Cellular Automata Evacuation Model Considering Information Transfer in Building with Obstacles

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Abstract The buildings are usually divided into two categories in light of whether obstacles exist: the large space with no obstacles (C-type buildings) and the complex buildings with lots of obstacles (L-type buildings). In this paper, considering the aisle region attraction factor, we proposed a revised model which is suitable to simulate the evacuation process in the L-type buildings (such as classroom, theater, and stadium bleacher) based on our original cellular automata occupant evacuation model. Furthermore, the revised model is able to implement the function that transfers real time information of the occupant density at exit area to evacuees. At last, a case study of simulation evacuation process in a theatre was proposed.

Introduction

An emergency occupant evacuation is mainly affected by either individual characteristics factors, including gender, age, education, experience, physical condition and so on, or environmental factors which are twofold, that is, dynamic environment information (i.e. fire spreading, evacuation instructions, and occupant density distribution) and static structural characteristics of the evacuation region. The buildings are usually divided into two categories in light of whether obstacles exist: the large space with no obstacles and the complex buildings with lots of obstacles. The former is usually called C-type buildings because pedestrians can directly move towards the target exits, such as main hall, and squares; in contrast, for the latter buildings, pedestrians have to change their movement direction to sheer obstacles, and the route is like the letter L, therefore this type of structure is L-type buildings, e.g. classroom, theater, stadium bleacher etc.

For evacuation in the C-type buildings, researchers pay considerable attention on the pedestrian distribution characteristics at exit bottleneck[1-3] and the mechanism of phase transition in the large-scale pedestrian flow[4-7]. Generally in the L-type buildings, the mass population evacuation is to a large extent affected by the obstacles. Unfortunately, only little research has been done with respect to

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the effect of obstacles[8-11]. Consequently, it is significant to investigate how apperceive and avoid the obstacles, how to arrange the obstacles, how to design the L-type buildings evacuation routes etc., especially in emergency.

It is crucial to grasp the dynamic real time information accurately for effective evacuation. In order to simulate evacuation process more realistically, a sophisticated model could declare the current environmental information to pedestrians in a particular area, such as information about the change of occupant density near the exit, and the spread of fire smoke, to provide pedestrians a basis for decision-making, or to guide people to choose a more secure and efficient evacuation route.

In this paper, we proposed a revised model which is suitable to simulate the evacuation process in the L-type buildings based on our original cellular automata occupant evacuation model. Furthermore, the revised model is able to transfer the information of the occupant density near the exits to evacuating pedestrians. At last, we investigate an evacuation process in a large theater using this new model.

Model

Cellular automaton [12] is a kind of multi-dimensional systems with finite states whose space and time are both discrete. It is widely used in traffic flow[13-16], occupant evacuation [17-20] and other complex non-linear sciences[21, 22]. In a cellular automata model, individual changes its state according to the states of its neighbors at the last time step, and the entire system updates by communicating and cooperating between individual and individual or between individuals and environment at each discrete time step. When simulated occupant evacuation process, a pedestrian chooses a destination cell for next time step in accordance with the current sates of his or her several neighboring cells.

Space segment and valuation

Building space is first divided into a series of square grids, and each grid is called a cell whose size is typically 0.5 m × 0.5m. At any time step, a cell can be occupied by one person at most. Each cell has a weight value, which we call total attraction value (TAV), representing each cell's attraction degree to pedestrians. In addition, pedestrians choose route based on the TAV. It means that they will select the cell which has large TAV with a larger probability as the target cell at next time step. There are two main aspects affecting the TAV of a cell: the static location information of building structure and the dynamic environmental information in evacuation process.

It is intuitive that the cells which belong to exits or much vacant space are more attractive and corresponding larger TAV. In contrast, the cells occupied by obstacles are smaller TAV since the obstacles will impede pedestrian movement. In addition, people are usually accustomed to follow the footprints of the crowd, namely, following behavior. Our previous model [23-25] has considered lots of factors, such as the exit location, the movement direction of the pedestrian crowd, the repulsion force between people and people or between people and obstacles. In this revised model, considering characteristic of L-type buildings, we introduce aisle area factors, which is considered in similar way as the exits attraction factor because both are static position information, the calculation of TAV can be obtained by the following equation:

$$N_{ij} = \exp[k_s \times (S_1 + S_2) + k_r \times R + k_d \times D]$$

where, S_1 is the attraction of exit position; S_2 is the attraction of aisle region; R is the repulsive force between people and people or between people and obstacles; D is a factor which represents the influence of people around, driven by a psychology of following others; k_s, k_r, k_d are the impact factors of parameters mentioned above, respectively. They are used to determine which parameter plays the dominant role.

The reminder of this section will discuss how to identify each factor:

Two main factors should be considered when calculate the S_1 value of a cell, namely, the distance between cell and exits and pedestrians' familiarity with the exits. In general, S_1 is larger if the cell is closer to the exit or pedestrians are more familiar with the exit. S_1 is identified in two steps: firstly, calculate the distance between the cell (i, j) and the exit k, then choose the minimum as the distance from the cell (i, j) to the exits; the second step is to choose the largest value among distance from all cells to exits as a benchmark, and establish the relative distance value from cell (i, j) to exits. The following type is in details:

$$S_1 = \max\{\min[\alpha_k \cdot \sqrt{(i-e_{1k})^2 + (j-e_{2k})^2}]\} - \min(\alpha_k \cdot \sqrt{(i-e_{1k})^2 + (j-e_{2k})^2})$$

Where, (e_{1k}, e_{2k}) is the coordinates of the exit k; α_k is the degree of familiarity with the exit k.

The establishment of S_2 is shown as the below following: if the cell is in aisle region, then assign; otherwise not be considered. To simplify matter, we assume S_2 is an integer,

$$S_2 = \begin{cases} \lambda & \textit{if the cell } (i, j) \textit{ is aisle region} \\ 0 & \textit{else} \end{cases}$$

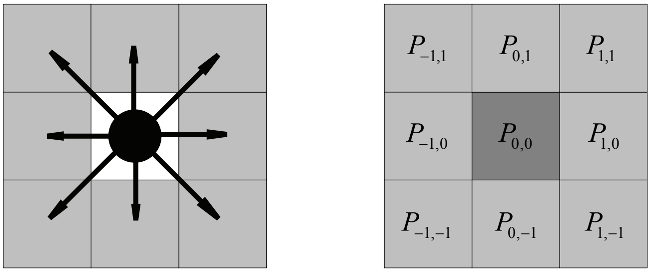
The factors S_1 and S_2 are both static information and cannot be changed during evacuation. The value of each cell is the same for different pedestrians, therefore they can be identified before evacuation. In contrast, the factors R and D are dynamic information, thus their values of cell (i, j) are different for different pedestrians at different time steps. Pedestrians choose movement direction according to local rules. Each cell has 8 neighboring cells at most (see Fig. 1). The values of R and D of the cell (i, j) and its neighboring cells update at each time step. The calculation process is as follows:

$$R = \begin{cases} \beta & \text{if the cell } (i, j) \text{ is occupied} \\ 0 & \text{else} \end{cases}$$

Where, $\beta < 0$, represents the repulsive force between people and people or between people and obstacles;

$$D = \begin{cases} \delta & \text{if the cell } (i, j) \text{ orientats crowd} \\ 0 & \text{else} \end{cases}$$

where, $\delta > 0$, represents the extent of following behavior of pedestrians. By counting all individuals' movement directions within a specific scope of cell (i, j), it could choose the direction which occurs most frequently as the crowd movement direction.



a) Moore neighbor **b) Transition probability**

Fig. 1. Moore neighbor and Transition probability: one pedestrian has 8 possible movement directions at most; the sum of P_{ij} is 1, namely, $\sum_j \sum_i P_{i,j} = 1$

So far, we have given the calculation process of several considered factors in revised model, the impact coefficient k_s, k_r, $k_d \in [0,\ 1]$, and if a coefficient is 0, it represents that we do not consider this factor; similarly, if it is 1, it means that this factor plays a dominant role. In this proposed model, it can be introduced different factors for different situations and for different investigation focus, thus it is an extended model. For example, we may introduce the factor of fire repulsion in fire situation; we can also introduce the impact of the attraction between family members considering the close relationship among a family.

Transition probability

Generally speaking, pedestrians choose preference direction as target for next time step according to combined effects of their neighboring cells' TAV values. Transition probability (see Fig. 1) is given by following type:

$$P_{ij} = \frac{N_{ij}}{\sum N_{ij}} \cdot (1 - n_{ij}) \cdot w_{ij}$$

Where, P_{ij} is the probability for pedestrians transfer to the cell (i, j); n_{ij} is the free coefficient for cell (i, j), if cell (i, j) has been occupied by another pedestrian at current time step, then $n_{ij} = 1$, otherwise $n_{ij} = 0$; in addition if cell (i, j) is occupied by obstacles, then $w_{ij} = 0$, or else $w_{ij} = 1$.

Occupant distribution

Occupant distribution is identified before evacuation simulation, and it mainly includes two aspects: namely, occupant density and occupant initial position. In China, Code of Design on Building Fire Protection and Prevention (GB50016-2006) provides that: the size of evacuation occupants in the video theatre should be calculated by 1.0 persons/m^2 multiplying the building area; and in other entertainment concourses, it should be determined by 0.5 persons/m^2 multiplying the building area. Furthermore, occupant initial position is either randomly or determined distribution. Considering a maximal capacity of L-type buildings, the maximal occupant density determined distribution is chosen, namely, each seat subjects to one people. In following study, we will select this type occupant distribution, if no special instructions are supported.

Until now, we have analyzed several steps of evacuation simulation process, and the whole simulation process is schematically in Fig. 2:

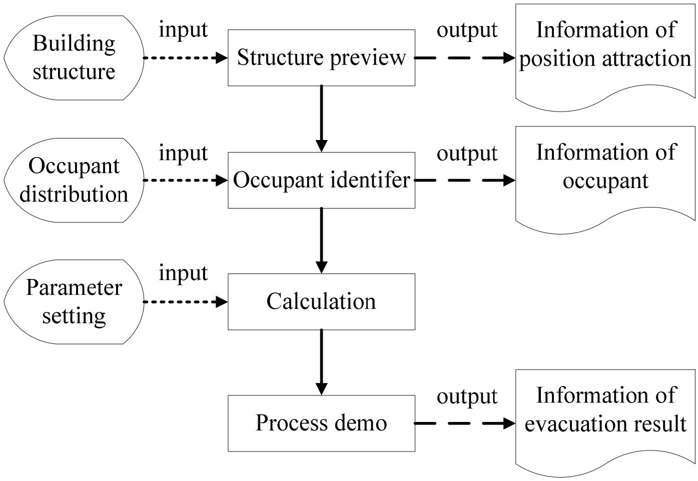


Fig. 2. Schematic drawing of evacuation simulation process

Information transfer

In emergency situation, it is significant to select reasonably a safe escape route for evacuees. Moreover, it is necessary that pedestrians access to real time information when they choose escape route. Thus, in real world, pedestrians often observe rapidly the situation around them to obtain current useful information before they take next action. For example, at an intersection, pedestrians would make a simple comparison about the situation in a visible region (the occupant density in visible region, the aggravating degree of environment, etc.) and then select a branch (turn left or turn right) as the next evacuation direction. In order to simulate evacuation process realistically, it is necessary to introduce information transfer function in an excellent evacuation model, in which pedestrians make decisions according to achieved environment information.

Take a video theater as an example, shown as Fig. 3. There are two exits (exit A and exit B) in front of the theater, 108 seats are arranged in 6 rows and 18 columns, and divided into three parts by four longitudinal passages. There is also a horizontal passage leading to the exits. A rectangular area is defined as the exit area at each exit, and two “message release” (MESSAGE RELEASE 1 and MESSAGE RELEASE 2) are also set at the crossing of longitudinal passages and horizontal passage (see Fig. 3), which transmit occupant density of exit area and update at each time step. Pedestrians decide to turn left or turn right based on the distance to each exit and the information of occupant density.

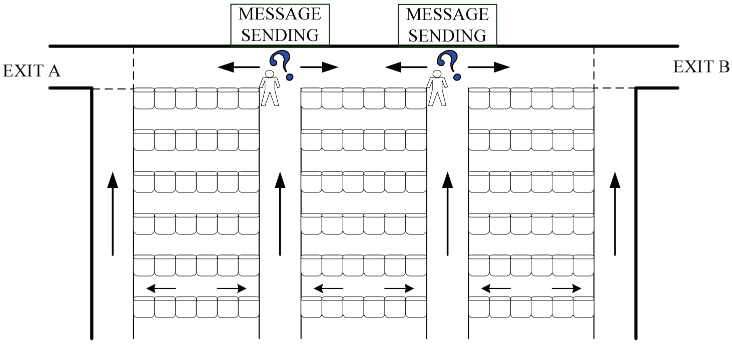


Fig. 3. Schematic illustration of simulation setup

The pedestrians who enter the horizontal passage from the passages close to the wall will evacuate directly out through exit A or exit B. However, the pedestrians entering from the middle longitudinal passages maybe have an alternative evacuation direction. Consequently, evacuees make decision by light of occupant density which received from "MASSAGE RELEASE" and the distance to each exit. The specific flow chart of the comparison process is shown in Fig. 4, where, D_1 and D_2 are the distance to exit A and exit B, respectively; ρ_1 is occupant density of exit area A, similarly, ρ_2 is that of exit area B.

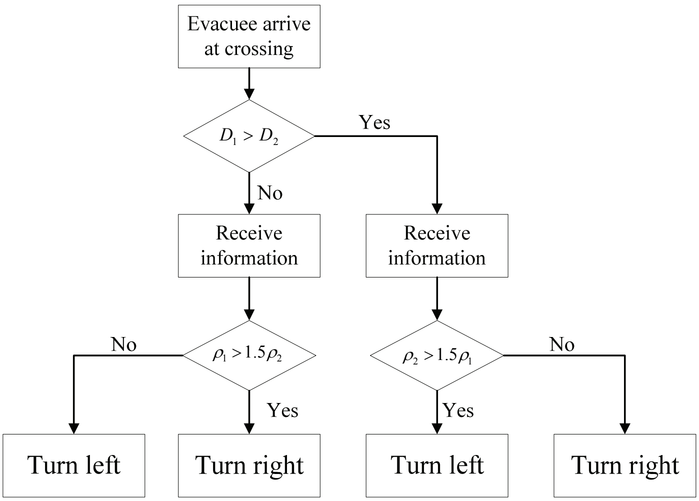


Fig. 4. the specific flow chart of the comparison process

Case study

It is wide to assess building safety by using computer simulation in view of its unique advantages compared with traditional methods: (1) Computer simulation can be applied to assess complex building structures, which is not traditional specification design competent; (2) Compared with evacuation drills, computer simulation is shorter time-consuming, less investment, more security, and will not cause accidents due to poor management; (3) Computer simulation can be applied at structure design stage, and gives suggestions for optimizing design to avoid money-waste, or even rebuilding owing to an unreasonable design.

Based on cellular automata theory mentioned above, we develop a software to simulate an evacuation in a theater. The theater's dimension is the same as that talked in section transfer information (see Fig. 3). In addition, Fig. 5 is snapshots of simulation evacuation process in the theater. Generally, this model is able to reproduce the evacuation process in L-type buildings.

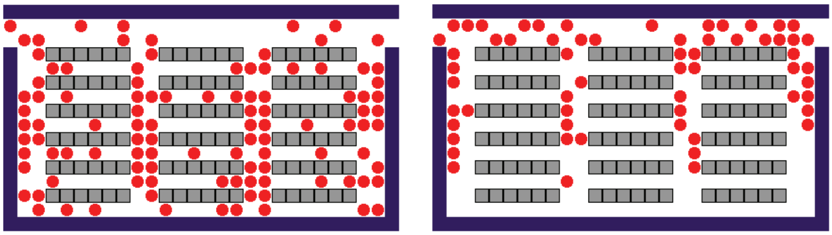


Fig. 5. Snapshots of simulation evacuation process in a theater

Conclusion and future work

We proposed a revised model which is suitable to simulate evacuation process in L-type buildings based on our original cellular automata occupant evacuation model. Furthermore, the revised model is able to implement the function that transfers real time information of the occupant density at exit area to evacuees.

The next phase of research will be to investigate how to arrange obstacles in L-type buildings rationally using this revised model. It is expected to provide suggestions for the design of the internal layout (seats and aisles) of theaters. In addition, we will continue our work focusing on refining the revised model perfectly, for example, to introduce fire effect factor for evacuation in fire. Furthermore, we will analyze the effect of making-decisions by comparison rules, such as occupant density ($\rho_1 > 1.5\rho_2$ or $\rho_2 > 1.5\rho_1$, see Fig. 4). In this paper, an experiment value, 1.5 is chosen.

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