COMPARISON OF TWO MODELS FOR HUMAN EVACUATING SIMULATION IN LARGE BUILDING SPACES

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ABSTRACT

This paper presents the simulated results of human evacuation in a large space building. Two different models, Cellular Automata (CA) model and social force (SF) model are adopted. The simulated evacuation time and main characteristics of human evacuation are simulated and these results by the two models are compared. To check the practicability of the models for actual complicated cases, the simulating time is also compared. The results denote that both the two models can simulate the “arch” and “faster-is-slower” effect for human evacuation. It also could be found that the CA model is easily analyzed and possess fewer CPU time, while the SF model is much easier to be expanded to consider more complicated human behavior models.

KEYWORDS

Human behavior, Simulation, Cellular Automata (CA) model, Social force model introduction

INTRODUCTION

During the last decade, the investigation of vehicle streams by means of experiments and models has captured the interest of many scholars. The statistical physics or fluid-dynamics method was used to reproduce the mechanisms behind many observed phenomena such as different forms of congestion and jamming. Those diverse phenomena between fluids, granular media, vehicles and pedestrians were owing to distinct laws and driving terms. In classical driven many-particle system, there are microscopic, molecular dynamic models, lattice gas automata or cellular automata model, gas models and fluid-dynamic models (Helbing 2001). While in self-driven many-particle system, the driving force is not of external, but is associated with each single particle, an “internal force”, which can represent the motion and mentality characteristics of human beings. Approximately, the human behavior in conflict situations is guided by social fields or social forces (Lewin 1951), an idea that has been put into mathematical terms by Helbing (1995).

While the pedestrian flow dynamics is also closely connected with the traffic stream. So many researchers study the pedestrian flow with the similar methods in traffic flow field. Very recently, Song *et al.* (2006) have studied dynamical features of fire escape panic by applying the improved cellular automata model. They have shown the characteristic features of escape panics: Arching and “faster is slower” of people occur at exit.

In most of the time, human behavior is relaxed and normal, different from the escape panics. So it is essential to research those features in large building space in order to instruct the architects to design buildings more optimized and reasonable, and avoid casualty in emergency cases.

In this paper, we learn to study the human evacuation features in a large-space building. We apply the pedestrian improved cellular automata model (CA) and social force model (SF) to simulate the crowd flow in a large-space building. We calculate the evacuation time and compare the two models’ result. We also simulate the main characteristics of human evacuation, such as “arch” and “faster is slower” effect, and draw the compared conclusions of two pedestrian models.

MODELS

Cellular automata (CA) model

Cellular automata (CA) model is a special many-particle model in which the topological structure is fixed. It is widely applied in both natural science and social science. In this paper, a large-scale building based on genetic cellular automata is established. Cells are used to represent people in the building, who has the capability of self-learning and are affected by the neighboring ones. The topological structure of CA in this paper is a two-dimensional square lattice, which the neighboring relationship can be considered as the *Von Neunann* style (Fig. 1.).

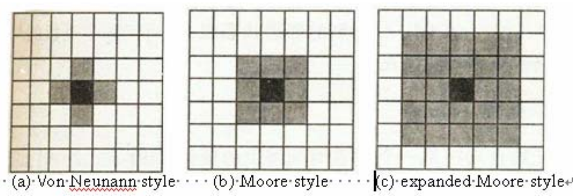

Fig.1. (Zhou et al. 1999) (a-c) shows the three styles of the neighboring relationship. The dark black lattice is the center cell and the gray ones are neighbors. The center cell can only have the interaction with their neighbors.

The two-dimensional simulated room is represented by the square of $L \times L$ sites where *L* is the length of the room. The room was divided into average cells with the square of $0.5 \times 0.5m^2$ which represents an adult. The room has a single exit with width *W*. We assume that people are randomly distributed, initially $t = 0$, over the square space of the room. At the next time $t > 0$, all people in the room move toward the exit. We define the evacuated speed v as the "desired velocity", while the $\Delta t = 0.5/v$ as the "time-step". Update the distributing at every time step and export the map.

People decision includes two steps: first, each person makes a preparatory choice of the neighboring cells by the "distance force law" (Song *et al.*2006.), they chose the lattice among the neighbors and go into it which has the smallest distance to the exit. Second, each person judges and modifies their primary decision. If there are no other people chose the same lattice, this person can walk into the cell in the next time step. But if there are more than one person make the same choice, we should calculate their friction and repulsion probability, then chose the right person enter the target based on our random function.

Fig.2. indicates all possible configurations of repulsion. The black dots and shadows indicate walker and wall. The repulsion probability of the walker corresponding to each configuration is given by the following equation (Song *et al.*2006.):

$$r = \frac{1 - e^{-\alpha V}}{1 + e^{-\alpha V}} \qquad (1)$$

Where α is the rigidity coefficient which generally reflects the possible injury between people and people or people and wall. For configuration (2-a): $\alpha = 1$, for configuration (2-b): $\alpha = 2$.

Fig.3. indicates all possible configurations of friction. The friction probability of the walker corresponding to each configuration is given by the following equation (Song *et al.*2006.):

$$f = \theta \times V \qquad (2)$$

Where θ is the friction coefficient which reflects friction degree between people and people or people and wall. In addition, V is the relative velocity. For configuration (3-a): $\theta = 0.1, V = 2v$, for configuration (3-b): $\theta = 0.1, V = v$, for configuration (3-c): $\theta = 0.5, V = v$.

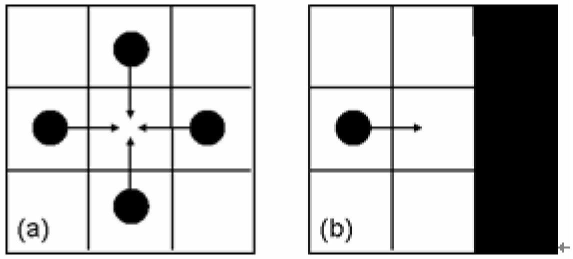

Fig.2. (Song et al.2006.) indicates two possible configurations of repulsion. Fig.(2-a) illustrates the interaction between several people. Fig.(2-b) illustrates the interaction between people and wall.

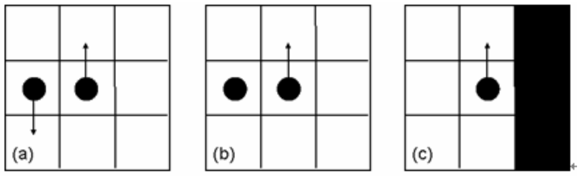

Fig.3. (Song et al.2006.) indicates three possible configurations of friction. Fig. (3-a) illustrates moving vis-à-vis. Fig. (3-b) illustrates the quiescence and movement. Fig. (3-c) illustrates the people and wall.

Social force (SF) model

CA model focus on the particle character of people, but for reliable simulations of pedestrian crowds we do not need to know the motion character of a certain person, we pay more attention on the whole crowd, the fluid character instead. On the other side, human behavior often seems to be chaotic, irregular, and unpredictable, one's own mentality and the interaction between particle bodies make more effect than external environment, so those can not be well simulated by CA model. *Lewin*(1951) suggests an approach for modeling human behavioral changes. According to his idea behavioral changes are guided by so-called *social field* or *social forces*.

In this study, we use the SF model established by *Helbing* (2000). According to his idea, a mixture of socio-psychological and physical forces influences the behavior in a crowd:

The mass of pedestrian is m_i, moving with a certain desired velocity v_i^0, which has a certain direction e_i^0, and a certain characteristic time τ_i.

The interaction force f_{ij} and f_{iW} which represent the velocity-dependent distance to other pedestrian j and walls W.

So in mathematical terms, the change of velocity in time t is then given by the equation:

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0 e_i^0(t) - v_i(t)}{\tau_i} + \sum_{i \neq j} f_{ij} + \sum_{W} f_{iW} \quad (3)$$

Then *Helbing* brings the concept *"psychological tendency"*, and puts f_{ij}, f_{iW} into mathematical terms based on the definition of *"body force"* and *"sliding friction force"*. The change of position $r_i(t)$ is given by the equation $v_i(t) = dr_i/dt$. So we can calculate the position $r_i(t)$ by the twice-definite integral of acceleration.

RESULTS COMPARISON

Both two models simulate the same evacuation process in a single-exit, $15m$ by $15m$ room. The width of the door is $1m$. There are 196 pedestrians in the room. The cell of the room is $0.5 \times 0.5m^2$.

Evacuation time

Table 1.denotes the evacuation time based on the different desired velocity of two models. Both of models consider that the pedestrian can evacuate smoothly within two and a half minute in our case, but the evacuation time calculated by SF is obviously faster than CA. Especially the desired velocity is higher.

The result depends on the different features of two models. In the CA model, we consider more about the interaction between cells, while in the SF model, we pay more attention to the fluid dynamic characteristic of the pedestrian.

Table 1. The evacuation time of two models based on different desired velocity

Desired Velocity(m/s)	Evacuation Time(s)	
	CA model	SF model
0.5	122.12	130.12
1	114.10	105.14
1.5	115.34	88.82
2	118.61	79.97
2.5	120.18	82.10
3	125.42	84.96
3.5	126.82	92.19
4	130.39	93.96
4.5	135.20	99.02
5	136.03	108.95

Although the evacuation time of two models is different, the typical stages of the process are similar. Fig.4. and Fig.5.denotes the patterns formed by walkers going to the exit at four different stages. The desired velocity is $1m/s$.At (a) the beginning stage ($t = 0$), all walkers are distributed and get the basic information of the room, like the location of obstacles and door. At (b) the arching stage ($0 < t < 25$), arching of walkers occurs since only a few walkers go, throughout the exit, outside the hall and most walkers cannot go out from the exit. At (c) the middle stage ($25 < t < 100$), the arching decays and most of pedestrians go out of the exit. At (d) the end stage ($t > 100$), the remaining walkers go out of the exit without choking.

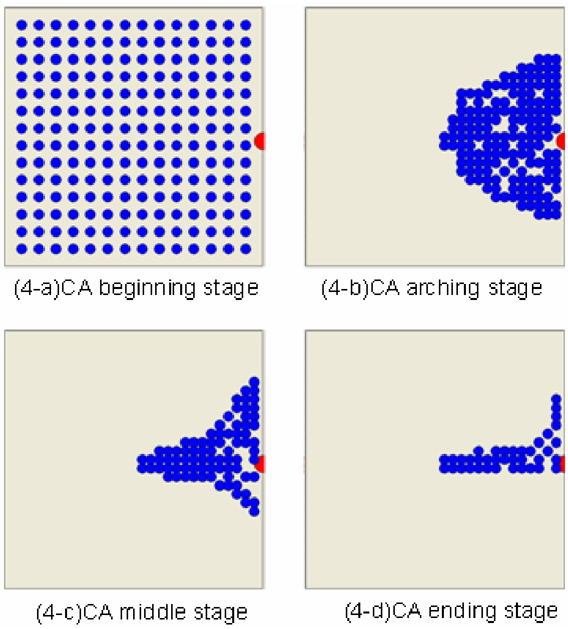

Fig.4. indicates the four typical stages of CA model: the beginning stage, the arching stage, the middle stage and the ending stage.

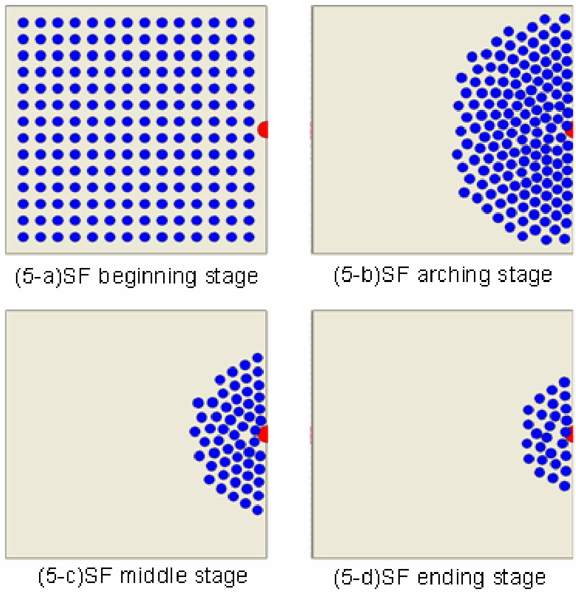

Fig.5.indicates the four typical stages of SF model: the beginning stage, the arching stage, the middle stage and the ending stage.

Arch effect

The result denotes that both the two models could predict the "arch" effect reproduced at the exit, as shown in Fig.6. Because all pedestrians move towards the exit, it becomes a bottleneck of pedestrian flow. The arching phenomenon of both the models is evident.

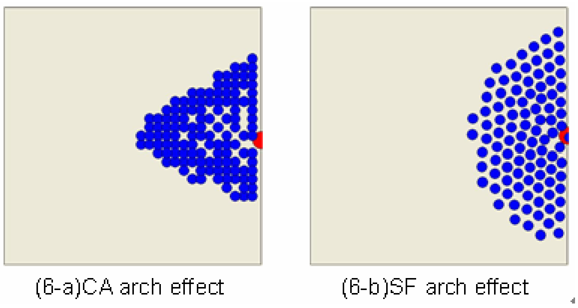

Fig.6. indicates the arching phenomenon of the two models.

Faster is slower effect

If the desired velocity is small, along with its increase, the evacuation time will decrease. However, both two models give a same simulation result that trying to move faster above a speed threshold leads to longer evacuation time. Fig.7 illustrates the faster-is-slower phenomenon reproduced by CA and SF as a comparison. The evacuation time of two models shown here does not decrease monotonously with the increase of desired velocity, but behave a parabola shape instead. Higher desired velocity increases the interaction between people, blocks the pedestrian flow, and reduces the efficiency of leaving. But the speed threshold of two models is different. The turning point of CA model is $1m/s$ in round numbers, half of SF's.

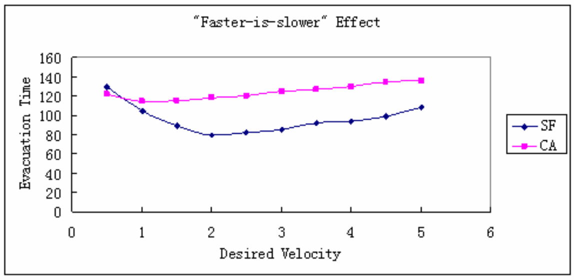

Fig.7. compares the evacuation time of two models and illustrates "faster-is-slower" effect. The upper line is CA model and the nether one is SF model.

Predicting time

We use a same personal computer to calculate all the cases, the CA model needs 5 seconds to finish the calculation approximately, compares 85 seconds of SF model. So the CA model consumes less CPU-time than SF. The main reason is that regulation of SF model is more complex, it should calculate whole people in the room during a time-step, while the CA model just considers the neighboring ones.

RESULTS COMPARISON

Discussion

The current CA and SF models can evaluate the major interactions between pedestrians, such as friction, repulsion and the distance force. They use the randomization of probability or the fluid dynamic features of pedestrian to simulate evacuation case in reality. However both the models have obvious deficiencies. One hand, the parameters of the model should be researched over again. We should design a series of experiment to test the human evacuation behavior so as to confirm the certain parameters. On the other hand, we are now improving the arithmetic and rules and calling for complementary data and additional video material on evacuation to test our model, consider multi-exit, obstacles and three-dimension cases, and implement more complex strategies and interactions.

Conclusion

In this paper, we use the improved CA model to simulate an evacuation case in a large-space two-dimensional room and compare its performance with the SF model. Despite the different types of rules, both of the models can simulate the "arch" and "faster-is-slower" effect. Considering the simple rules, the CA model is easily analyzed and possessed fewer CPU times, while the SF model is much easier to be expanded to consider more complicated human behavior models.

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