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Cellular Automata Simulation of Public Emergency Evacuation Training and Education

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Abstract

Evacuation is the most common action during an extreme disaster. Disaster emergency evacuation training and education based on computer simulation model can reduce the casualties. An improved two-dimensional Cellular Automata (CA) model was built to simulate public building evacuation process. In the model, cellular space and cellular states were defined. Rules of individual's evacuation behavior were established. The CA model adopts the structure with square cells. In the model, Von Neumann neighborhood is applied to decide direction for the occupants. Pedestrians intend to move to the same cell, this conflict is decided by the generating a random number. The tendency of pedestrians and is determined by the distance between one's current coordinate and coordinate of the door. Simple simulation is studied in which pedestrians try to evacuate from a room. A case is study by using the CA model. The model can simulate process of the evacuation effectively. The simulation results of the model can clearly show the influence of building pattern and the initial number of pedestrians of the evacuation process. The model provides effective means for social public security education responding to the disaster.

Keywords: Evacuation, Cellular automata, Disaster, Flood risk, Education.

1. Introduction

The rapid urbanization leads to increase vulnerability of city [1]. Natural disasters research is very important [2-5]. Successful emergency evacuation can avoid casualties effectively. When it is on flooding, ineffective evacuation may cause loss of life and property. Therefore, the study on evacuation simulation is necessary. At the present day, computer simulation is widely used [6,7]. Therefore, Computer simulation model is a main method to study flood evacuation simulation.

As we know, the emergency evacuation is an important measure for preventing and reducing injures and death during large-scale emergency. The efficiency and effect of evacuation is not only based on comprehensively understanding of the emergency situation and evacuation, but also the analysis and judgment of integrated information. By modeling and simulating the crowd movement during emergency in public facility, objective and comprehensive information of the whole evacuation could be provided and help to optimize the preparedness and response planning.

Pedestrian evacuation is very common during emergency. Recently, pedestrian dynamics has been studied by using methods from physics. The methods include the continuum model and the discrete model. Social force (SF) model is a famous continuum models, which has been used in modeling pedestrian dynamics [8].

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Evacuation simulation of evacuation procedures includes how to avoid a collision, bypassing, queuing, returning, and many other complex phenomena may occur. Simulating these processes is one of the difficult tasks in evacuation simulation. However, with the advantages of simple rules and fast computation, discrete models are widely studied to simulation pedestrian flows, including lattice gas (LG) model [9], and extended lattice gas model [10], and cellular automata (CA) models [11]. In these studies, many scenarios have been considered, Counter channel flow, exit dynamics [12], and microscopic forces effect [13]. These achievements show that pedestrian simulation based on CA is effective and become hotspot.

In the next section, the basic evacuation CA model and the rules are introduced. Then, we show the simulation results in Section 3. Finally, the concluding remarks are given in Section 4.

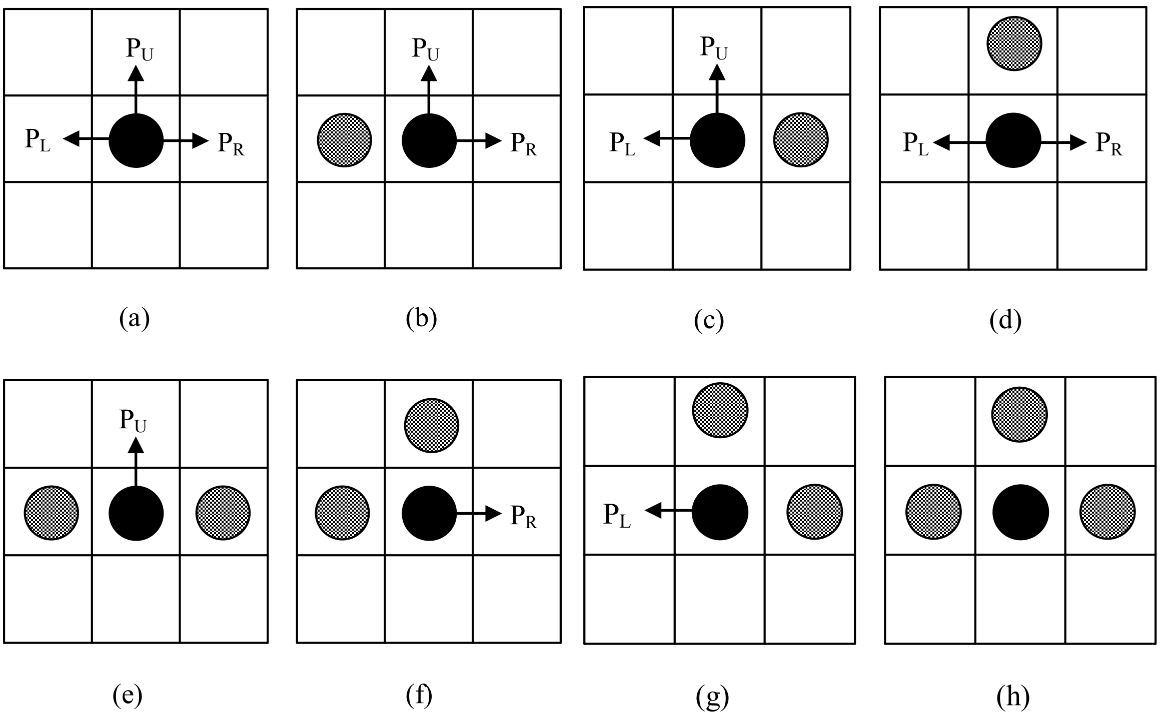

Fig. 1. All possible cases of a walker on the ground.

2. Model description

Cellular Automata (CA) model was first proposed by Von Neumann and Ulam, which is a discrete mathematical model of time, space and status. The CA model constructs the dynamic evolutional systems by interaction among units, has stronger ability of simulating various physical systems and natural phenomena. That's why CA is widely used in social, economic, environmental, geological, biological, and many other areas.

The basic components of CA are Cell, Lattice, Neighbor and Rule. Cellular Automata is formed by a cellular space and the transform functions in this space. CA can be described by the following formula.

$$A=(d,S,N,f) \tag{1}$$

Where A represents a cellular automata system; d is a positive integer, which represents the dimension of cellular automata; S is a set of limited discrete cellular states; N represents the composition of cells in neighborhood space.

Pedestrian CA models consider the situation that occupant walk or craw on the flat ground. Flat ground pedestrian CA models use two-dimensional grids to describe the area. Each cell can be empty, occupied by a pedestrian or by an obstacle. Each cell has a 0.5m*0.5m grid size, and average velocity of pedestrians is around 1m/s.

In the model, Von Neumann neighborhood is applied to decide direction for the occupants. By reference to the Tajima's biased random walkers lattice gas model, biased random direction selection rules for model is developed.

Von Neumann neighborhood model:

$$N_{Neumann} = \{v_i = (v_{ix}, v_{iy}), \left|v_{ix} - v_{ox}\right| + \left|v_{iy} - v_{ox}\right| \le 1, (v_{ix}, v_{iy}) \in Z^2\} \quad (2)$$

Where, V_{ix} , V_{iy}— neighbor cell ranks coordinate value, V_{ox} — center cell ranks coordinate value.

In the model, each pedestrian chooses one of the adjacent cells as object at next time step, if more than one pedestrian wants to enter same cell, randomly assign it to one of them with a certain probability; other pedestrians still stay where they are. The walkers are inhibited from countermove. Fig. 1 shows all possible cases of a walker on the ground. The gray-circle indicates the site occupied by another walker or by an obstacle, the black-circle indicates a walker. The transition probabilities of the walker corresponding to each case are given by the following:

Case (a):

P_U= Ty +(1 − T)/3, P_R= Tx +(1 − T)/3, P_L=(1 − T)/3

Case (b):

P_U= Ty +(1 − T)/2, P_R= Tx +(1 − T)/2, P_L =0

Case (c):

P_U= T +(1 − T)/=2, P_R =0, P_L =(1 − T)/2

Case (d):

P_U =0, P_R = T +(1 − T)/2, P_L =(1 − T)/2

Case (e):

P_U =1, P_R =0, P_L = 0

Case (f):

P_U =0, P_R =0, P_L = 1

Case (g):

P_U =0, P_R =1, P_L = 0

Case (h):

P_U = P_R = P_L = 0

Where, T is the tendency to the preferential direction;

$Tx = T|x - x_0|/(|x - x_0| + |y - y_0|)$ is the x component of the tendency;

$Ty = T|y - y_0|/(|x - x_0| + |y - y_0|)$ is the y component of the tendency;

P is the transition probabilities of the walker,

U is front direction, L is left direction, R is right direction.

Where, (x,y) is the coordinate of the walker; (x_0,y_0) is the coordinate of the exit.

Initially, randomly distributed walkers on the ground and move to exit according to above rule. When a walker arrived at the exit, the walker is removed from the model.

There are some basic assumptions in this simulation as follows.

(1) Pedestrians are distributed randomly in the room.

(2) All the pedestrians' position will be updated in each time step.

(3) If two pedestrians intend to move to the same cell, this conflict is decided by the generating a random number. The bigger value moves.

(4) The main obstacles are the walls towards the door due to the congestion between merging pedestrian flow.

(5) In this model, the interaction between every two pedestrians and that between a pedestrian and the building wall are determined by the distance, if the distance is shorter, the interaction is stronger.

3. Comparison of models

Based on the model established in Section 2, the cellular automata evacuation model is built. The evacuation process in a room is analyzed by computer simulation method.

In a room, 50 pedestrians are distributed randomly at the time of beginning. Each cell has a 0.5m*0.5m grid size; average velocity of pedestrians is around 1m/s. All the pedestrians' position will be updated in each time step. A pedestrian is removed from the simulation system when walking on the building exit. The evacuation clearance time of a building is defined as the last person evacuation from the building. Fig.2-5. show the process of pedestrians walks out a room. Fig.2 shows the initial distribution of pedestrians. Fig.3 shows the evacuation snapshot at 15 time-step. Fig.4 shows the evacuation snapshot at 30 time-step, in this figure, also show congested phenomenon around the corner. Fig.5 shows the evacuation snapshot at 50 time-step.

During the beginning stage, pedestrians quickly move to the building exit, and because of the building exit is narrow, the waiting phenomenon is appeared. As the time step increasing, pedestrians quickly evacuate out from room. In the last stage, there are some pedestrians far from the exit begin out the room. The evacuation process ended at 50 time-step. Fig.6 shows the curve of relationship between evacuation times and number of evacuated pedestrians. It also shows that number of evacuated pedestrians increases with the increase of time. At the beginning of evacuation, pedestrians evacuated slowly because block and high density. During 9 to 16 time-step, evacuation become fast. From results of the model, the process of the evacuation is simulated effectively. The model can clearly reflect the building pattern and the initial number of pedestrians of the evacuation process influence.

Using the CA model, another case is study. At the beginning 150 pedestrians are distributed randomly, show in Fig.7. The cell size, average velocity of pedestrians and the rule of pedestrians are the same as before. Fig.8-10. show the process of pedestrians walks out a room. Fig.8 shows the evacuation snapshot at 45 time-step. Fig.9 shows the evacuation snapshot at 90 time-step, in this figure, also show congested phenomenon around the corner. Fig.10 shows the evacuation snapshot at 135 time-step.

Number of evacuated pedestrians increases with the increase of time in this case. At the beginning of evacuation, because high density and some person are around the exit, pedestrians evacuated fast. As time increasing, because of high density around the corner pedestrians evacuated slowly. Fig.11 shows the curve of relationship between evacuation times and number of evacuated pedestrians.

Fig. 2. Evacuation simulation based on CA model initial distribution of pedestrians(50 pedestrians)

Fig. 3. 50 pedestrians,ime-step=15

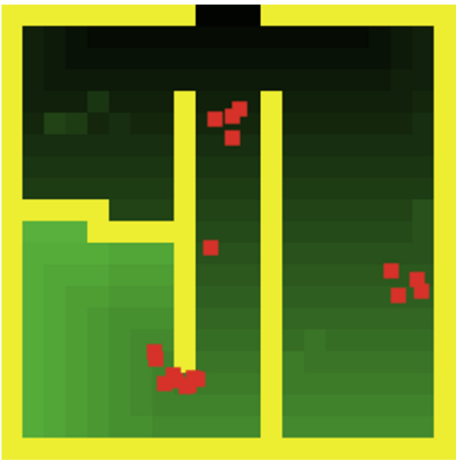

Fig. 4. 50 pedestrians, time-step=30

Fig. 5. 50 pedestrians, time-step=50

Fig. 6. Curve of relationship between evacuation times and number of evacuated pedestrians(50 pedestrians).

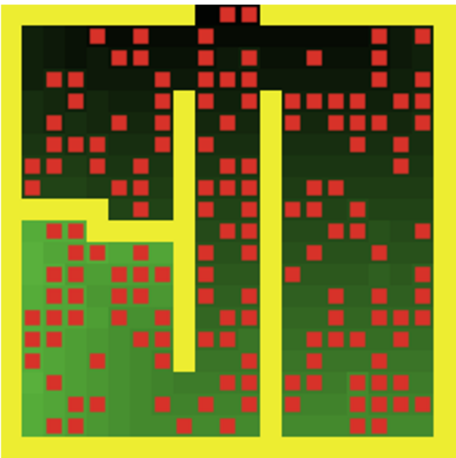

Fig. 7. Evacuation simulation based on CA model initial distribution of pedestrians (150 pedestrians)

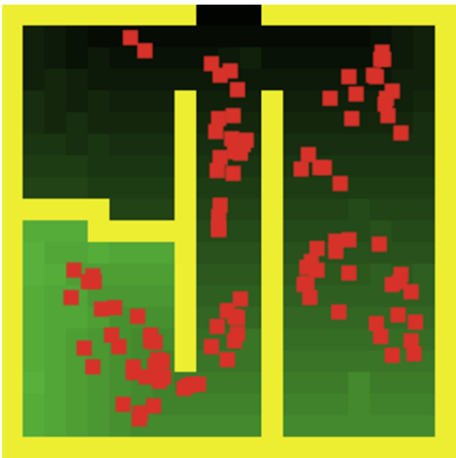

Fig. 8. 150 pedestrians, time-step=45

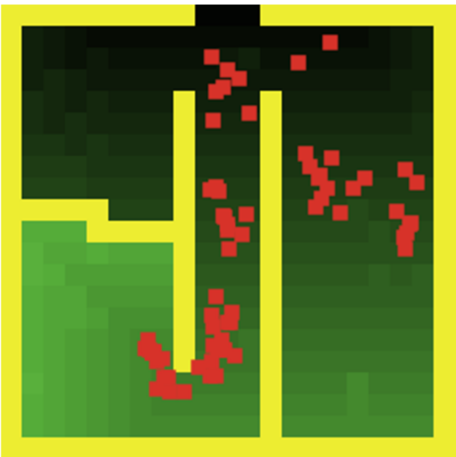

Fig. 9. 150 pedestrians, time-step=90

Fig. 10. 150 pedestrians, time-step=135

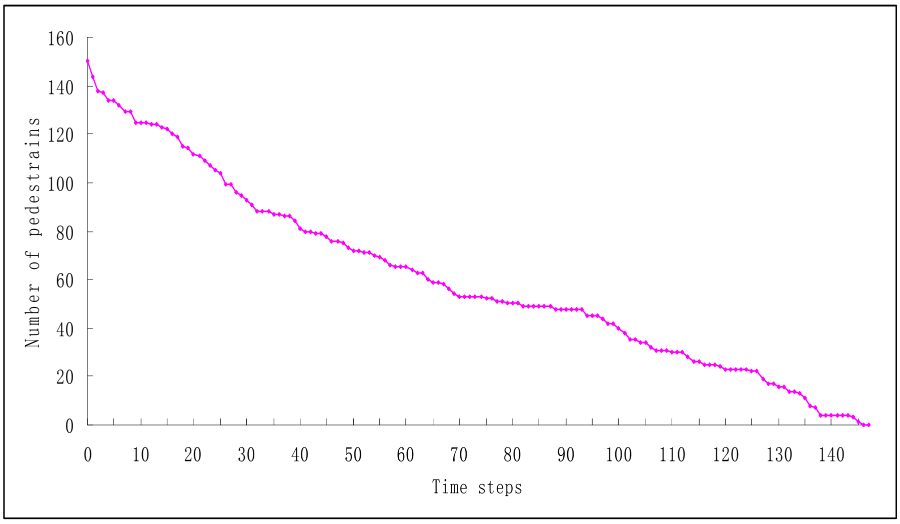

Fig. 11. Curve of relationship between evacuation times and number of evacuated pedestrians(150 pedestrians).

4. Conclusion

Evacuation is the most common action during an extreme disaster. In this paper, an evacuation cellular automata model to simulate the walking on the ground during evacuation is proposed. The research results can make contribution to disaster emergency plan and public emergency evacuation drill and education.

In the model, cellular space and cellular states were defined. Rules of individual's evacuation behavior were established. The CA model adopts the structure with square cells. Simple simulation is studied in which pedestrians try to evacuate from a room. In the model, Von Neumann neighborhood is applied to decide direction for the occupants. Pedestrians intend to move to the same cell, this conflict is decided by the generating a random number. The tendency of pedestrians and is determined by the distance between one's current coordinate and coordinate of the door. In addition, there are some unexpected elements that appear during a real emergency. During an emergency evacuation, pedestrians try to escape from the building as fast as possible, pedestrians' action, emotion and psychology are different from usual condition. Human behavior can significantly impact the performance of an evacuating population, such as carrying items, especially multiple items or large items, tiredness when walking on stairs for long periods, push behavior during walking. In the future research, these factors should be considered.

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