ICIC Express Letters ICIC International ©2017 ISSN 1881-803X
Volume **11**, Number **7**, July **2017** pp. **1253–1260**

AN IMPROVED FLOOR FIELD MODEL FOR PEDESTRIAN SIMULATION UNDER ATTRACTIVE INCIDENTS

Linglin Wang[1,2], Linjiang Zheng[1,3], Longyou Tan[4]
Hang Li[4] and Dihua Sun[1,2]

[1]Key Laboratory of Dependable Service Computing
in Cyber Physical Society of Ministry of Education
[2]School of Automation
[3]School of Computing
Chongqing University
No. 174, Shazheng Street, Shapingba Dist., Chongqing 400044, P. R. China
zlj_cqu@cqu.edu.cn

[4]Chongqing City Transport Hub Development & Investment Co., Ltd.
Chongqing 401123, P. R. China

Received January 2017; accepted March 2017

Abstract. *The study of pedestrian behaviors is very significant for promoting pedestrian traffic management and optimizing the layout of public facility. In order to simulate and reproduce pedestrian behaviors under attractive incidents, an improved floor field model is proposed in this paper. This improved model is composed of static floor field, dynamic floor field and the new proposed attractive field, which takes account of the attractive degree of incident, view distance of onlooker, and pedestrians' safe psychological distance. Besides, pedestrian movement state is divided into three types under attractive incidents: walking, stay, and leaving, which can depict the pedestrian behaviors of gathering, looking and dissipation. The experiment results show that the proposed model can not only capture the typical characteristics of arched phenomenon and torus-shaped phenomenon, but also can reproduce the whole onlooking processes under attractive incidents.*
Keywords: Pedestrian behaviors, Floor field model, Onlooking, Attractive incidents

1. **Introduction.** Nowadays, the study of pedestrian can be divided into two types: pedestrian detection [1] and pedestrian simulation [2]. The knowledge of pedestrian behaviors is necessary and significant for improving pedestrian traffic management and optimizing the layout of public facility. So the study of pedestrian model has been developed widely.

Pedestrian microscopic model captures both microscopic and macroscopic characteristics. Cellular Automata (CA) model is one of the typical microscopic models and has been widely studied. Fukui and Ishibashi [3] proposed a CA model to study the self-organization phenomena of bidirectional pedestrian flow on passageway. Based on this model, a series of improved and variant models was proposed. Burstedde [4] proposed Floor Field (FF) model which is a great advance in pedestrian CA model. In the model, floor field consists of static floor field and dynamic floor field. Xia et al. [5] presented a pedestrian flow model considering the effect of backward looking. Kretz [6] reproduced more realistic pedestrian behaviors around corners. Lu et al. [7] took account of the influence of group behavior during emergency evacuation. Some other models have been presented to reflect pedestrian dynamics of counter flow [8].

When some incidents happen such as street art, quarrel fight injury and street stall, some pedestrians will be attracted by the incidents and gather to look, and these incidents are named attractive incidents. However, only a few models involve the onlooking behavior of pedestrians. Besides, the following behavior and the dissipation process of onlooking process are not considered in the existing method [9]. In this paper, an attractive field is put forward to describe the influence of the attractive incidents on the pedestrian movement. Besides, the impact of following behavior, pedestrian visual range and psychological distance are taken into account. Based on the above the improved floor field model under attractive incidents is built, which is composed of static floor field, dynamic floor field and attractive field.

The remainder of this paper is organized as follows. In Section 2, we formulate an improved floor field model. In Section 3, several simulation results based on the proposed model under normal circumstances and attractive incidents are presented. Finally, in Section 4, the summary is given.

2. **Model.** Moore neighborhood is introduced to discretize the space and pedestrians' movements are decided by the cell probability [10], seen as in Figure 1. The experiment space is divided into a certain number of small cells, and every cell can either be empty or occupied by exactly one pedestrian. Pedestrian will choose the neighboring empty cell corresponding to the maximum probability to move. The probability is decided by the state of cell and the interaction of static floor field, dynamic floor field and attractive field. At each time step, pedestrian moves one cell or keep staying.

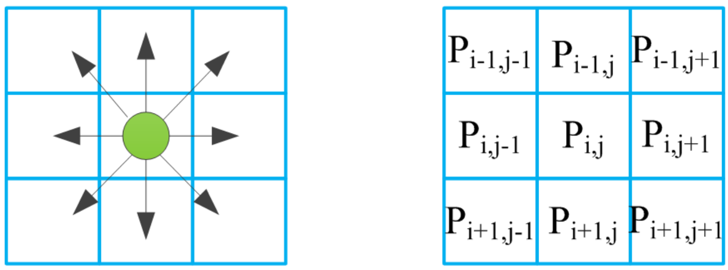


FIGURE 1. Moore neighborhood and the corresponding transition probability

2.1. **Static floor field.** Static floor field describes the shortest distance from the current cell to the destination. The static floor field of $cell(i, j)$ is denoted as $S_{i,j}$, and it increases with the decrease of shortest distance between cell and destination, which can be calculated as Henein and White [11] proposed:

$$S_{i,j} = \max_{k_\Gamma,l_\Gamma} \left\{ \min_{k_\varphi,l_\varphi} \left\{ d\left(k_\Gamma, l_\Gamma, k_\varphi, l_\varphi\right)\right\} \right\} - \min_{k_\varphi,l_\varphi} \left\{ d\left(i, j, k_\varphi, l_\varphi\right)\right\} \tag{1}$$

where $\min_{k_\varphi,l_\varphi} \{d(i, j, k_\varphi, l_\varphi)\}$ is the minimum Euclidean distance between the current $cell(i, j)$ and destination $cell(k_\varphi, l_\varphi)$, $\max_{k_\Gamma,l_\Gamma}\{\min_{i_\varphi,j_\varphi}\{d(k_\Gamma, l_\Gamma, i_\varphi, j_\varphi)\}\}$ is the maximum of all cells to the shortest distance of the destination, φ is the destination region and Γ is the whole simulation region. Figure 2 shows graphical representation of S for different geometries of the simulated unidirectional passageway.

2.2. **Dynamic floor field.** The dynamic floor field is a virtual trace left by pedestrians [12], and it is denoted as $D_{i,j}$, which changes with the movement of pedestrian. If a pedestrian leaves the $cell(i, j)$, $D_{i,j}$ will increase ΔD. Besides, at each time step, $D_{i,j}$ will diffuse to the neighboring cells and one part of $D_{i,j}$ will decay. In other words, dynamic floor field reflects the processes of trace broadening, dilution, and finally vanishing.

The diffusion and decay effects of dynamic floor field are decided by the diffusion coefficient as α and decay coefficient as β, so the continuous diffusion-decay equation of dynamic floor field can be derived as follows:

$$\frac{\partial}{\partial t} D_{i,j}(t) = \alpha \nabla^2 D_{i,j}(t) - \beta D_{i,j}(t) \tag{2}$$

Here $\nabla^2 D_{i,j}(t)$ can be written as the following equation using Laplace transform:

$$\begin{aligned}\nabla^2 D_{i,j}(t) = D_{i-1,j-1}(t) + D_{i-1,j}(t) + D_{i-1,j+1}(t) + D_{i,j-1}(t) + D_{i,j+1}(t) \\ + D_{i+1,j-1}(t) + D_{i+1,j}(t) + D_{i+1,j+1}(t) - 8D_{i,j}(t)\end{aligned} \tag{3}$$

After discretization, dynamic floor field is updated at each time step according to:

$$\begin{aligned}D_{i,j}(n+1) = (1-\beta)D_{i,j}(n) + \alpha[D_{i-1,j-1}(n) + D_{i-1,j}(n) + D_{i-1,j+1}(n) + D_{i,j-1}(n) \\ + D_{i,j+1}(n) + D_{i+1,j-1}(n) + D_{i+1,j}(n) + D_{i+1,j+1}(n) - 8D_{i,j}(n)]\end{aligned} \tag{4}$$

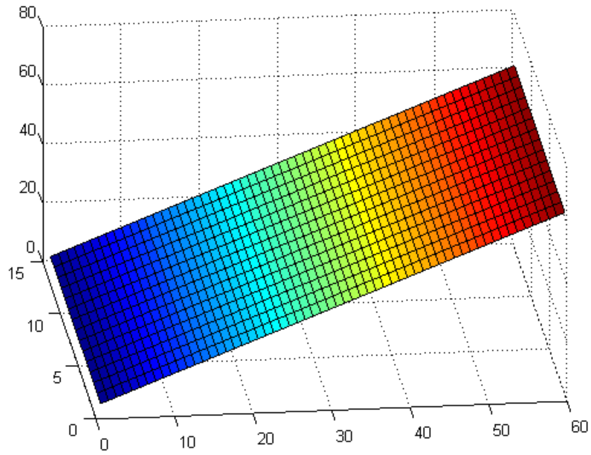


Figure 2. Static floor field of the unidirectional passageway for 15 × 60 cells

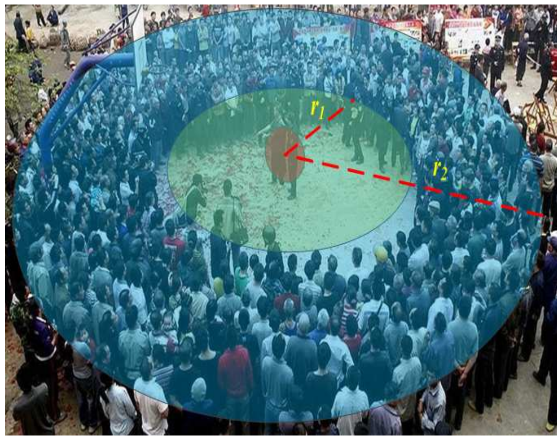


Figure 3. Pedestrian onlooking behavior caused by an attractive incident

2.3. **Attractive field.** In order to authentically describe the complex behaviors of pedestrian under attractive incidents, we propose an attractive field, which is calculated as follows:

$$A_{i,j} = \begin{cases} -k_{A1}\sqrt{(i-k)^2 + (j-l)^2}, & \sqrt{(i-k)^2 + (j-l)^2} \le r_1 \\ k_{A2}/\sqrt{(i-k)^2 + (j-l)^2}, & r_1 < \sqrt{(i-k)^2 + (j-l)^2} \le r_2 \\ 0, & \text{others} \end{cases} \tag{5}$$

where k and l are the coordinate of the incident center cell, k_{A1} and k_{A2} are two constant coefficients. Besides, the coefficients of r_1 and r_2 are defined as "safe psychological distance" and "maximal onlooking distance", respectively. "Safe psychological distance" describes pedestrian will keep a distance from the attractive incident, as r_1 seen in Figure 3. If the distance between $cell(i,j)$ and incident center is less than r_1, the attractive field of $cell(i,j)$ is a negative value. In addition, "maximal onlooking distance" means the maximal view distance of onlookers, as r_2 seen in Figure 3. When the distance between outer onlooker and incident center is more than "maximal onlooking distance", the onlooker's view will be blocked by the front onlookers, and then, they will choose to leave the incident. So the region between "safe psychological distance" and "maximal onlooking distance" is defined as "onlooking region".

2.4. **Transition probability and update rules.** Pedestrian movement is decided by the transition probabilities of neighboring cells and the transition probability depends on cell's state and the interaction of static floor field, dynamic floor field and attractive field. The transition probability of $cell(i,j)$ is denoted as $P_{i,j}$ and can be calculated as follows:

$$P_{i,j} = N \cdot \exp\left(K_S \cdot S_{i,j} + K_D \cdot D_{i,j} + K_A \cdot A_{i,j}\right)\zeta_{i,j} \cdot \lambda_{i,j} \tag{6}$$

where N is the normalized operator:

$$N = \left[\sum_{i=1}^{i=m}\sum_{j=1}^{j=n} \exp\left(K_S \cdot S_{i,j} + K_D \cdot D_{i,j} + K_A \cdot A_{i,j}\right)\zeta_{i,j} \cdot \lambda_{i,j}\right]^{-1} \tag{7}$$

m, n are the maximal coordinate in pedestrian moving region. The parameters of K_S, K_D, and K_A are the weight of static floor field, dynamic floor field and attractive field, respectively. $\zeta_{i,j}$ and $\lambda_{i,j}$ indicate the state of $cell(i,j)$, if $cell(i,j)$ is occupied by a pedestrian, $\zeta_{i,j} = 0$; otherwise, $\zeta_{i,j} = 1$. Similarly, if $cell(i,j)$ is occupied by the incident, $\lambda_{i,j} = 0$; otherwise, $\lambda_{i,j} = 1$.

The update rules are performed using parallel update mechanism. Figure 4 shows the simulation flow chart, and the update rules are given as follows.

(1) Set pedestrian arrival rate. Pedestrian can be divided into two types, one will be attracted by the incident, and the other will neglect the incident and keep walking.
(2) Get the position of incident and calculate static floor field, dynamic floor field, and attractive field, respectively. If there is no incident, the value of attractive field is 0.
(3) Judge whether pedestrian is attracted by the incident or not. If the pedestrian is not attracted by the incident, set the weight of attractive field as $K_A = 0$. Conversely, the parameter of K_A is a nonzero constant.
(4) Calculate the transaction probability and divide pedestrian movement into 3 types:

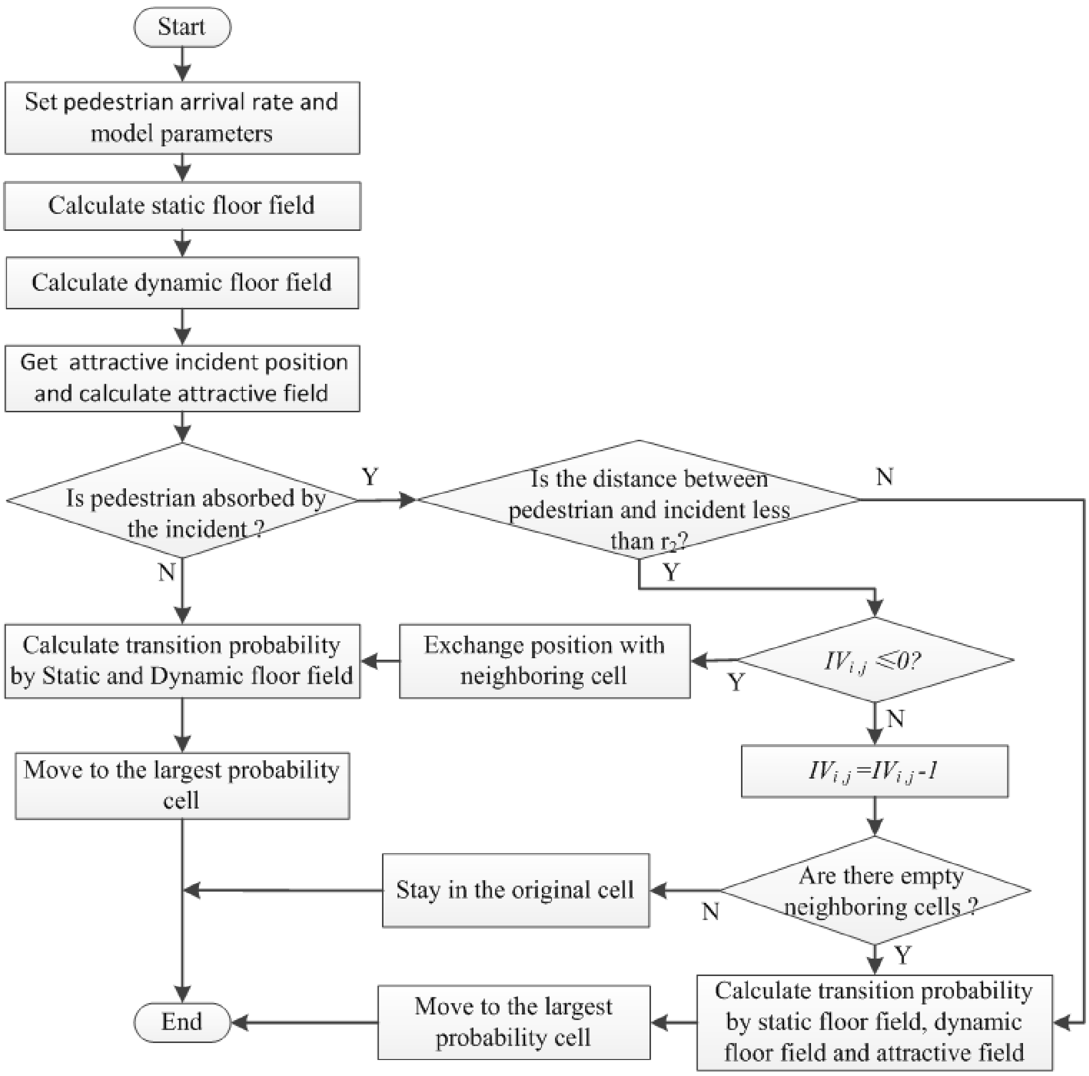


FIGURE 4. The process of pedestrian simulation

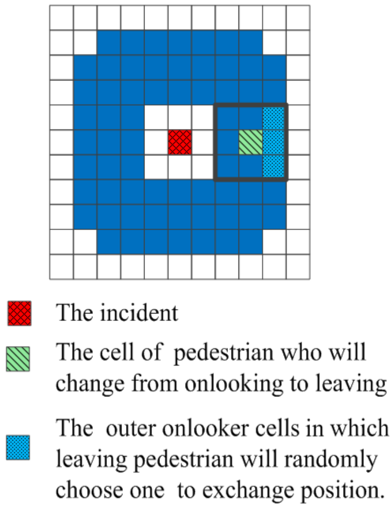


Figure 5. The leaving process of the onlookers

(i) Walking. If a pedestrian is not attracted by the incident or has not yet got into the onlooking region to look on the incident, the pedestrian will choose the maximal probability of neighboring empty cell to move.

(ii) Stay. The stay time is proportional to the interests of onlooker to the incident. Thus, a parameter of "interest value" is proposed, which is denoted as IV. If a pedestrian firstly gets into the onlooking region of $cell(i, j)$, the $IV_{i,j}$ of this pedestrian will be randomly assigned a value greater than 0. If the $IV_{i,j}$ of the pedestrian has been assigned before, $IV_{i,j} = IV_{i,j} - 1$. In case $IV_{i,j} > 0$, the pedestrian will stay at the position and continue to look on the incident.

(iii) Leaving. If $IV_{i,j} \leq 0$, onlooker has no interest to look on the incident and will choose to leave. The pedestrian will choose the maximal probability of neighboring empty cell to move. However, if all of the neighboring cells are occupied, the pedestrian needs to randomly choose one of the outer onlookers to exchange position, which is illustrated in Figure 5.

(5) Conflict resolution. When more than one pedestrian choose the same destination cell, one of the pedestrians is chosen at random to move.

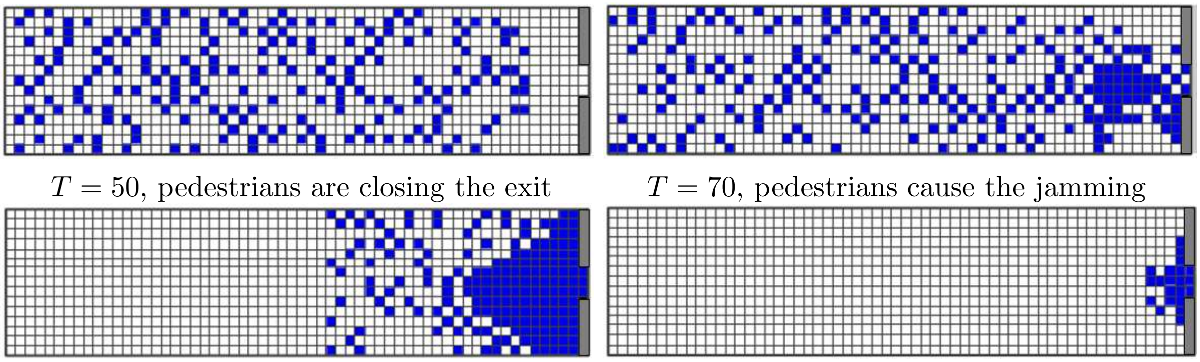
3. **Simulation and Results.** The experiment aims for a unidirectional passageway. Usually, the size of a cell is set as 0.4×0.4 m^2. Simulation time step is 0.3 s ($\Delta t = 0.3$ s), and the passageway is 24 m $\times$ 6 m which is divided into 60×15 cells.

The parameters of the model are set as follows: $K_S = 2$, $K_D = 1$, $K_A = 1$, $K_{A1} = 5$, $K_{A2} = 3$, $\alpha = 0.4$, $\beta = 0.8$, $r_1 = 0.6$, $r_2 = 2.5$. In order to validate our model, we do experiments under normal circumstances and attractive incidents, respectively.

When a great number of people try to leave a room at the same time, the jamming and arched phenomenon will happen at the bottleneck or exit [13]. Here, we set the exit width of unidirectional passageway as 1.2 m, occupied 3 cells, and the arrival rate of pedestrian is set to 4 ped/Δt, equating to 800 ped/min. Figure 6 shows the experiment results under normal circumstances. When $T = 50$, a large number of pedestrians have entered the passageway. After 70 time steps, some pedestrians are clogged at the exit. When $T = 150$, many pedestrians are clogged and the self-organization phenomenon of arching is captured. At time step 225, most of the jamming pedestrians have gone out from the passageway exit. From the results, we can know that the presented model can capture the typical characteristics and self-organization phenomena under normal circumstances.

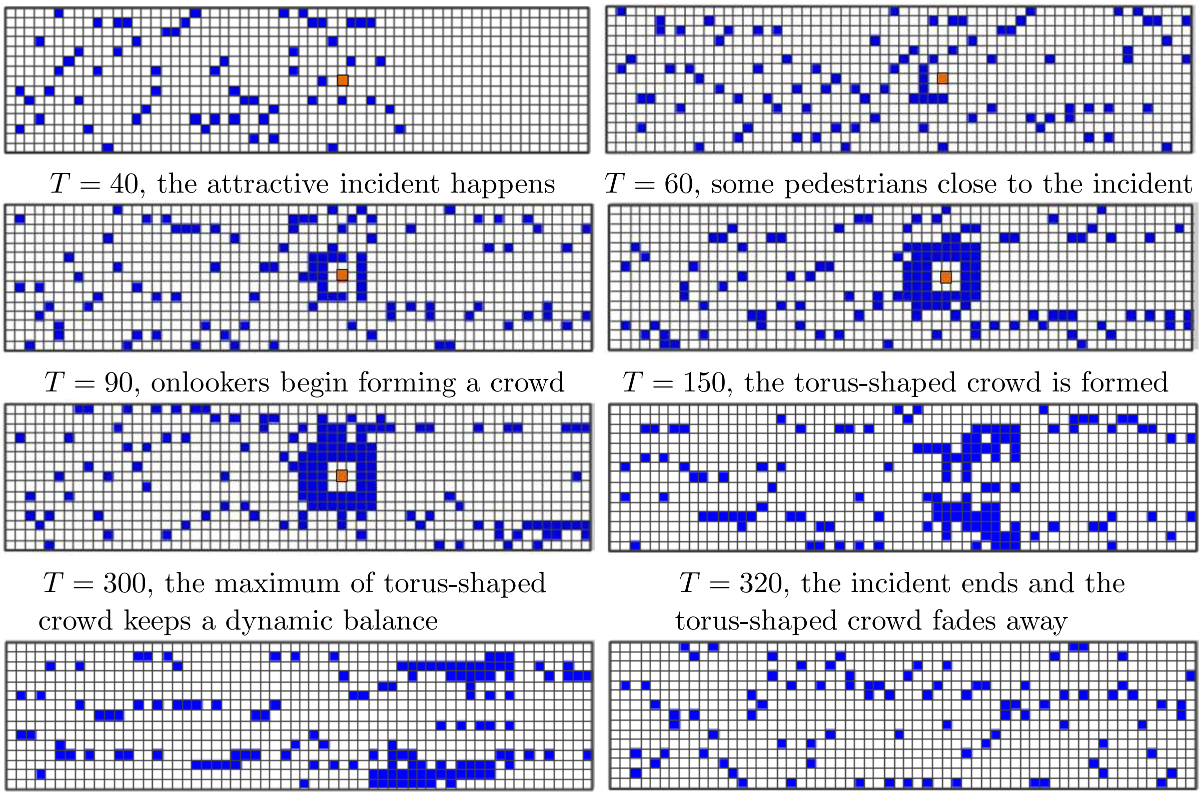
According to the result of pedestrians' movement from questionnaires [9], when quarrel or fight happens, the proportion of being attracted pedestrians and unaffected pedestrians are 39% and 61%, and the average stay time lasts 80 seconds. Thus, the minimum stay time and maximum stay time are set as 10 s and 150 s. Pedestrian arrival rate is set as 1 ped/Δt and the other parameters of model are set as before.

From the snapshots of simulation in Figure 7, we can see the whole onlooking processes of gathering, staying and dissipation under attractive incidents. When $T = 40$, an attractive incident happens. After 60 time steps, several pedestrians are attracted by the incident and stop walking. After 90 time steps, there are more pedestrians attracted by the incident. At time steps 150, it is obviously to see the onlooking pedestrians form a torus-shaped crowd, which is in accordance with the real scenes. When $T = 300$, the number of onlooking pedestrians is almost the same as 150 time steps; in other words, when the number of onlookers reaches a certain threshold, it will keep a dynamic balance.



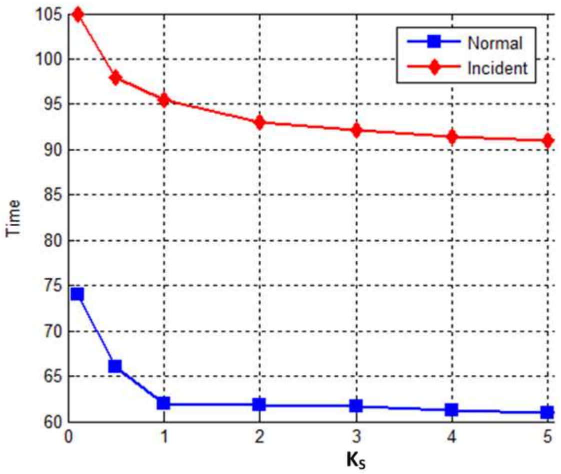
$T = 50$, pedestrians are closing the exit
$T = 70$, pedestrians cause the jamming
$T = 150$, the arching phenomenon is forming
$T = 225$, the crowd is fading away

FIGURE 6. The snapshots of simulation from 0 to 225 under normal circumstances

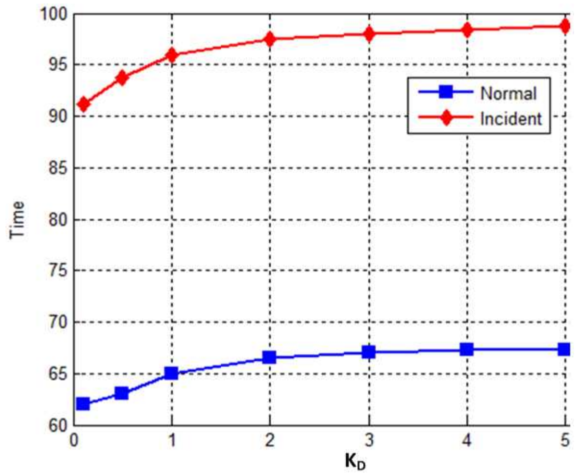


$T = 40$, the attractive incident happens
$T = 60$, some pedestrians close to the incident
$T = 90$, onlookers begin forming a crowd
$T = 150$, the torus-shaped crowd is formed
$T = 300$, the maximum of torus-shaped crowd keeps a dynamic balance
$T = 320$, the incident ends and the torus-shaped crowd fades away
$T = 340$, the onlookers fade away
$T = 370$, pedestrians' move returns to normal

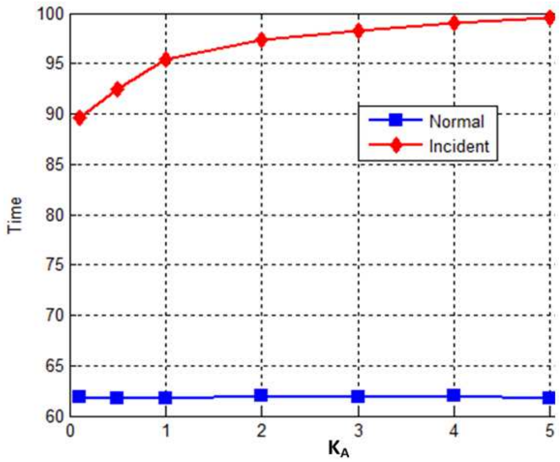
FIGURE 7. The snapshots of simulation from time step 0 to 370 under attractive incidents



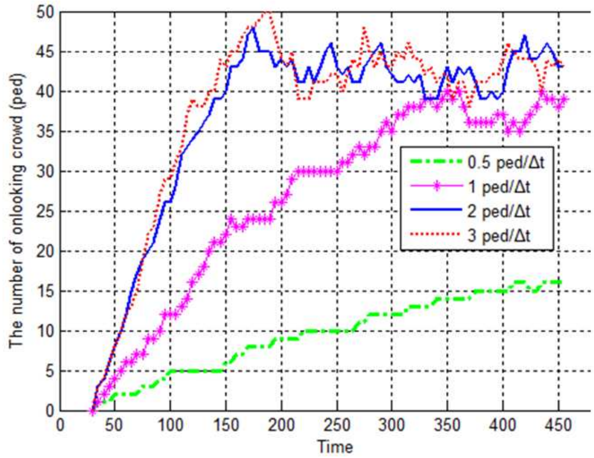
(a) Correlation between the average travel time and K_S with fixed $K_D = 1$, $K_A = 1$



(b) Correlation between the average travel time and K_D with fixed $K_S = 1$, $K_A = 1$



(c) Correlation between the average travel time and K_A with fixed $K_S = 1$, $K_D = 1$



(d) The variation of onlooking crowd number under different pedestrian arrival rates

FIGURE 8. The impact of model parameters on model

From 320 time steps to 340 time steps, due to the end of incident, the torus-shaped crowd fades away. After 370 time steps, the onlooking crowd has left and pedestrians walk normally.

By comparing our simulation results with real scenes, the appearance characteristics are in accordance with real scenes under attractive incidents. Therefore, the proposed model is validated and can effectively capture the dynamic features of pedestrians.

Furthermore, in order to illustrate the effects of static floor field, dynamic floor field and attractive field, respectively, more experiments have been conducted. In Figure 8(a), the travel time is inversely proportional to the value of K_S at first. However, when K_S is more than 2, the travel time tends to be stable. Figure 8(b) shows that, with the increase of K_D, the travel time tends to increase obviously at first and then keep stable. Dynamic field indicates the behaviors of following, so there may be some crowd or wait under dynamic field and the travel time will increase with K_D to a certain degree. Figure 8(c) shows the travel time is irrelevant to K_A under normal circumstances. However, the attraction of the incident will increase with the value of K_A to some extent under attractive incidents. In Figure 8(d), the correlation between pedestrian arrival rate and the number of onlooking crowd changing over time is studied. The result shows that the maximum of onlookers is increased with pedestrian arrival rate. More specifically, before the maximum of onlooking crowd reaches the equilibrium point, the greater the arrival rate is, the less time that onlooking crowd reaching the largest scale needs.

4. Conclusion.

In this paper, we introduced the improved floor field model to describe the onlooking processes of pedestrian under attractive incidents, which is composed of static floor field, dynamic floor field, and attractive field. The attractive degree of incident, the view distance of onlooker, and pedestrian's safe psychological distance are considered in this model. Based on the model, a series of experiments is conducted. From the simulation results, we can see the clogged and arching phenomena under normal circumstances. Besides, from the onlooking crowd forming to fading away, the appearance characteristics of the onlooking process are in accordance with real scenes. What is more, in order to validate the impact of sensitivity coefficients and pedestrian arrival rate on model, numerical simulations are carried out. According to the results, the model can be adapted to simulate a variety of pedestrian behaviors under different circumstances by adjusting the coefficients. In summary, our model can effectively reproduce pedestrian behaviors under both normal circumstances and attractive incidents. However, this paper only studied the onlooking processes of unidirectional pedestrian flow. We can further study the bidirectional or cross pedestrian flow simulation under attractive incidents.

Acknowledgment. This work is supported by the Key Projects of Application Development Plan of CQ (No. cstc2014yykfB30003), the Fundamental Research Funds for the Central Universities (No. 106112014CDJZR188801), China Post-doctoral Science Foundation (No. 2014T70852) and the Post-doctoral Research Funds of CQ (No. XM201305). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

[1] T. Li and X. Ding, A pedestrian detection method based on boosted MQDF classifiers, *ICIC Express Letters*, vol.7, no.7, pp.2041-2046, 2013.
[2] R. Löhner, On the modeling of pedestrian motion, *Applied Mathematical Modelling*, vol.34, no.2, pp.366-382, 2010.
[3] M. Fukui and Y. Ishibashi, Self-organized phase transitions in cellular automaton models for pedestrians, *Journal of the Physical Society of Japan*, vol.68, no.8, pp.2861-2863, 1999.
[4] C. Burstedde, K. Klauck and A. Schadschneider, Simulation of pedestrian dynamics using a 2-dimensional cellular automaton, *Physica A*, pp.295-507, 2001.
[5] D. Xia, X. Tang, S. Yang and T. Zhou, Effect of backward looking in the lattice hydrodynamic pedestrian flow model, *ICIC Express Letters*, vol.9, no.1, pp.255-259, 2015.
[6] T. Kretz, The use of dynamic distance potential fields for pedestrian flow around corners, *Computer Science*, no.1, pp.353-365, 2009.
[7] L. Lu, C. Y. Chan and J. Wang, A study of pedestrian group behaviors in crowd evacuation based on an extended floor field cellular automaton model, *Transportation Research Part C: Emerging Technologies*, 2016.
[8] L. Fu, W. Song and W. Lv, Multi-grid simulation of counter flow pedestrian dynamics with emotion propagation, *Simulation Modelling Practice and Theory*, vol.60, no.3, pp.1-14, 2016.
[9] Y. Chen, N. Chen and Y. Wang, Modeling pedestrian behaviors under attracting incidents using cellular automata, *Physica A: Statistical Mechanics and Its Applications*, vol.432, pp.287-300, 2015.
[10] C. Wang and J. Wang, A modified floor field model combined with risk field for pedestrian simulation, *Mathematical Problems in Engineering*, 2016.
[11] C. M. Henein and T. White, Macroscopic effects of microscopic forces between agents in crowd models, *Physica A: Statistical Mechanics and Its Applications*, vol.373, pp.694-712, 2007.
[12] S. Nowak and A. Schadschneider, Quantitative analysis of pedestrian counterflow in a cellular automaton model, *Physical Review E*, vol.85, no.6, 2012.
[13] D. Helbing, I. J. Farkas and P. Molnar, Simulation of pedestrian crowds in normal and evacuation situations, *Pedestrian and Evacuation Dynamics*, vol.21, no.2, pp.21-58, 2002.