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A modified floor field cellular automata model for pedestrian evacuation simulation

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Abstract

Considering the fact that the interaction among pedestrians in a high-density crowd is asymmetric, accumulative and transferable, we present a modified floor field cellular automata model for simulating the pedestrian evacuation. In this model, the space for evacuation is discretized into smaller cells, every pedestrian is allowed to occupy multiple cells and the interaction among pedestrians is characterized by their own inertia and the forces received or to be imposed on others. By numerical simulation the effects of the pedestrian movement manner and the model parameters on evacuation efficiency are investigated. The results obtained by our modified model are compared with those by the original floor field model.

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1. Introduction

Recently, the pedestrian flow problem has attracted much attention of researchers [1–21]. Understanding the movement behavior of pedestrians in various situations is very important in designing and improving public places such as waiting rooms in railway stations, supermarkets, banquet halls, meeting rooms, theatres and movie houses. The dynamic properties of ordinary pedestrian crowds, including the self-organization phenomena, have been observed and successfully reproduced by various physical methods [22–25]. However, pedestrian evacuation is much more difficult to observe and study than normal pedestrian flow because of the danger and panic caused by incidents. A real-life experiment for evacuation is almost impossible. This encourages researchers to develop efficient modeling approaches [2, 3, 6, 8, 10, 13–21].

Existing models for studying pedestrian flow can be classified into two categories, namely continuous [1–5, 19–21] and discrete ones [6–18]. The former mainly includes the social force (SF) model [2] and the discrete choice (DC) model [5]. The social force model was applied to study the influence of the degree of panic on the evacuation velocities of pedestrians [19, 20] and modified for qualitatively analyzing the influence of various approaches for the interaction between the pedestrians on the resulting velocity–density relation [21]. The latter mainly includes the lattice gas (LG) model [6–10] and cellular automata (CA) model [11–18]. In the CA models [26–31], time and space are discretized. This makes these models ideally suited for large-scale computer simulations. A cellular automata model, which quantifies the evacuation process with three basic forces, was proposed in [18] and its performance was compared with the social force model. For the discrete model the idea of finer discretization of the space has been introduced and studied in [6, 8, 17]. There are good reasons to introduce a finer discretization of space for the discrete models [16]. First, finer discretization corresponds to a more accurate representation of geometrical structures in a natural way. Second, some situations require the use of velocities more than once. If one wants to keep the timescale unchanged this has to be compensated by introducing a smaller length scale. Third, it would be interesting to consider the case where the cell size approaches zero in order to make contact with such models that are based on a continuous representation of space, e.g., the social force model [2]. Furthermore, pedestrians of different sizes may occupy different numbers of cells, which requires a finer discretization of the space for formulating heterogeneous pedestrians' behavior. It is thus conceivable that the existing discrete models should be improved by at least discretizing the space in a finer method.

The floor field cellular automata (FFCA) model [14–17] has the advantage of reproducing most of the collective effects of pedestrian dynamics and taking less computational cost than the continuous models. In this paper, we propose a modified FFCA model in which the space for evacuation is discretized into smaller cells and every pedestrian is allowed to occupy multiple cells. The interaction among pedestrians is characterized by their own inertia and the forces received or to be imposed on others. These interactions are transmitted among pedestrians in an accumulative and asymmetric manner. We apply this modified model in a typical scenario where people in some danger try to escape from a room, analyze the impacts of several model parameters on evacuation efficiency and compare the results with those by the original floor field model.

2. The model

In our model, the space is represented with two-dimensional foursquare cells. Each cell is approximately 13.3×13.3 cm^2, and a pedestrian occupies 3×3 cells. Suppose that there are N pedestrians randomly distributed in a room at initial time. In each simulation time step, pedestrians move one cell size in forward, backward, left and right directions or remain unmoved.

Figure 1 shows the current position of a pedestrian and the possible movement directions in the next time step. The real line circle represents the current pedestrian and the dashed circle the pedestrian after moving to right. The choice of a moving direction is governed by a so-called transition probability which represents the possibility that the pedestrian intends to move a cell size in this direction. The transition probability $P_{i,j}$ towards a heavy gray cell (i, j) is determined by the local dynamics and floor fields on heavy gray cells as follows:

$$P_{i,j} = H \exp(k_S S_{i,j}) \exp(k_D D_{i,j}) \mu_{0,0} \xi_{i,j}, \tag{1}$$

where H is a normalization factor for ensuring $\sum_{(i,j)} P_{i,j} = 1$, $S_{i,j}$ and $D_{i,j}$ denote the static and dynamic fields of the heavy gray cell (i, j), respectively. The static field $S_{i,j}$, initialized at the beginning of the model run, is a gradient with high values nearby desirable areas (i.e., the exits of the evacuation space) and low values elsewhere. The dynamic field $D_{i,j}$ is the

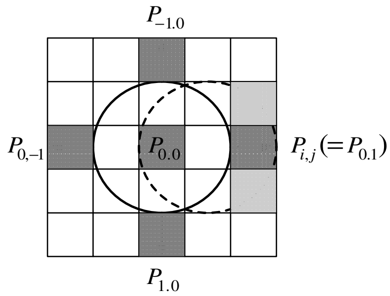

Figure 1. Possible transitions of a pedestrian and the corresponding transition probabilities.

number of bosons, dropped by moving pedestrians, on the cell (i, j). Initially, all cells do not contain bosons. When a pedestrian moves a cell size, he or she drops a boson at each departure cell. Suppose that each boson decays with a probability δ in every time step and those bosons without decaying will diffuse (i.e., randomly move to a neighboring cell) with a probability α. In equation (1), k_S and k_D are two positive parameters for scaling $S_{i,j}$ and $D_{i,j}$, respectively. The parameter $\mu_{0,0}$ is given by

$$\mu_{0,0} = \begin{cases} 1, & \varepsilon \leqslant \exp(-\theta(S - S_{0,0})) \\ 1 - \varphi_{i,j}, & \varepsilon > \exp(-\theta(S - S_{0,0})) \end{cases} \tag{2}$$

where ε is a number between 0 and 1 generated randomly. This says, $\mu_{0,0}$ equals 1 with a probability $\exp(-\theta(S - S_{0,0}))$ and $1 - \varphi_{i,j}$ with the probability $1 - \exp(-\theta(S - S_{0,0}))$. Here, the parameter $\varphi_{i,j}$ indicates whether the three neighboring cells (i.e., the two light gray cells and the cell (i, j) in figure 1, as a pedestrian intends to move to right) are occupied. It is 0 if these three cells are not occupied and 1 otherwise. S is the maximum value of static floor fields associated with all cells on the whole space, and $S_{0,0}$ is the static field of the current cell (0, 0) of the pedestrian. The parameter θ represents an intention that the current pedestrian minds whether or not the three neighboring cells in the direction to the cell (i, j) are occupied by other pedestrians. For a given position, when other parameters in equations (1) and (2) remain unchanged, a smaller parameter θ implies that the pedestrians mind less whether the target cells are occupied by others, i.e., the pedestrians are more willing to push and jostle other pedestrians. In addition, equation (2) contains such a mechanism that, for a position with a larger static floor field (or a position closer to exits), pedestrians consider less whether or not the target position is occupied by others. In a word, it represents the degree of push and bump among pedestrians.

Finally, we explain the parameter $\xi_{i,j}$ in equation (1). It represents the obstacle in the three neighboring cells (i.e., the two light gray cells and the cell (i, j) in figure 1, as a pedestrian intends to move to right), and equals 0 if there exists obstacle (e.g., the room wall) in these three neighboring cells and 1 otherwise.

Note that the above transition probability is not used to probabilistically select a movement direction, but determine a direction in which a pedestrian intends to move. In fact, a pedestrian who intends to move in a direction may have to move in another direction because of the strong action imposed by other pedestrians. In addition, it is impossible for a pedestrian to move to his or her desired cells which have been occupied by others. Considering these two factors, in this paper we use the following rules to regulate the pedestrian movement. Each pedestrian has some inertia that drives him or her to move or remain unchanged. In the intended direction, an action that a pedestrian receives consists of both the force imposed by others and the

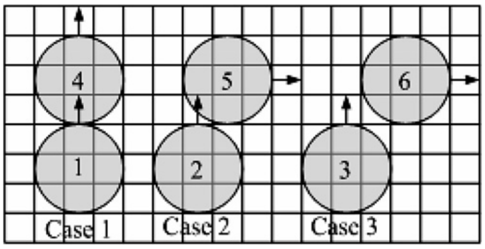

Figure 2. Direction of the force that a pedestrian imposes on someone who occupies his or her neighboring cells in the intended movement direction. In case 1, three neighboring cells are occupied; in cases 2 and 3, two and one neighboring cells are occupied, respectively.

own inertia. In other directions, however, the action only refers to the force imposed by others. A pedestrian selects a direction that has the largest received action as the movement direction. If these neighboring cells in the movement direction are not occupied by other pedestrians, he or she moves a cell size; otherwise, he or she imposes a force on pedestrians who are occupying these cells. Thus and so, the crowd forces are repeatedly transmitted from pedestrian to pedestrian through the inter-personal contacts; consequently the interaction among pedestrians becomes accumulative and asymmetric. The own inertia plays role in the intended direction only. Note that the intended direction and the moving direction may be different due to the interactions.

We now analyze the interaction among pedestrians in detail. Let $F^n_{i,j}$ denote the action that pedestrian n receives in a direction to the cell (i, j), $f^{mn}_{i,j}$ be the force that pedestrian m imposes on pedestrian n in the direction to the cell (i, j) and e_n be the inertia that pedestrian n has for moving or remaining unchanged. For simplicity, we assume that for all pedestrians, the inertia is uniformly, randomly distributed in an interval $[\underline{e}, \overline{e}]$. We then have

$$F^n_{i,j} = \sum_m f^{mn}_{i,j} + \tau_{i,j} e_n, \tag{3}$$

where $\tau_{i,j}$ is 1 if the direction to the cell (i, j) is a direction in which pedestrian n intends to move and 0 otherwise.

The actual movement direction is determined by comparing the so-called relative action $\mathrm{RF}^n_{i,j}$. A pedestrian moves in a direction which has the maximal relative action. The relative action of a direction is defined as the action difference between this direction and its contrary direction, e.g., $\mathrm{RF}^n_{0,1} = F^n_{0,1} - F^n_{0,-1}$. Let the relative action of the position (0, 0) be $\mathrm{RF}^n_{0,0} = F^n_{0,0}$. If the three neighboring cells in an actual movement direction are not occupied by others, the pedestrian moves a cell size in the direction. Otherwise, the pedestrian imposes a force on the pedestrians who are occupying these cells. As illustrated in figure 2, the direction of the force that a pedestrian imposes on another pedestrian depends upon the relative positions of these two pedestrians. The forces that pedestrians 1, 2 and 3 impose on pedestrians 4, 5 and 6, respectively, are given below:

$$f^{14}_{-1,0} = \lambda\, \mathrm{RF}^1_{-1,0}, \qquad f^{25}_{0,1} = \lambda\, \mathrm{RF}^2_{-1,0}, \qquad f^{36}_{0,1} = \lambda\, \mathrm{RF}^3_{-1,0}, \tag{4}$$

where $\lambda (0 < \lambda < 1)$ is a parameter reflecting the sensitivity to the relative action in the transmission process. A smaller λ corresponds to a smaller sensitivity to the force. In contrast, a larger λ means that the force is preserved in the transmission process and the interaction among pedestrians would become strong. It is believed that the above regulation is reasonable because in reality pedestrians generally push those in front of them for jostling

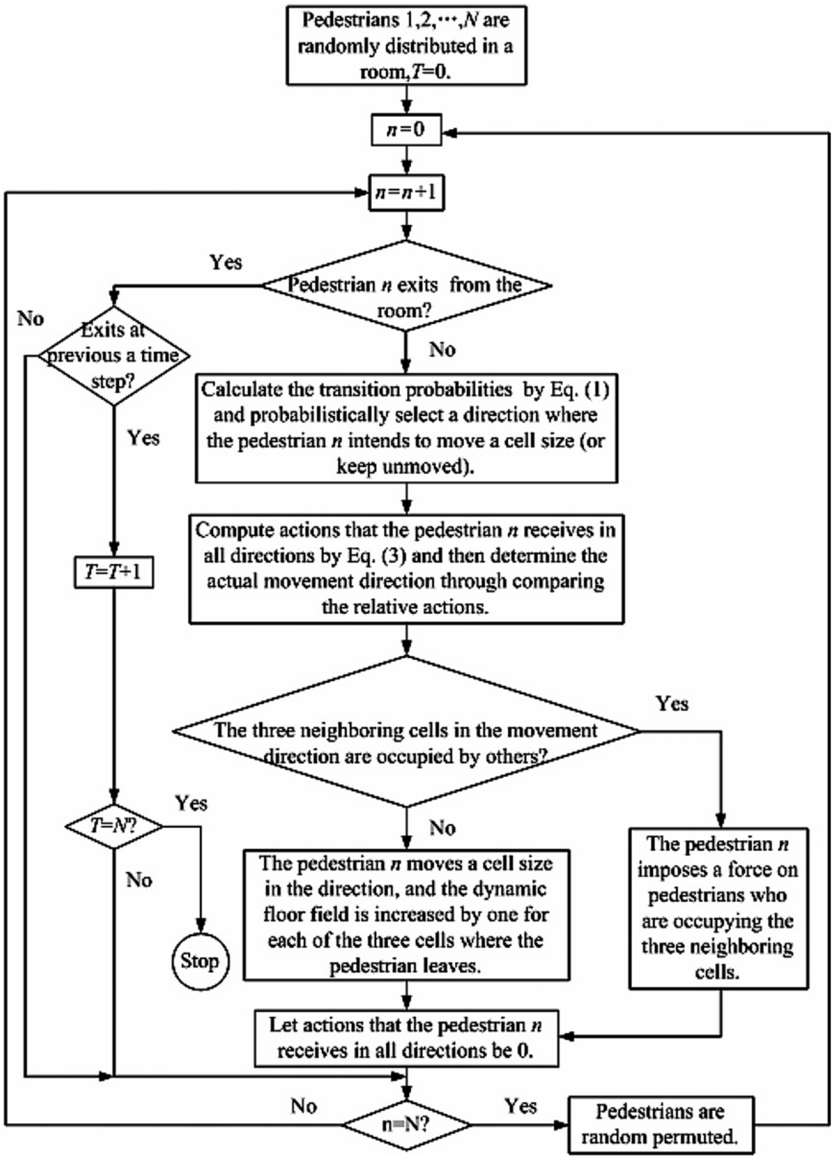

Figure 3. The flow chart of a model run.

their paths through a crowd. The force transferred to pedestrians in front may prevent them from exiting the room as well as being in favor of them exiting. Whether the force is helpful for their evacuation is mainly dependent upon their position.

A detailed description of the model run is shown in figure 3. In this figure the counter T is used to decide whether all pedestrians exit from the room. The simulation stops if $T = N$ (i.e., all pedestrians have exited from the room). A pedestrian is removed from the room if he or she is within the door cells (denoted by light gray in figure 4). In each discrete time step all pedestrians are updated in a random sequence.

The floor field model had been modified by Henein *et al* [31] by considering the interaction among pedestrians. In that swarm force model, the interaction is represented by the force field.

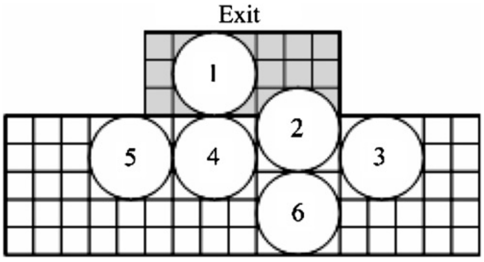

Figure 4. The door cells denoted by light gray.

In our model, however, the interaction is formulated by the finer discretization of space and the inertia of pedestrians. Both forces in these two models are accumulative and transferable, but the mechanisms of forming them are different. In [31], if the force exerting on a pedestrian in a direction is more than some value, the pedestrian then moves along the direction, otherwise the pedestrian selects a movement direction probabilistically. The process in our model is contrary, i.e., a pedestrian initially selects a direction for movement intention and then may change the movement direction due to the forces exerted by others. Thus, our model can formulate the degree of push and bump among pedestrians near exits (see the numerical simulations presented later); the swarm force model cannot do so. In [31], moreover, if a pedestrian receives forces three times more than his/her pushing force, along a direction, he/she moves along the direction. In our model, if the sum of forces that a pedestrian receives along a direction is the maximum compared with that of other directions, the pedestrian moves along the direction. In reality pedestrians generally push those in front of them for jostling their paths through a crowd. The force transferred to the pedestrians in front may prevent them from exiting the room and be in favor of them to exit. Clearly, this state of affairs is not considered in the swarm force model.

3. Simulation results

The scenario of simulation is as follows. There are 240 pedestrians who attempt to escape from a room having 90×120 cells (i.e., the density is 0.2 pedestrians per nine cells). This room has a door sized by nine cells. The door is in the north wall of the room and contains the cells 58–66 from west. The length of the simulation time step is 0.1 s. The inertia interval is $[\underline{e}, \overline{e}] = [1, 1.5]$. The static floor field of each cell is determined using the method developed in [15]. In the following experiments, we conduct 20 simulations for each value of the investigated parameter and record the mean of evacuation times. The evacuation time for each simulation is the average of all pedestrians' evacuation times.

First, we examine the influences of the parameters θ and λ on the evacuation of pedestrians, as the decay probability is $\delta = 0.5$ and the diffusion probability $\alpha = 0.5$. Figures 5 and 6 show the average evacuation times against θ and λ, respectively.

The parameter θ in equation (2) represents the degree of push and bump among pedestrians. A relatively smaller θ-value means more unorganized movement of pedestrians, more push and bump among them. When the θ-value approaches positive infinity, μ_{00} takes $1 - \varphi_{ij}$ with probability approaching 1. This says pedestrians only move to cells unoccupied by others and they do not impose interactions on others. Hence, our model becomes the original FFCA model with finer cells [17]. Figure 5 shows the relationship between the mean

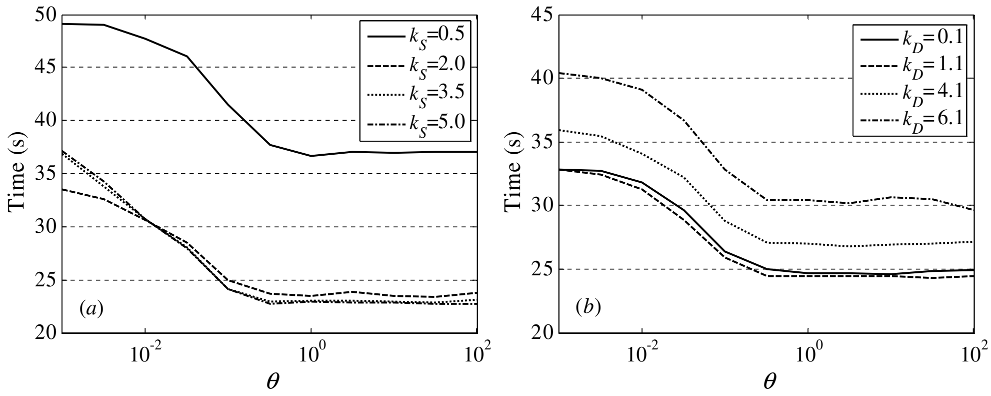

Figure 5. Average evacuation time against the parameter θ (other parameters: $\delta = 0.5, \alpha = 0.5, \lambda = 0.6, [\underline{e}, \overline{e}] = [1, 1.5]$ and the initial density = 0.2 pedestrian per 9 cells): (*a*) $k_D = 0.1$; (*b*) $k_S = 1.5$.

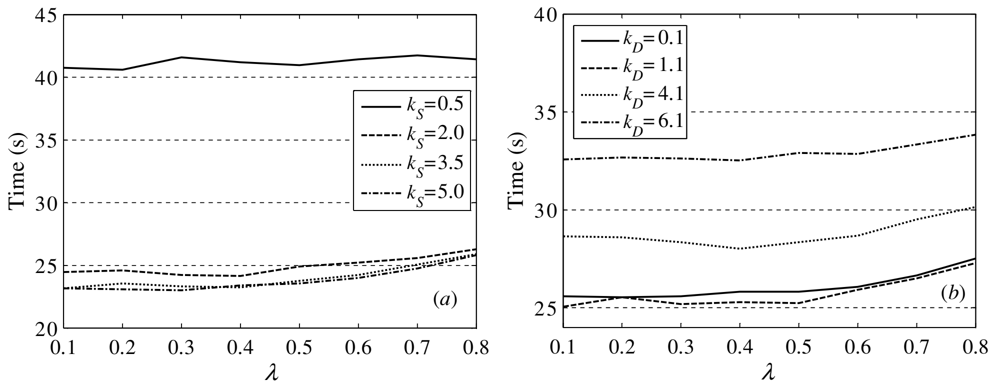

Figure 6. Average evacuation time against parameter λ (other parameters: $\delta = 0.5, \alpha = 0.5, \theta = 0.1, [\underline{e}, \overline{e}] = [1, 1.5]$ and the initial density = 0.2 pedestrian per 9 cells): (*a*) $k_D = 0.1$; (*b*) $k_S = 1.5$.

value of evacuation time and the θ-value. With the increase of the θ-value, the evacuation time decreases. This states that considering interactions among pedestrians in the process of evacuation will increase the evacuation time. The degree of increase is related to the degree of push and bump. When pedestrians do not like body congestion (i.e., the θ-value is very small), they move in a careless and sloppy manner. As a result, the evacuation time is relatively long. When pedestrians can endure body congestion, they would move in an organized manner, which causes the evacuation time to decrease. In a word, relatively less push and bump among pedestrians, especially their organized movement in the case of panic (i.e., larger parameter θ), can decrease the evacuation time. But, there exist limits for people to endure the congestion, this says, the evacuation time changes little when the θ-value exceeds some value. The faster-is-slower [2] refers to the phenomenon that when pedestrians' velocities are relatively high in a crowd near an exit, it takes them more time to go through the exit. Here, we illustrate that stronger push and bump among pedestrians, being independent of pedestrians' velocities, will result in increasing of the evacuation time. This is different from the faster-is-slower phenomenon.

The parameter λ in equation (4) represents the sensitivity to the relative action in the transmission process. A larger λ means that the force is preserved in the transmission process and the interaction among pedestrians would become strong. Figure 6 shows that the mean value of evacuation time increases with increasing λ-value on the whole. This is in accordance with our empirical feeling because larger interaction among pedestrians necessarily leads to longer evacuation time.

The value of k_S can be viewed as a measure of the pedestrians' knowledge about the location of the exit. A large k_S implies a motion to the exit on the shortest possible path. For a relatively small k_S, pedestrians will perform a random walk and just find the exit by chance. In figure 5(*a*), it can be seen that the evacuation time decreases as the k_S-value changes from 0.5 to 2.0 for different θ-values. When the k_S-value increases from 2.0 to 5.0, for a θ-value less than 0.01 the evacuation time increases; however, for a θ-value more than 0.01 the evacuation time decreases. The reason for this result may be that as k_S-value increases from 2.0 to 5.0, all pedestrians are more willing to move along the shortest path regardless of others, hence relatively large push and bump among them (θ-value is relatively large) lead to more severe conflicts and increase the evacuation time. As push and bump among pedestrians become relatively small (θ-value is relatively small), increasing evacuation time for push and bump is relatively small compared with decreasing evacuation time for moving along shorter path, hence the sum of the two sections decreases. One can see from figure 6(*a*) that evacuation time declines with increasing k_S-value, regardless of the λ-values. This illustrates that the parameter λ basically does not affect the declining trend of evacuation time with the increasing parameter k_S.

The parameter k_D reflects the tendency that a pedestrian follows the leader of others in the process of evacuation. It can be seen from figures 5(*b*) and 6(*b*) that the evacuation time first decreases and afterward increases with increasing k_D. It implies that relatively stronger or weaker herding behavior can influence evacuation time [15]. This finding is basically not affected by the degree of push and bump among pedestrians.

Figure 6(*a*) shows that the ascending rate of evacuation time against λ-value increases when k_S takes a larger value. A large k_S implies that pedestrians have more information about the shortest distance to the exit and their decisions become deterministic. In this case, the neighboring pedestrians will intend to compete for the same routes to the door. Consequently, stronger interaction among them occurs and more time is required for reaching the exit. Contrarily, for a small k_S pedestrians perform random walks and the neighboring ones have less push and bump among each other in their movements. As a result, the evacuation time is less sensitive to the λ-value. Figure 6(*b*) shows that the ascending rate of evacuation time against λ-value decreases when k_D takes a larger value. This can be explained below. For a larger k_D more pedestrians would like to follow others for leaving the room. In this case, there exist relatively less interactions among pedestrians. Then, the evacuation time becomes less sensitive to the λ-value. For the above analyses, it should be recalled that $\lambda (0 < \lambda < 1)$ is a parameter reflecting the sensitivity to the relative actions in the transmission process.

Interactions among pedestrians probably make their actual movement direction deviate from the intended direction. We now analyze how the interactions affect the pedestrians' movements. We here introduce two indices, namely the occupation number and the deviation occupation number. The occupation number for a cell is defined as the number of time steps for which the cell is occupied by pedestrians in the process of evacuation. The deviation occupation number for a cell is the number of time steps for which the cell is occupied by the pedestrians whose movement direction is different from the intended direction due to interactions. The second number can be regarded as a measure of the degree of push and

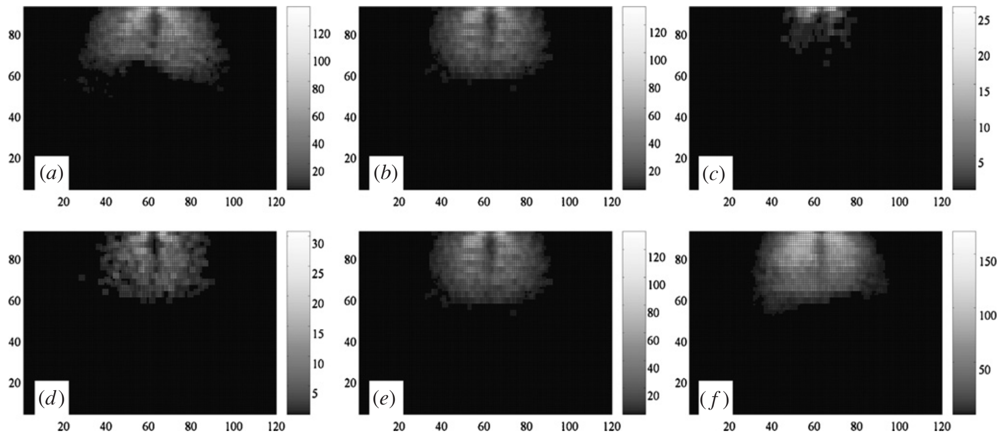

Figure 7. Pseudo-color plots delineating the deviation occupation numbers for all cells (other parameters: $k_S = 1.5, k_D = 0.5, \delta = 0.5, \alpha = 0.5, [\underline{e}, \overline{e}] = [1, 1.5]$ and the initial density = 0.2 pedestrian per 9 cells): (*a*) $\theta = 0.001$ and $\lambda = 0.6$; (*b*) $\theta = 0.01$ and $\lambda = 0.6$; (*c*) $\theta = 0.1$ and $\lambda = 0.6$; (*d*) $\theta = 0.01, \lambda = 0.4$; (*e*) $\theta = 0.01$ and $\lambda = 0.6$; (*f*) $\theta = 0.01, \lambda = 0.8$.

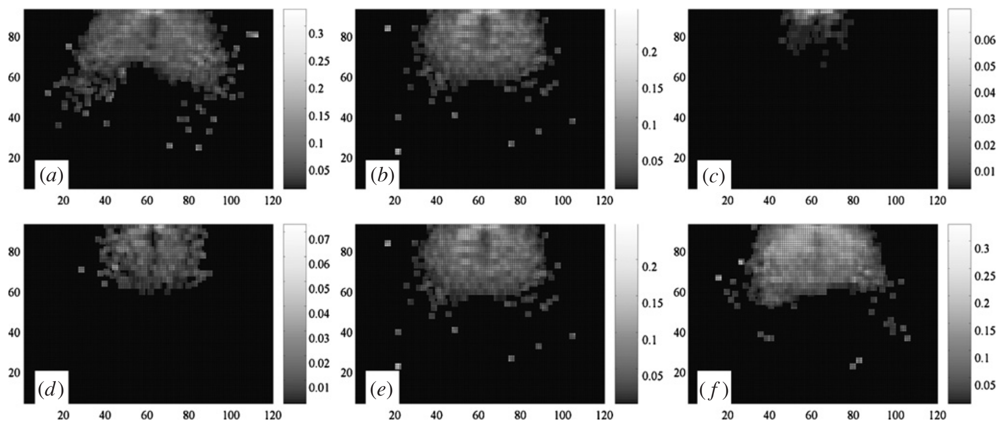

Figure 8. Pseudo-color plots delineating the ratio of the deviation occupation number to the occupation number for all cells (other parameters: $k_S = 1.5, k_D = 0.5, \delta = 0.5, \alpha = 0.5, [\underline{e}, \overline{e}] = [1, 1.5]$ and the initial density = 0.2 pedestrian per 9 cells): (*a*) $\theta = 0.001$ and $\lambda = 0.6$; (*b*) $\theta = 0.01$ and $\lambda = 0.6$; (*c*) $\theta = 0.1$ and $\lambda = 0.6$; (*d*) $\theta = 0.01, \lambda = 0.4$; (*e*) $\theta = 0.01$ and $\lambda = 0.6$; (*f*) $\theta = 0.01, \lambda = 0.8$.

bump among pedestrians. Figures 7 and 8 respectively plot the deviation occupation number and the ratio of the deviation occupation number to the occupation number for every cell subject to the different parameters θ and λ. One can see that the number and the ratio for cells nearer to the exit are relatively large. This states that more push and bump among pedestrians exist near the exit because in the case of urgency pedestrians would more likely leave the room ahead. Here we can define a so-called congestion zone which is the area covering these exit nearby cells with relatively large deviation occupation numbers, for example, the light gray areas in figure 7. Comparing figures 7(*a*)–(*c*), we can find that as the λ-value remains unchanged, with increasing θ-value less cells near the exit have relatively large deviation occupation numbers, and the maximum value of the deviation occupation number decreases

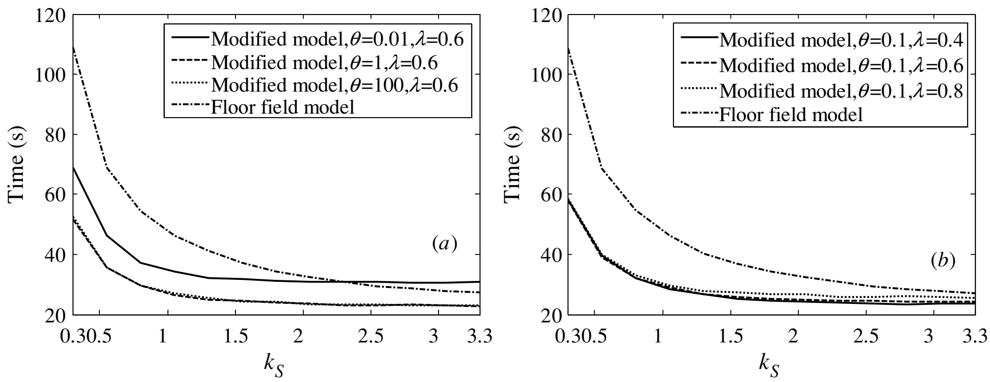

Figure 9. Average evacuation time against k_S ($k_D = 0.3$, $\delta = 0.5$ and $\alpha = 0.5$): (*a*) θ takes three values but λ is fixed; (*b*) λ takes three values but θ is fixed.

and the congestion zone diminishes gradually. This phenomenon illustrates that more push and bump among pedestrians force more pedestrians near exit to move along directions deviating from the intended directions. From figures 7(*d*)–(*f*) where θ-value remains unchanged, we can see that with increasing λ-value, more and more cells near the exit have larger and larger deviation occupation numbers, hence the congestion zone is enlarged. This indicates that when pedestrians are sensitive to interactions more push and bump occur near the exit. Similar phenomena can be observed in figure 8. It is interesting that the push and bump probably occur at positions away from the exit, but the occurring frequency is relatively lower in comparison to the positions near the exit.

Note that the above phenomena were not reproduced by the model in [31]. This is because in our model, the degree of push and bump among pedestrians and the area of the congestion zone can be controlled by adjusting the parameters θ and λ. For instance, in figure 7(*a*), the size of the congestion zone in the diagonal direction is larger than that in the vertical direction, and in figure 7(*b*), the shape of the congestion zone is a semi-circle. As observed in reality, the shape of the congestion zone is basically a semi-circle. Our model provides flexibility to reproduce various shapes of the congestion zone if required.

Finally, we compare the results of our model and the original floor field model. Simulation scenarios for these two models are identical and described by the following parameters: the room is discretized into 30×40 cells, the initial density of a pedestrian is 0.2 pedestrian per cell, the door is sized by 3 cells located in the north wall of the room and contains the cells 20–22 and the time step is 0.3 s.

Figure 9 shows the average evacuation time as a function of the parameter k_S. For both models, with increasing parameter k_S the evacuation time declines and the rate of decreasing becomes smaller and smaller. It can be seen from figure 9(*a*) that when the parameter θ is relatively small (i.e., $\theta = 0.01$), the curve of our modified model intersects with that of the floor field model at $k_S \approx 2.3$. When k_S is less than this value the evacuation time given by our modified model is smaller than that given by the floor field model, a contrary result holds when k_S exceeds the value. A small θ-value corresponds to large interactions among pedestrians. In the case of k_S taking small value, some pedestrians likely push those randomly walking in the front to move along the best direction to the exit. Hence, pedestrians may spend less time to leave the room. As k_S becomes large, strong interactions among pedestrians prevent them from moving along the shortest path, thus they have to spend more time to leave the room. When the parameter θ takes large values, implying weak interactions among pedestrians, the evacuation time given by our modified model is always smaller than that given by the floor field model. In figure 9(a), the two curves corresponding to $\theta = 1$ and $\theta = 100$, respectively, are overlapped because our model is not sensitive again to the θ-value when it is larger than 1, as shown in figure 5.

Figure 9(b) shows the results when the θ-value remains unchanged (i.e., $\theta = 0.1$). For different λ-values and k_S-values the evacuation time by the floor field model is always larger than that by our modified model. This is because that the parameter θ takes a relatively large value, even if pedestrians are sensitive to interactions (i.e., λ takes value approaching to 1); interactions among the pedestrians are not strong enough to have the pedestrians conflicting among each other and spending more time to leave the room.

We have also numerically compared the results given by the two models with respect to various combinations of k_D, k_S, δ and α. It is found that the evacuation time given by our modified model is always less than that given by the floor field model, and not highly sensitive to the variations of some model parameters such as the floor field model. It is believed that the reason for these outcomes should be attributed to the finer discretization of the evacuation space in simulation.

4. Summary

For simulating the pedestrian evacuation process, we presented a modified floor field cellular automata model by discretizing the space into smaller cells and considering the asymmetric, accumulative and transferable interaction among pedestrians. We conducted simulations in a typical scenario where people in some danger try to escape from a room. The results show that more unorganized movements, stronger push and bump among pedestrians will result in the increase of the evacuation time. Relatively stronger or weaker herding behavior can influence the evacuation time too. Push and bump among pedestrians will force more individuals near exit to move along a direction deviating from the intended direction. It was demonstrated that the degree of push and bump among pedestrians and the size and shape of the congestion zone can be adjusted as required by calibrating the model parameters. We also found that in the same simulation scenarios, the evacuation time by the original floor field model is larger than that by our modified model. Our modified model is not more sensitive to some parameters compared with the original floor field model.

Applying the modified model to investigate the evacuation process in a building with multiple obstacles and two or more doors is our on-going work.

Acknowledgments

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