = \min_u \sqrt{(x - x^R_u)^2 + (y - y^R_u)^2}
\]

(2)

If a pedestrian current position's coordinate is \((i, j)\), the shortest distances of 5 direction's corresponding cellular grids in his neighborhood are shown in Equation (3), where \(S^L_{ij} ((x, y) \in \{i-1, i\} \times \{j-1, j, j+1\})\) is the shortest distance from the cellular \((i, j)\) to a cellular \((x, y)\) in his left neighbourhood, and \(S^R_{ij} ((x, y) \in \{i, i+1\} \times \{j-1, j, j+1\})\) is the shortest distance to a cellular \((x, y)\) in his right neighborhood.

\[
S^L_{ij} = \begin{cases} S^L_{i,i+1} = 0, \\ S^L_{i,j+1} = \frac{D^L_{i,j+1} - D^L_{i,i+1}}{\sqrt{2}} \\ S^L_{i+1,j} = \frac{D^L_{i+1,j} - D^L_{i,j+1}}{\sqrt{2}} \\ S^L_{i+1,i} = \frac{D^L_{i+1,i} - D^L_{i+1,j}}{1} \\ S^L_{i,j} = \frac{D^L_{i,j} - D^L_{i+1,i}}{1} \end{cases}, \quad S^R_{ij} = \begin{cases} S^R_{i+1,j+1} = 0, \\ S^R_{i+1,j} = \frac{D^R_{i+1,j} - D^R_{i+1,j+1}}{\sqrt{2}} \\ S^R_{i+1,j+1} = \frac{D^R_{i+1,j+1} - D^R_{i,j+1}}{\sqrt{2}} \\ S^R_{i,j+1} = \frac{D^R_{i,j+1} - D^R_{i+1,j}}{1} \end{cases}
\]  \hspace{1cm} (3)
The values of $S_u^L$ and $S_u^R$ calculated in Equation (3) are normalized as shown in Equation (4), where $\tilde{S}_u^L$ and $\tilde{S}_u^R$ are normalized values, $\max_{(i,j)}(S_u^L)$ is the maximum value in the cellular $(i,j)$ left neighborhood, $\max_{(i,j)}(S_u^R)$ is the maximum value in the right neighborhood, $\min_{(i,j)}(S_u^L)$ is the minimum value in the cellular $(i,j)$ left neighborhood, $\min_{(i,j)}(S_u^R)$ is the minimum value in the right neighborhood.

$$
\tilde{S}_u^L = \frac{S_u^L - \min_{(i,j)}(S_u^L)}{\max_{(i,j)}(S_u^L) - \min_{(i,j)}(S_u^L)}, \quad \tilde{S}_u^R = \frac{S_u^R - \min_{(i,j)}(S_u^R)}{\max_{(i,j)}(S_u^R) - \min_{(i,j)}(S_u^R)}
$$

### 2.3. Evolution rules

This model uses synchronous update mechanism, and the whole process of system simulation is discretized into equal time-step $t$. At each time-step $t$, pedestrians use direction force parameter in crowd space and each cellular normalized distance value to determine the movement of the next time-step. Every pedestrian must follow the rules of movement.

- Pedestrians can only move one cellular length at each time-step $t$. They have 6 optional positions as displayed in Fig 2. Pedestrians can choose to waiting or to one direction around themselves neighborhood.
- The model calculates the direction force parameter $F_{ij}$ in crowd space and the normalized distance values $\tilde{S}_{ij}$ of 6 optional positions in every pedestrian neighborhood. Furthermore, it obtains moving profit $E_{ij}$ of every cellular as shown in Equation (5).

$$
E_{ij} = F_{ij} + \tilde{S}_{ij}
$$

- When pedestrians choosing the next target position, they calculate moving profit values in their neighborhood at first, and choose the position as their target position that has the maximum moving profit value. Pedestrians randomly select a cellular grid based on the same probability, when there is a plurality of cellular had maximum benefits value in their neighborhood.
- When there are multiple pedestrians simultaneous choose a void cellular grid to access, there is conflict among these pedestrians. The model will randomly select a pedestrian based on the same probability to access this void cellular grid, not selected pedestrians will hold their positions in the next time-step.
- Only when two pedestrians with face to face simultaneous choose each other current position as their target position, they will exchange their positions in the next time-step.
- The model is simulated respectively by two methods when pedestrians move to exits: first they will be removed from the system in the next time-step; second if pedestrians in the left border, they will move to the right boundary and vice versa.
- The end conditions of the system simulation have two kinds: first the simulation process is end when all pedestrians removed from the system; second it adopts the maximum number of iteration ($Max\text{iteration}$) as the end condition.

### 3. Simulation and results

In the simulation study, pedestrian density $K$ is defined pedestrian’s number $N$ divided by the total cellular $L \times W$, moving left and right proportion of pedestrian $P^L / P^R$ is expressed the ratio of moving left pedestrian’s number and moving right pedestrian’s number, pedestrian evacuation time $T$ is said time-steps required all pedestrians leaving system. In process of the simulation, we take the average value of operated 20 results as statistical index in order to reduce the effect of initial condition on the statistical indexes.
When the simulation choosing the first end condition, this paper studied curves of pedestrian evacuation time $T$ changing with pedestrian density $K$, based on $L \times W = 40 \times 20$, and $P^e / P^p = 0/100, 10/90, 20/80, 30/70, 40/60, 50/50$, as demonstrated in Fig 5. In the case of fixed system scale, there has an increasing trend in the process of pedestrian evacuation time changing with pedestrian density. The different moving left and right proportion of pedestrian has the different evacuation time. There is no significant difference in the case of small value $K$; however, there is significant difference in the condition of higher value. This difference will have significant change when pedestrian density approximate equals to 0.4. It demonstrated that $K = 0.4$ is a turning point in the pedestrian feeling crowded.

Fig. 5. The curves of pedestrian evacuation time changing with pedestrian density

Fig 6 shows curves of pedestrian evacuation time $T$ changing with pedestrian density $K$, based on different length of the system $L$, $W = 20$ and $P^e / P^p = 20/80$. In the case of fixed system width, there is significant difference in the condition of different system length. It is shown that the length is a key factor on the evacuation time.

Fig. 6. The curves of pedestrian evacuation time based on different length of the system

Fig 7 demonstrates curves of pedestrian evacuation time $T$ changing with pedestrian density $K$, based on different width of the system $W$, $L = 40$, and $P^e / P^p = 20/80$. In the case of fixed system length, there is no significant difference in the condition of different system width. It expressed that to expand the system width is the effective way to control the evacuation time in the condition of big gatherings.
When the simulation selecting the second end condition, this paper analyzed the processes and evolution of pedestrian movement as demonstrated in Fig 8, based on $L \times W = 40 \times 20$, $K = 0.8$, and $P^L / P^P = 50/50$. Fig 8 (a) shows the state of pedestrian flow movement when the system running to the steady state. We are starting to see in this figure that pedestrian movement in one direction would form the line in a sufficiently high density. There is no considering the rule of keeping to the right side, so moving left and right pedestrians do not clearly appear to separate bi-directional pedestrians in the process of system evolution. Therefore, Fig 8 (b) is shown that the state of pedestrian flow movement in the condition of sticking to the right side. There is obviously appearing to separate bi-directional pedestrians.

4. Conclusions and remarks

Based on the model of CA, this paper defines the density of 6 optional positions in every pedestrian neighborhood to describe the repulsive force of personal space and the gravitational force of information processing space, and synthesizes these forces to the direction force parameters. Furthermore, it simulates bi-direction pedestrian movement in corridor. The model assumes that there does not have obstacles in the system and every pedestrian sight is not affected. The conclusion indicates that pedestrian density and system scale have significant effects on evacuation time and pedestrian movement in one direction would form the line. The proposed model is beneficial to simulate human psychology, which has a considerable effect on his action and choice in real life, and would work as a supplement to the theory of pedestrian flow.

However, it is a fuzzy process when a pedestrian judge his movement direction, this process is not considered in the model. And because of space constraints of this paper, it is not considering that obstacles impact on pedestrian movement. These related themes worth further studying.
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References


