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Research Article

Floor Field Model Based on Cellular Automata for Simulating Indoor Pedestrian Evacuation

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A new static floor field method for simulations of evacuation processes based on cellular automaton was presented in this paper. This model applies an inertia static floor field approach to describe the interaction between the pedestrians and the cell. Here we study a rather simple situation and a complex scenario. We simulate and reproduce Seyfried's field experiments at the Research Centre Jülich and use its empirical data to validate our model. The concept of scenario-familiarity of the crowd has been proposed to explain the model. It is shown that the variation of the model parameters deeply impacts the evacuation efficiency. The relation between minimal evacuation times and the knowledge of the exit that the pedestrian acknowledges is discussed.

1. Introduction

With the development of economy and the speeding up of urbanization, the number of urban population has increased dramatically in all countries. The possibility of congestion occurring also gradually increased; in the face of such a large stream of people, some public facilities produce all kinds of evacuation problems, and reasonable evacuation of pedestrian flow will play a positive role for the construction of wisdom city. How to better handle the evacuation problem becomes a hotspot in the research field, also it brings the difficulties. This is especially true in developing countries; the big events in these countries tend to have more people. Now more and more scholars begin to pay close attention to public safety and the research of pedestrian evacuation; the results will be widely used in the emergency evacuation simulation, the safe evacuation design, potential risk prediction, and so on.

2. Floor Field Model

Floor field is a kind of widely used cellular automata model; Burstedde et al. [1] proposed static floor field and dynamic floor field in 2001; many scholars improved the different aspects of potential model and got a lot of extension of the model.

A cellular automaton (pl.: cellular automata (CA)) is a discrete model studied in computability theory, mathematics, physics, complexity science, theoretical biology, and microstructure modeling. Cellular automata are also called cellular spaces, tessellation automata, homogeneous structures, cellular structures, tessellation structures, and iterative arrays [2]; a standard cellular automaton A can be defined as $A = (L, d, S, N, f)$, L is the cellular space, d is the number of dimensions of the cellular space, S is the limited dispersed collection, N is the collection of all the cells in its neighborhood, and f is the local map or rules.

Kirchner et al. [3] presented the irrationality that all the pedestrians share the same speed in evacuation; Ma et al. [4] and Guo and Huang [5] use the smaller cell to simulate the pedestrian evacuation and succeed in showing some self-organizing phenomenon; Yanagisawa et al. [6] apply floor field model to the turning corner; Chraibi et al. [7] proposed the force-based models of pedestrian dynamics; Zeng et al. [8] used a local-view floor field model to optimize the efficiency of the evacuation.

The floor field adjusts the movement probability by static floor field and real-time dynamic floor field to realize

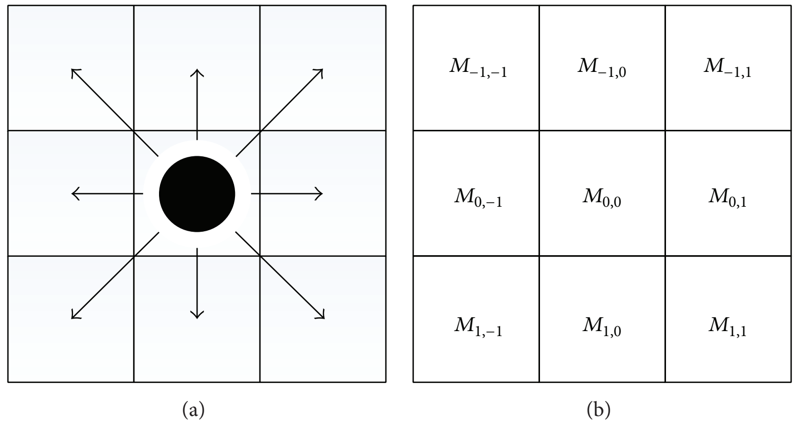


Figure 1: Move selection and preference matrix.

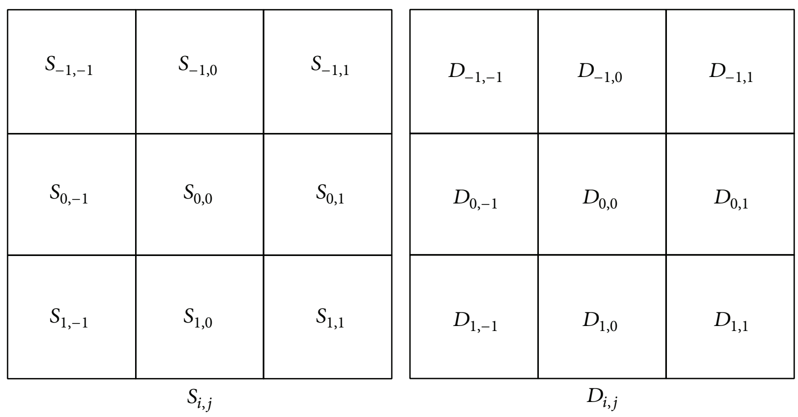


Figure 2: Static and dynamic floor field matrix.

the interaction of the pedestrian. The static floor field is defined as the distance from the cell to the exit (Formula (1)), it is constant after the initialization, and the static floor field value of the cell is in inverse proportion to the distance to the exit; the dynamic floor field is changing as the evacuation goes; the movement information of the pedestrian will be recorded, along with the diffusion and decay. The floor field model gives expression to terrain information of the scene; by using this model, pedestrian follow and automatic canalization can be simulated:

$$S_{i,j} = \min_{(i_{\tau_s}, j_{\tau_s})} \left\{ \max_{(i_l, j_l)} \left\{ \sqrt{\left(i_{\tau_s} - i_l\right)^2 + \left(j_{\tau_s} - j_l\right)^2} \right\} - \sqrt{\left(i_{\tau_s} - i\right)^2 + \left(j_{\tau_s} - j\right)^2} \right\}. \tag{1}$$

The move selection should be predefined (Figure 1(a)), and then set up a corresponding preference matrix (Figure 1(b)), also the static floor field matrix and the dynamic floor field matrix (Figure 2). For the different distance between the vertical direction and the diagonal direction, the moving speed of the two directions can be set to $1 : \sqrt{2}$ approximately.

The pedestrian moving probability p_{ij} in Burstedde et al.'s paper [1] is as follows:

$$p_{ij} = N M_{ij} D_{ij} S_{ij} \left(1 - n_{ij}\right). \tag{2}$$

Kirchner and Schadschneider [9] improved the formula:

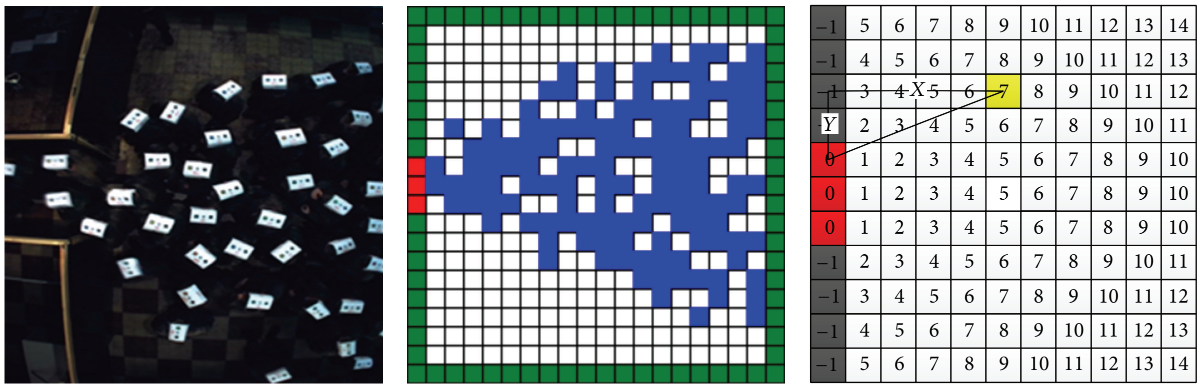
$$p_{ij} = N \exp\left(k_D D_{ij}\right) \exp\left(k_S S_{ij}\right) \left(1 - n_{ij}\right). \tag{3}$$

The data coming from Formula (3) is closer to the actual situation, so we choose this formula. The description of the formula parameters is shown in Table 1:

$$N = \left[\sum_{(i,j)} \exp\left(k_D D_{ij}\right) \exp\left(k_S S_{ij}\right) \left(1 - n_{ij}\right) \right]^{-1}. \tag{4}$$

3. The Improved Floor Field Model

First, we reproduce Seyfried's experiment by the standard floor field model; then we discuss the efficiency of the new floor field model. The static and dynamic floor field calculation methods were improved, respectively; we put forward a new static floor field calculation method and compared with classical calculation method by simulation



(a) (b) (c)

Figure 3: Experiment simulation and the values of static floor field.

Table 1: Formula parameter.

Parameter	Interpretation
M_{ij}	Pedestrian moving preference
n_{ij}	Cell occupy mark (occupied = 1 and unoccupied = 0)
k_D & k_S	Static and dynamic floor field weight
D_{ij} & S_{ij}	Static and dynamic floor field value
N	Normalization coefficient

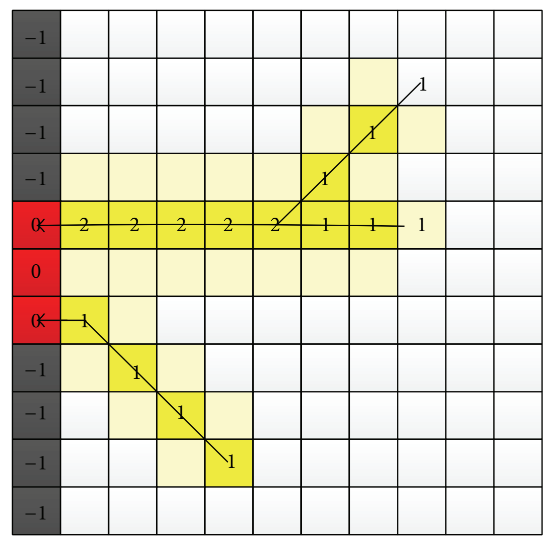


Figure 4: Dynamic floor field (light yellow cell stands for the cells diffused by Von Neumann).

experiments. We compare the improved FF model with the standard FF model.

3.1. Model Description

3.1.1. Seyfried's Experiment and Analysis. Seyfried et al. [10] considered that there are a variety of models proposed to discuss the pedestrian dynamic evacuation, but only few attempts try to validate these approaches; it is necessary to have more reliable data that can be used as basis for validation and calibration which then would allow making quantitative predictions based on computer simulations. The pedestrian evacuation experiment is data-oriented behavior [11]; we still need much more data to test the accuracy of the models.

The experiments were recorded by video cameras and pedestrian trajectories were extracted from the videos; then we reproduced the pedestrian dynamics of the experiment by the simulated model based on floor field model. The simulated result is showed in Figure 3(b). Although Seyfried's experiment has focused on the influence of the bottleneck to the pedestrian, it revealed the evacuation time and the density of the pedestrian evacuation. We set up our model to simulate the section from the beginning to the moment the pedestrian is about to walk into the bottleneck.

3.1.2. The New Static Floor Field Model. The floor field is based on the cellular automata model; the state of the next moment of each cell is dependent on the neighbors. Since this simulated indoor pedestrian evacuation process, setting up and down the room in addition to the four borders where exports are obstacles, pedestrians cannot pass. Each cell has the properties of occupation and the static floor field. First, determine the direction of the pedestrian, begin with what the surrounding cell can move, mark it as a selected target, and then subtract the value of the static floor field between the pedestrian cell and the selected neighbor cell. If the difference is positive, indicating that there is great willingness for pedestrians moving in that direction, there is a greater probability that the choice of the cell, if the value is negative, indicates that there is little willingness for pedestrians walking in that direction; there is a small probability of selecting the cell point. If the surrounding grid points are not available, it can only wait.

This model is defined in a two-dimensional plane (50 × 50), as shown in Figure 3(c). Reference [12] stated the space that one pedestrian takes; each person occupies about $0.4 \times 0.4\,\text{m}^2$; the simulation is dispersed; the speed of

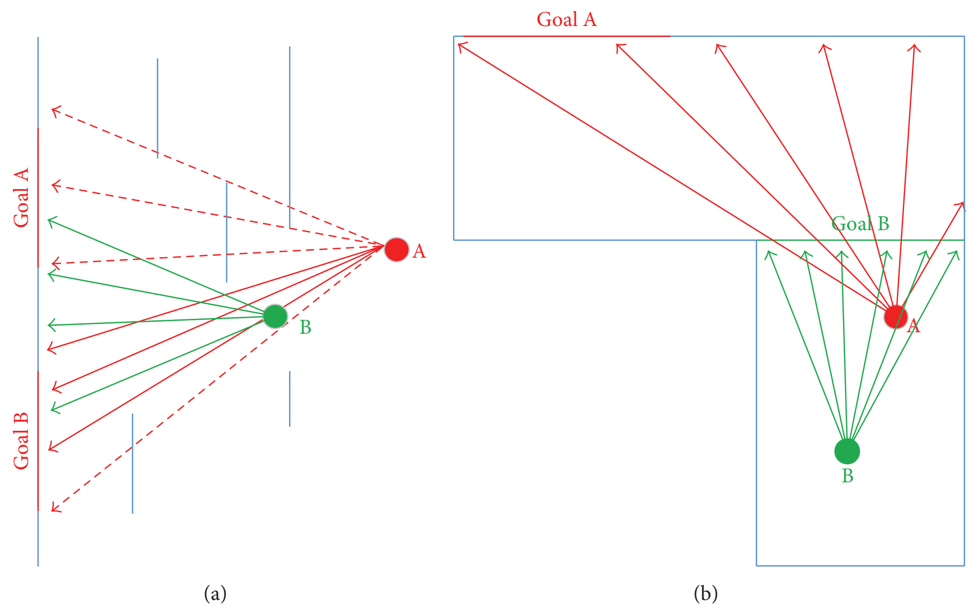


Figure 5: (a) The visibility of the pedestrian; the destination may change when the pedestrian moved (moving from A to B). (b) Different positions bring about different goals.

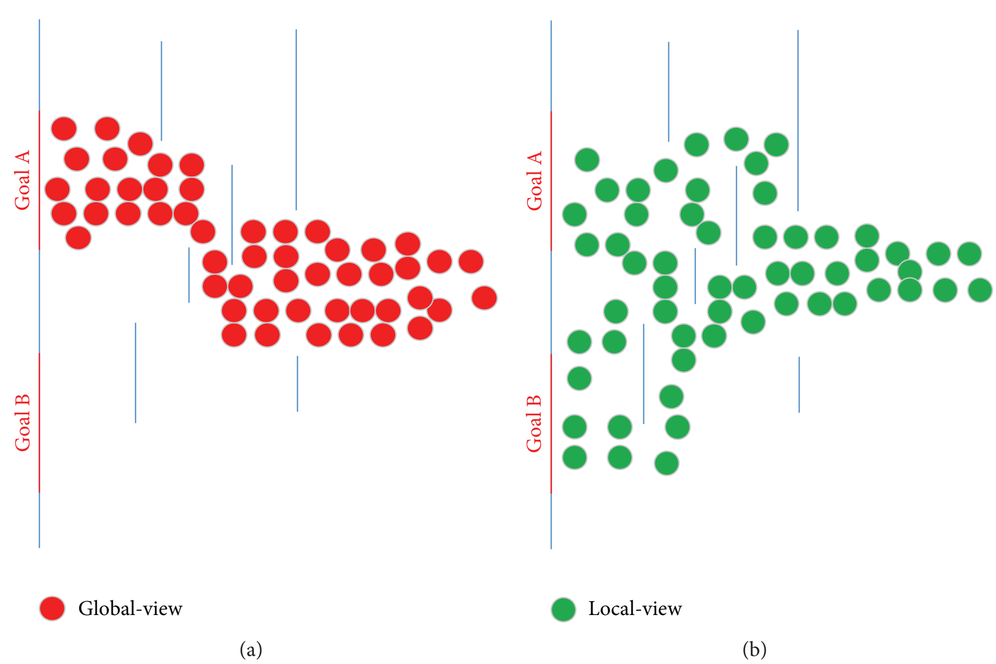


Figure 6: The sketch of global-view model and local-view model.

the pedestrian is 1 (cell/step); every time step the pedestrian chooses to move towards the direction of the selected step, or in situ waiting. Figure 3(c) showed part of the values of the static floor field. The static floor field S can be simply defined as the Manhattan distance between the cell and the exit; that is, these two line segments on the axis of the projection distance are summed on the rectangular coordinate system; the static floor field of the marked cell in Figure 3(c) is $X + Y$.

In this paper, an improved algorithm of static floor field for some specific scenarios was proposed; for example, the static floor field reflects how familiar the pedestrian is with the export message in the indoor evacuation model, with static floor field weigh coefficient, after the cognizance of the exit message, especially to some pedestrian far from the exit; the pedestrian always chooses the same direction at the first few steps, which may be blocked by the other obstacles, but with the exit of the running direction the case of more than a certain threshold will not change; we call it inertia static floor field; walking along this direction; simply record the value of the static floor field of the cell that has passed, until

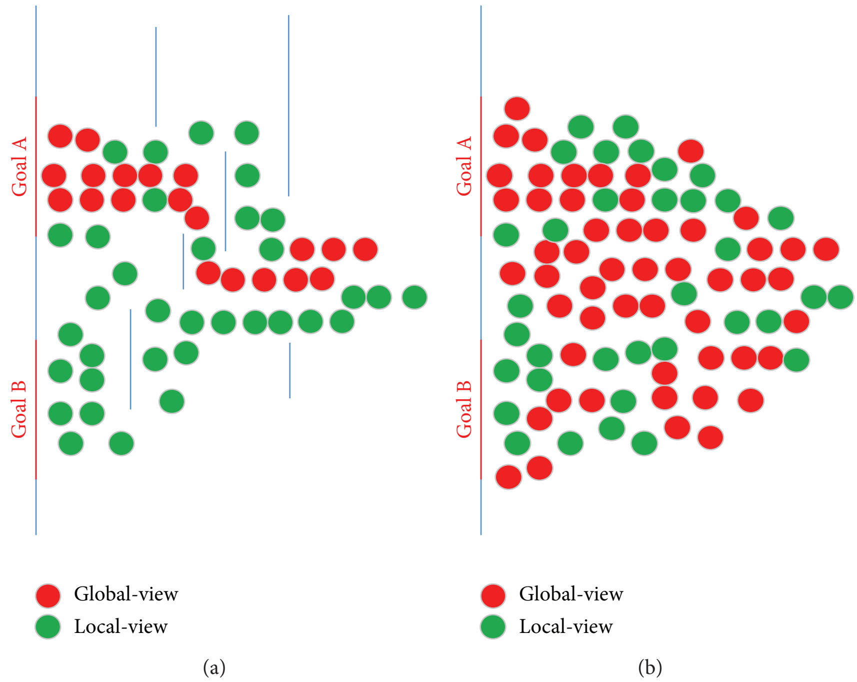
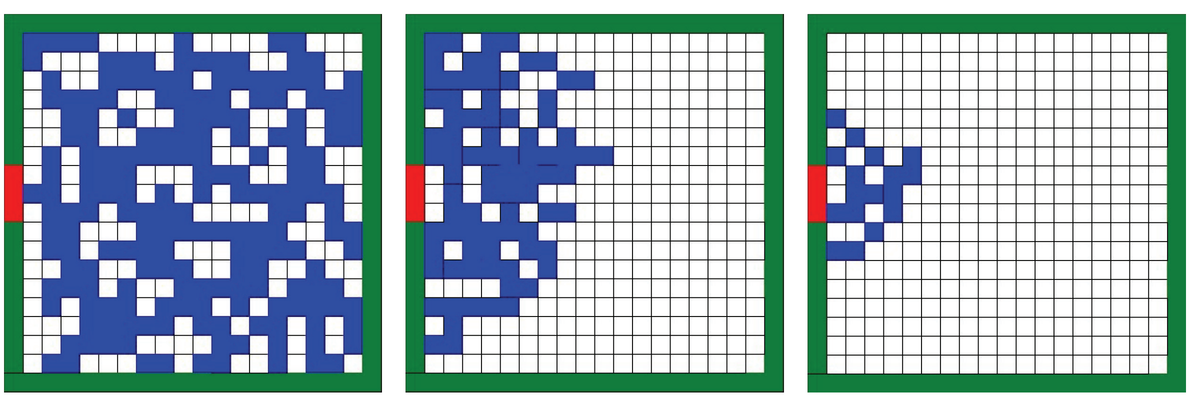
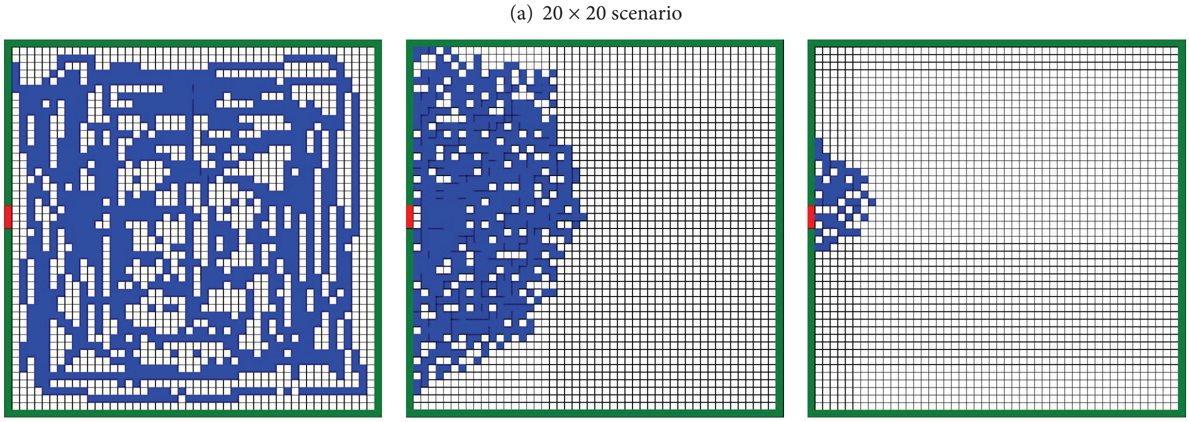


FIGURE 7: (a) The new model we proposed (b) using our model in the simple scenario.

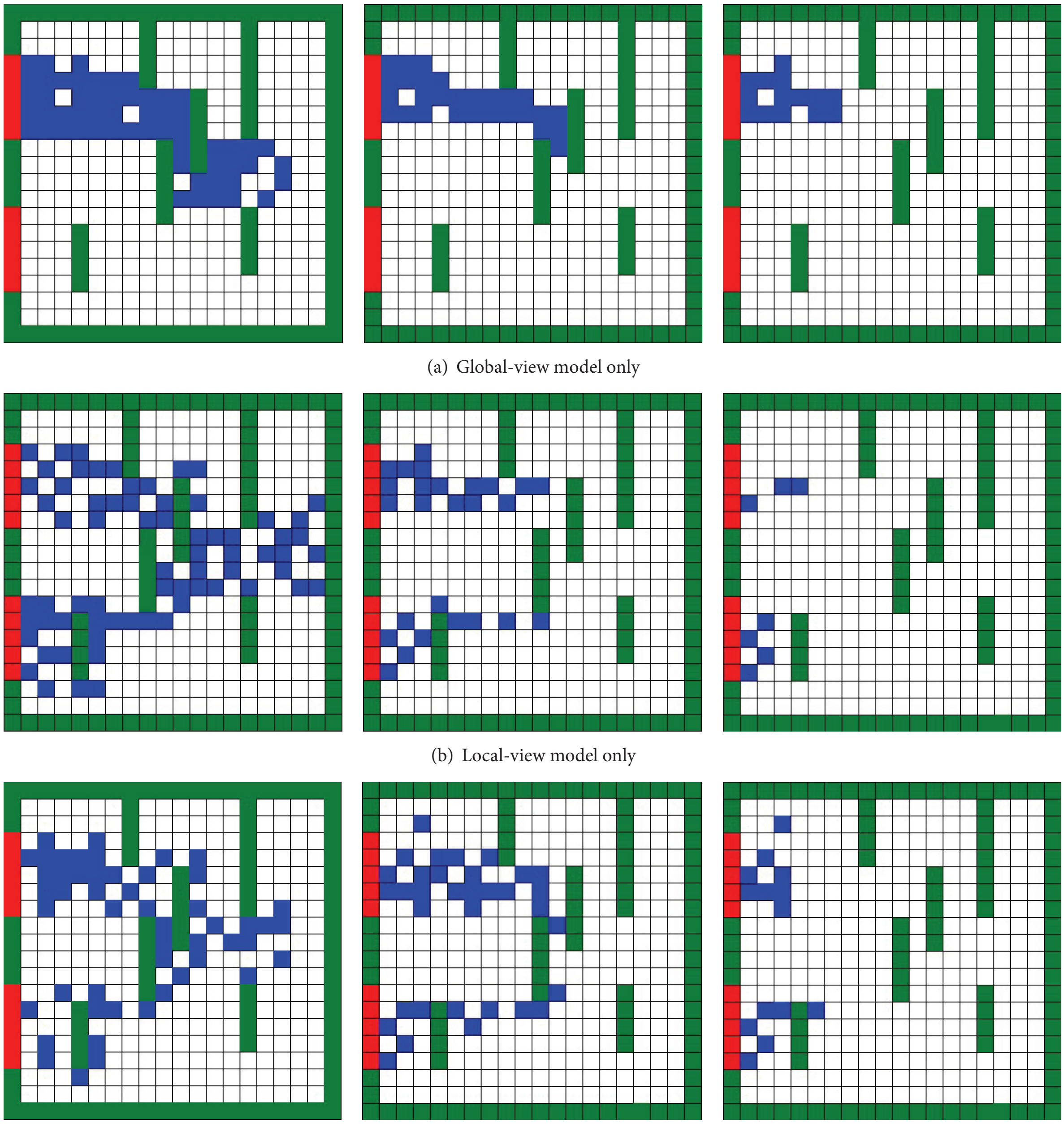


(a) 20 × 20 scenario



(b) 100 × 100 scenario

FIGURE 8: Pedestrian evacuation simulation in simple scenario.



(a) Global-view model only

(b) Local-view model only

(c) Global-view and local-view

Figure 9: Pedestrian evacuation simulation in complex scenario.

the distance to the exit is less than the threshold; then use traditional methods of calculation.

We can see in Figure 4 that the dynamic floor field is more complex; it can be explained as the virtual path left by the pedestrian, and each step goes with the diffuse and decay to the neighbor cells; the diffuse probability is δ, while the decay probability is α, so the dynamic floor field can be regarded as a variable related to δ, α, and t.

3.1.3. The Local-View Floor Field and the Scenario-Familiarity. The local-view model assumed that the pedestrian can find the optimized goal in their visual range. Zeng et al. [8] proposed a local-view floor field model to solve the problem when pedestrians are unaware of the complex scenario (Figure 5); part of the pedestrians may feel blindness in the situation. The local-view floor field model performs better than the global-view model; it is common for a pedestrian to find a temporary goal as the destination, especially in some unfamiliar and complex environment, in people's real life. We analyze the local-view model proposed by Zeng et al. and join it with the standard global-view model; the result is much closer to the real situation.

As shown in Figure 5(a), when pedestrian is at the position A, they cannot see Goal A; although Goal A has

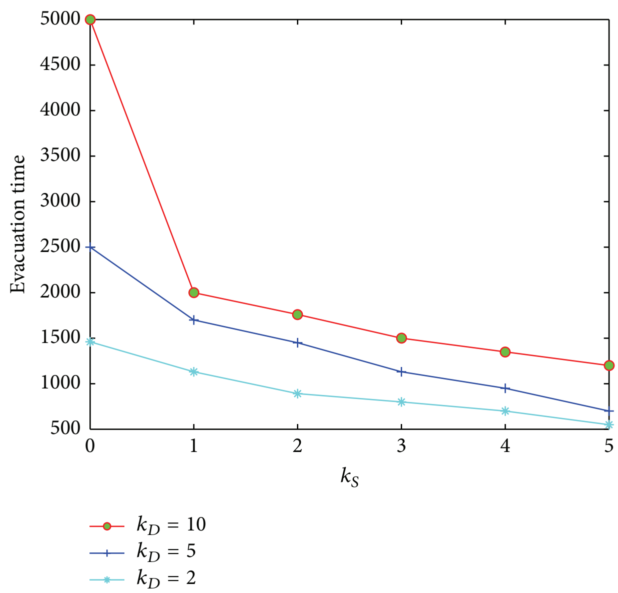


FIGURE 10: The relation between k_S and the evacuation time.

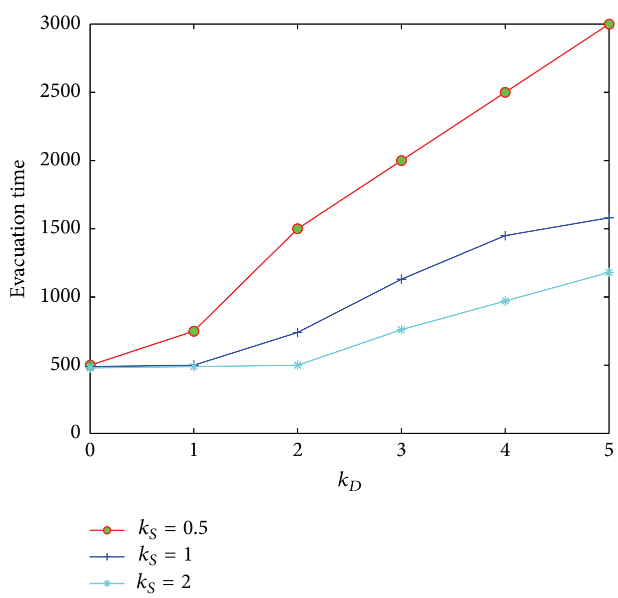


FIGURE 11: The relation between k_D and the evacuation time.

an advantage over Goal B for them, they cannot see Goal B until they move to position B. In Figure 5(b), pedestrians at position A and position B have different goals because of the different visual range; the pedestrian at position B cannot find the final destination, so he just finds a local-view destination instead, and the evacuation efficiency of local-view floor field model was validated to be better than the global-view model by Zeng et al. [8].

In our opinion, using single local-view model only is not live up to the matter of fact, because, in people's real life, part of people may be familiar with the complex scenario while the others are unfamiliar; also some people are in some ways familiar with the scenario. Aiming at this problem, we proposed the parameter of scenario-familiarity; λ indicates the pedestrian familiar degree to the environment.

We analyze the evacuation efficiency of three models in complex scenario; we can see from Figures 6 and 7 that the local-view model has the best evacuation efficiency, because the pedestrian flow is dispersed. The pedestrians have known the final targets in Global-view model, so the pedestrian knows the way to get to the exit, and the density of the flow is high in this model. The global- and local-view model has the weaker efficiency compared to the local-view model only.

3.2. Update Rules. Update rules are mainly aimed at the pedestrian location in each time slice; the dynamic floor field is unified:

(a) The dynamic floor field is mainly influenced by diffuse and decay of neighbors.

(b) To every pedestrian, moving probability p_{ij} is decided by static floor field and dynamic floor field:

$$p_{ij} = \lambda N \exp\left(k_D D_{ij}\right) \exp\left(k_S S_{ij}\right)\left(1-n_{ij}\right)\zeta_{ij},$$
$$N = \left[\sum_{(i,j)} \exp\left(k_D D_{ij}\right) \exp\left(k_S S_{ij}\right)\left(1-n_{ij}\right)\zeta_{ij}\right]^{-1}. \quad (5)$$

(c) The target cell is chosen by the moving probability p_{ij}.

(d) If many pedestrians choose the same cell, compare their willingness probability.

(e) All the pedestrians use parallel update strategy.

3.3. Experiment Flow

(1) Initialization step contains some parameters initializations, such as pedestrian number I, static floor field weight k_S, and the dynamic floor field weight k_D [13].

(2) After initialization, the target cell for pedestrian i can be computed when $i < I + 1$, and then check whether there are conflicts. Then work out all the conflicts. Part of the code is shown in Algorithm 1.

(3) Each pedestrian begins to move until they arrive at the exit when $t < T + 1$. Part of the code is shown in Algorithm 2.

4. Experiment Results

We show the classic floor field model, pedestrian density $\rho = 0.7$, $k_S = 2$, and $k_D = 2$; the pedestrian evacuation in simple scenario is simulated; the process is shown in Figure 8; the 20×20 scenario is too simple, so we use 100×100 scenario instead to estimate the evacuation efficiency; the results of different models in complex scenario are shown in Figure 9.

4.1. Parameters. Figures 10 and 11 showed the change of the evacuation time when we fixed k_S or k_D; it can be seen that the model we choose is similar to the Ansgar Kirchner model, so

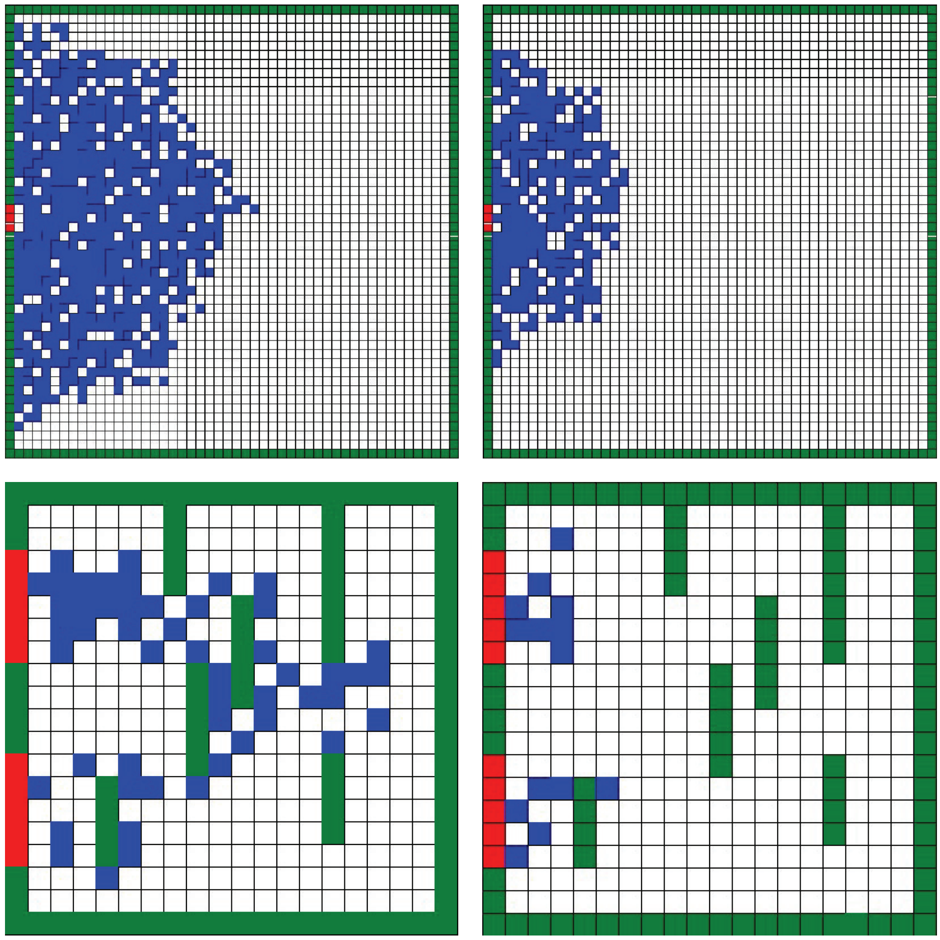


Figure 12: Inertia static floor field experiment.

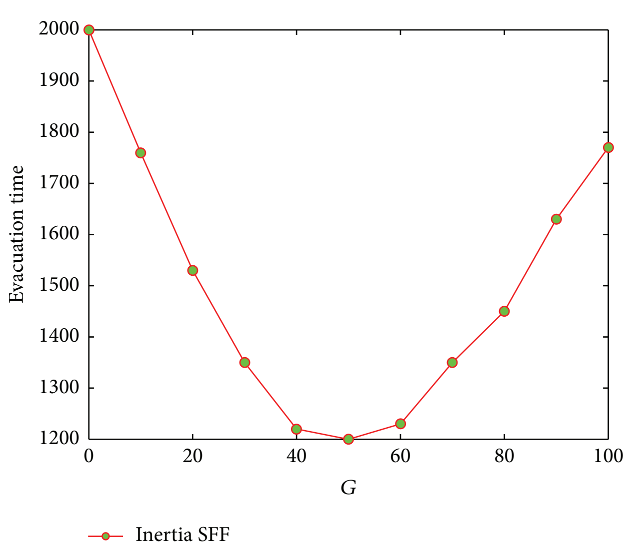


Figure 13: Threshold and the evacuation time.

Table 2: Inertia static floor field.

Evacuation time (MS)	Standard	Use inertia
Simple scenario	214200	164500
Complex scenario	375400	263200

our experiment model is credible. The solid lines in Figure 10 are corresponding to $k_D = 10$, $k_D = 5$, and $k_D = 0$. The solid lines in Figure 11 are corresponding to $k_S = 0.5$, $k_S = 1$, and $k_S = 2$.

4.2. The Inertia Static Floor Field. We mainly discussed the effect of the inertia static floor field and the value of G on the evacuation time shown in Table 2; after 2000 steps, the evacuation result is shown in Figure 12; we can see the inertia static floor field is superior to the standard model.

The inertia static floor field threshold G has strong relation with the indoor space and the number of the pedestrians, so we only analyze the relation between G and total evacuation time in our model. The threshold G can be explained when we bring static floor field into the algorithm. The relation between G and the evacuation time is shown in Figure 13; we can find that there is an optimal value for G.

```
public double MovingProbabilityForOneCell(ArrayList mapList, int i, int j)
{
    ArrayList columnList = (ArrayList)mapList[i - 1];
    FloorFieldModel floorFieldModel = (FloorFieldModel)columnList[j - 1];
    double probability = 0;
    if (floorFieldModel.mapObject == 1 || floorFieldModel.mapObject == 2)
    {
        return probability;
    }
    else if (floorFieldModel.mapObject == 0 || floorFieldModel.mapObject == 3)
    {
        probability = Math.Exp(FloorFieldModel.kd * floorFieldModel.dynamicFloorField + FloorFieldModel.ks
                        * floorFieldModel.staticFloorField);
    }
    return probability;
}
```

Algorithm 1: Part of the code.

```
public void AddAllPedestrianAndExitToList(ArrayList mapList, int row, int column)
{
    int i, j;
    for (i = 0; i < row; i++)
    {
        for (j = 0; j < column; j++)
        {
            ArrayList columnList = (ArrayList)mapList[i];
            FloorFieldModel floorFieldModel = (FloorFieldModel)columnList[j];
            if (floorFieldModel.mapObject == 2) //2 is pedestrian
            {
              pedestrianList.Add(new PedestrianModel(i + 1, j + 1));
            }
            else if (floorFieldModel.mapObject == 3) //3 is exit
            {
              exitList.Add(new ExitModel(i + 1, j + 1));
            }
        }
    }
}
```

Algorithm 2: Part of the code.

5. Conclusion

In this paper, we established pedestrian flow simulation model with dynamic parameters based on cellular automata; the model assumes each pedestrian in the process of choosing the shortest possible route to the destination. Pedestrians during the move quickly and continuously optional on their own trade-offs in different positions, choose a more reasonable position as their next move target position. Model uses the weighting static and dynamic floor field to compute the move probability, detailing the definition of the parameters and the calculation methods of evacuation simulation.

On the basis of the actual analysis experiments Ansgar Kirchner model, we proposed an improved floor field model based on cellular automata. The update rules of the cellular automaton model fully restored classic phenomenon of various evacuation models; through simulation, we analyze the influence of parameters such as threshold values to the model results, show the problems that the interior space crowded evacuation may produce, and measured the optimal threshold of inertia static floor field. The proposed model is more suitable to simulate large plaza and complex structures, as well as some of the fire and other emergency evacuation situations.

Due to the different speeds and destinations of pedestrian movement in different scenes, so as to make the simulation more realistic, we should also introduce a variety of pedestrian movement speed processing mechanisms and clogging mechanism in the future. For depth study on different speeds, different purposes are a new direction. Pedestrians moving direction and the moving distance can be unified into a simulation vector [14]. In addition, in different densities and pedestrians congested states, the individual behavior characteristic of a pedestrian are different; the various social forces [15] factors should be taken into account.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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