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Public Evacuation Process Modeling and Simulatiaon based on Cellular Automata

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Abstract

Considering attraction of the nearest exit, repulsive force of the fire, barrier and its display style, effect of fire exit location on escape time in fire hazard, a mathematical model of evacuation process model was build based on cellular automatic theory. The program was developed by JavaScript. The influencing factors of evacuation were obtained through the simulation model by inputting crew size, creating initial positions of crew and fire seat stochastically. The experimental results show that the evacuation simulation model with authenticity and validity, which has guiding significance for people evacuation and public escape system design.

Keywords*: evacuation, cellular automata, simulation, javascript*

1. Introduction

In recent years, due to the fire, terrorist attacks, geological disasters such as the public security gradually attracted people's attention; During the design of public facilities, safety evacuation performance has become the crucial factor, so it is of great significance to the evacuation process modeling and Simulation of personnel.The fire caused by many factors in the public security problems happen more frequently, so the modeling and Simulation of evacuation in public places is more significance when breaking out of the fire [1-4].

The evacuation model was studied most based on the distance, density, friction objective factors, this paper based on these factors, considering the advantages and avoid disadvantages, conformity psychological factors as well as the fire smoke spread and other uncertain factors, both to the pedestrian different of age and gender which step to move the distance is different, the evacuation of personnel application of cellular automaton model for further research in emergency fire emergency and evacuation efficiency.

Do a lot of research on the evacuation problem, effect of building plane geometry and the obstacles of personnel evacuation efficiency [5-8]. use the cellular automata model to studying the evacuation process and rules. The model showed a discrete state in time, space and state, can simulate very complicated phenomenon, at the current, domestic research and application more widely.

2. Model Assumptions

Evacuation model need to consider many factors, such as the evacuation space virtualization, evacuation route choice, factors the researcher's evacuation process as well as the various effects, which on evacuation behavior using cellular automata simulation model is the key to research.

2.1. Building Space Model Hypothesis

Set a public place settings in a two-dimensional space, according to the average size of the human body to a two-dimensional space projection, two-dimensional space the evenly divided by rectangular method, each grid into a cell, all cellular together constitute the cellular space, each in the model cellular space can accommodate a individual, its size is 0.5m× 0.5m.

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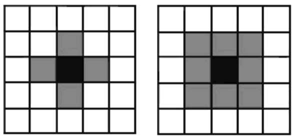
Among the cellular space, each cell can have the three following kinds of state: a building or obstacles to occupy, two persons being occupied, three empty. A two-dimensional array $B(i,j)$ representation space personnel positioning confidence, "2" said buildings or obstacles to occupy, "1" said, "0" is empty. In addition to the cellular set a special attribute to describe the spread of fire scene. If the cellular smoke concentration reaches a certain men are still in it will pose a threat to human life. All cellular (except by the buildings occupy) state are in constant change, cellular state and $t+1$ time step t time shop state and its neighboring cell state related. You can use Von Neumann or Moore two stats [9-11], as shown in Figure 1. In which cellular black center for cellular, grey cell as its neighbors.



(1) Von Neumann (2) Moore
Figure 1. Cellular Automata Neighbor Model

In a two-dimensional plane on the upper left corner vertex at the origin of the two-dimensional coordinates $x-y$ and two-dimensional array rows, columns increasing direction, the grid order in the ranks of direction, it can determine any cellular center $A(i,j)$ coordinates (x,y):

$$x(i,j) = 0.5i - 0.25; y(i,j) = 0.5j - 0.25 \tag{1}$$

2.2. Personnel Model Hypothesis

The same features that are in the process of evacuation, sober, can identify the direction of exports, in the evacuation start time at the same time in order to evacuate, and return not half-way in the evacuation process alternative evacuation routes, with cellular center coordinates to calculate the distance between the center of cell to export.

(1) Initial personnel position: in a cell in the cellular automata, can be randomly generated or according to the actual situation of the preset.

(2) The mobile direction: each person can move to around 4 or 8 cellular, if a cell is a building or personnel occupy, it cannot move in. When a cellular smoke reaches a certain density, if the move is in danger.

(3) The conflict detection: when multiple people choose the same cell is the need for conflict detection. The individual competition ability to resolve conflicts.

$$W = A / D \tag{2}$$

Where A denotes the individual characteristics of evacuation, evacuation personnel of young, the value of A is relatively higher than the individual characteristics of the young and old and sick people. D is the researchers from the target point in the direction of value, is generally believed that the target point in the personnel around when its value is less than in the 4 diagonal directions distance value. If competitiveness is the same, it generates a random sequence of evacuation.

2.3. Evacuation Model

Simulation of complex phenomena, including how to avoid collision bypass, queuing, reentry and other personnel in the process of evacuation behavior after the fire, simulation of these phenomena are difficult problems in evacuation simulation research [12-14]. Starting from the positions in the virtual plane change in this paper, considering the personnel to export the distance and the effect of fire, put forward the basic rule to follow the evacuation, evacuation process simulation of complex phenomena and on this basis.

(1) The evacuation rules

First of all, all the staff will be based on the state of grid and the neighborhood of all grid state to select a mesh grid attraction the highest probability as target grid next time step, then during the evacuation of staff who are always looking for the nearest exit as the goal, this is the most basic behavior pattern; in regard to the fire, the fire around the space threat to the safety of personnel, the fire scene repulsion probability; the grid location attraction and repulsion probability of fire scenario probability are obtained the target mesh time step next. As shown in Figure 2. The next step in the direction of movement and probability. The main basis for individual selection evacuation route several concepts of parameter in this introduction.

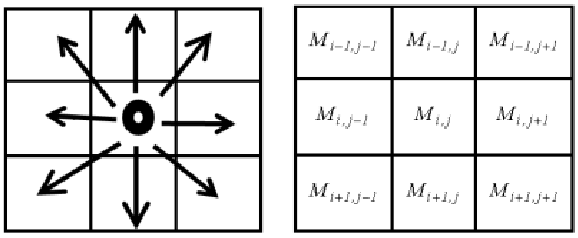


Figure 2. Direction and the Probability may be Moving Next Step

1) Grid location attraction probability:

$$W_1 = \frac{\max d_{(i,j)} - d_{(i,j)}}{\max d_{(i,j)} - \min d_{(i,j)}} \quad (3)$$

Formula: $d(i, j)$ for the grid (i, j) to exit distance; $\max d(i, j)$ distance exports the largest grid distance; $\min d(i, j)$ distance minimum outlet grid distance value. Distance of exit closer to the grid, the greater the probability of its location attraction, and distance from the exit farther, the position probability less attractive.

Researchers first according to the grid location attraction probability, in eight grid of the adjacent grid position selection within the maximum probability of target grid attractive for their.

2) Conflict avoidance rules:

For the more competitive the same person (set the value to "1") also compete with a space grid (set the value to "0"), randomly selects one cell into the space grid, other cellular then go back. The cellular random number "sent back" place needs to determine whether to enter the other space grid, even if the cell reselection walking route, until all the occupying state value target grid "1" will find only the next time step. At this time, completed the first update the cellular state, save the data repeat the above steps can be evacuated the whole process of the grid occupancy, and display in figure.

3) Rules repulsion fire scene:

When a fire occurring, the instinct would be to avoid fire, in order to simulation this instinct, supposes fire on the everyone there is a repulsive field, and the repulsive field decreases with the distance between the people and the fire increases sharply, with each source and field is a vector and all sources and the people field.

As the Formula shows to calculate the force field of the i source and the j personal [15]:

$$p_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \quad (4)$$

$$\theta_{i,j} = arc\cos\frac{(y_i - y_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}, \quad (5)$$

$$\overline{U}_{fire}^{i,j}(p)=\frac{1}{2}k_{fire}(\frac{1}{p+\omega})+\lambda_{fire}p_{fire}, \quad (6)$$

$$\overline{U}_{fire}^{i,j}(p)=\frac{1}{2}k_{fire}(\frac{1}{p+\omega})+\lambda_{fire}p_{fire}, \quad (7)$$

$$\overline{U}_{fire}^{j}(p)=\sum_{i=1}^{n_{fire}}\overline{U}_{fire}^{i,j}(p_{i,j}), \quad (8)$$

(x_i, y_j) is not only the first i fire is also the location of the j personal position, $p_{i,j}$ is j between individuals and the i fire distance, $\theta_{i,j}$ is The angle between the j and the i source, $\overline{U}_{fire}^{i,j}(p)$ is repulsive field between j and the i source, k_{fire} is the repulsion field coefficient fire, ω is fine-tuning index, n_{fire} is the number of fire, λ_{fire} is the Correction coefficient, $\overline{U}_{fire}^{j}(p)$ Is the j person with all fire and electric field strength, According to the vector sum of income.

Each people have the negative gradient fire repulsion and field intensity is proportional to the force, the corresponding calculation formula is as follows:

$$\begin{aligned}\overline{F}_{fire}^{j}(p_{i,j})&=-\nabla\overline{U}_{fire}^{i,j}(p_{i,j})=F_{fire}^{j}(p_{i,j})\\&=k_{fire}(\frac{1}{p+\omega})^2+\lambda_{fire}\end{aligned} \quad (9)$$

$$\overline{F}_{fire}^{j}(p)=\sum_{i=1}^{n_{fire}}\overline{F}_{fire}^{i,j}(p_{i,j}) \quad (10)$$

Among them: $\overline{F}_{fire}^{j}(p_{i,j})$ Is the j by the i fire repulsion, $\overline{F}_{fire}^{j}(p)$ is the resultant force j individuals are all sources of repulsion, in accordance with the vector summation. In summary, the ability of all factors of production $\overrightarrow{F}$, namely:

$$\overrightarrow{F}=\lambda_{re}\overrightarrow{F}_{re}+\lambda_{att}\overrightarrow{F}_{att}+\lambda_{peo}\overrightarrow{F}_{peo}+\lambda_{fire}\overrightarrow{F}_{fire} \quad (11)$$

λ_{re}, λ_{att}, λ_{peo}, λ_{fire} is the export, obstacles, personnel; fire the repulsion weight for weight, larger influence is bigger, according to different circumstances, the weight value by a corresponding adjustment.

(2) The personnel walk algorithm

As the parallel rule, that all the cellular state is also changed. Each cell for the next time step state is determined by the neighborhood of all cellular and its current time step are jointly determined, each cell at each time step can only move or not move.

Consider the cellular $A(i, j)$'s Moore Neighborhood [16], Cellular target grid four areas above, below, left, right, neighborhood and diagonally or own a total of nine neighborhoods for the next time step. Suppose there are two exports, export center coordinates of $01(x_1, y_1), 02(x_2, y_2)$ can be obtained:

$A(i, j)$ To the nearest exit O distance:

$$D(i,j)=\min\left\{\begin{matrix}\sqrt{(0.5i-x_1-0.25)^2+(0.5j-y_1-0.25)^2},\\ \sqrt{(0.5i-x_2-0.25)^2+(0.5j-y_2-0.25)^2}\end{matrix}\right\} \quad (12)$$

$A(i, j)$ To Up and down the four neighborhoods and O point distance respectively:

$$D(i-1,j)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1-0.75)^2+(0.5j-y_1-0.25)^2},\\ \sqrt{(0.5i-x_2-0.75)^2+(0.5j-y_2-0.25)^2}\end{array}\right\} \quad (13)$$

$$D(i+1,j)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1+0.25)^2+(0.5j-y_1-0.25)^2},\\ \sqrt{(0.5i-x_2+0.25)^2+(0.5j-y_2-0.25)^2}\end{array}\right\} \quad (14)$$

$$D(i,j-1)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1-0.25)^2+(0.5j-y_1-0.75)^2},\\ \sqrt{(0.5i-x_2-0.25)^2+(0.5j-y_2-0.75)^2}\end{array}\right\} \quad (15)$$

$$D(i,j+1)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1-0.25)^2+(0.5j-y_1+0.25)^2},\\ \sqrt{(0.5i-x_2-0.25)^2+(0.5j-y_2+0.25)^2}\end{array}\right\} \quad (16)$$

$A(i,j)$ to diagonal four neighborhoods and O points respectively:

$$D(i-1,j-1)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1-0.75)^2+(0.5j-y_1-0.75)^2},\\ \sqrt{(0.5i-x_2-0.75)^2+(0.5j-y_2-0.75)^2}\end{array}\right\} \quad (17)$$

$$D(i-1,j+1)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1-0.75)^2+(0.5j-y_1+0.25)^2},\\ \sqrt{(0.5i-x_2-0.75)^2+(0.5j-y_2+0.25)^2}\end{array}\right\} \quad (18)$$

$$D(i+1,j\text{-}1)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1+0.25)^2+(0.5j-y_1\text{-}0.75)^2},\\ \sqrt{(0.5i-x_2+0.25)^2+(0.5j-y_2-0.75)^2}\end{array}\right\} \quad (19)$$

$$D(i+1,j)=\min\left\{\begin{array}{l}\sqrt{(0.5i-x_1+0.25)^2+(0.5j-y_1\text{-}0.25)^2},\\ \sqrt{(0.5i-x_2+0.25)^2+(0.5j-y_2+0.25)^2}\end{array}\right\} \quad (20)$$

(3) The special treatment of boundary and exit

The cellular boundary, because do not meet the Moore type neighborhood of eight possible direction, this paper will extend the initial two-dimensional matrix around a layer and set to "2" can meet the requirements of the neighborhood (such as black side in Figure 1 Shows), can also be understood this layer for the walls of buildings occupy, for around into this region of domain personnel will be pushed back. For exit may appear as "cell 1", in order not to change the current step for information, need to wait for the target mesh all cellular completely determined later changed "0".

3. Theoretical Model

Cellular automata (Cellular Automaton, CA) model is a simulation of evacuation process model, be first found by Von Neumann and Ulam. Variables of the model in a uniform grid by finite state (or cell) which composed of discrete, decentralized and spatially scalable system [9].

Cellular automaton consists of the most basic including cellular (Cel), cellular space (Lattice), neighborhood (Neighbor), rules (Rule). Each cell in the system and the discrete state limited, do update according to the rules established local effect. Systems of all cellular interactions by simple constitute the dynamic evolution of the whole system. Cellular automata model is not determined by the strict physical function and equation, by cellular series and the interaction rules [10, 11].

Those who similar with the rule models are called cellular automata model, also the cellular automata is a general term for a class of models, or cellular automata is a methodological framework. Cellular automata can be regarded as composed of a cellular space and the definition of the transformation function in the space can be represented by a group of four.

$$CA = (d, S, N, f) \tag{21}$$

Formula (1): CA represents a cellular automata system, d for the cellular space, which is a kind of discrete spatial grid; S is cellular finite discrete state of the collection; N represents a combination of spatial neighborhood within cells, including space vector, different cell states are written as: $N = (S_1, S_2, S_3.....S_n)$, n is a number in the neighborhood of the cell; S_i belongs to Z (integer), $i = (1,2,3,.....n)$; f is changes in the rules, S_n as a local transformation mapping to the function S. Cellular all located in dimensional space d, its location can be an Z_d integer vector to determine.

4. Simulation Analysis on the Assumption

Circumstances personnel in consideration of export in different directions when the evacuation process. And these two kind of situations with and without obstacles and have no fire evacuation process simulation respectively.

(1) Within the building structure of personnel in different circumstances the evacuation process simulation.

In the situation of export of fixed position under consideration has no barriers and obstacles placed respectively, simulation.

Through the simulation of evacuation process, respectively to the different obstacles placed under the evacuation process many simulation results show, in each kind of obstacles placed under the evacuation time with constant. Evacuation time as shown in Table 1 and Figure 3, comparison of different obstacles placed under the staff.

Table 1. Different Obstacles Placed under the Evacuation Time with the Control Table

Random simulation times	No obstacle structure1 (seconds)	Lateral obstructions structure 2 (seconds)	Vertical obstacle structure 3 (seconds)
1	30.5	33.5	39.5
2	30	32.5	38
3	30.5	34	37
4	30	33.5	37
5	30	34	38.5
6	30.5	33	38.5
7	30.25	33.4	38
Average (seconds)	30.5	33.5	39.5

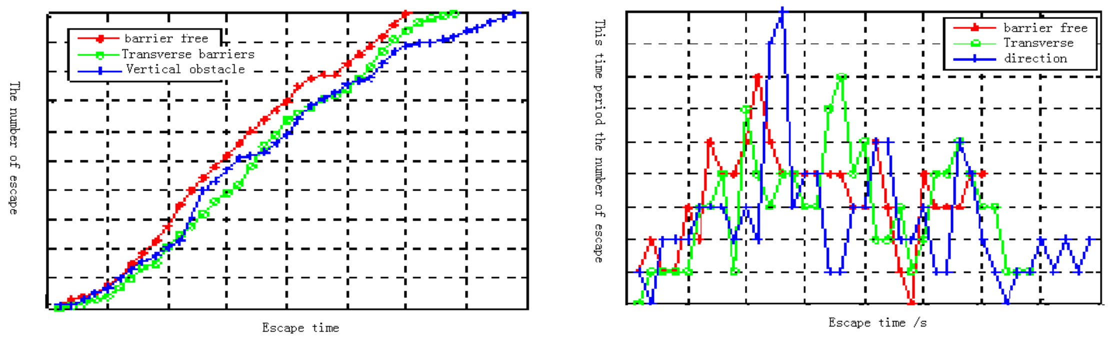


Figure 3. Different Obstacles Placed Escape between Number and Time Form Diagram

In the evacuation began, the different obstacles placed in every time step method have little difference in number of evacuation, evacuation in the late structure 2 because of the tension was lost, obstacles placed with the personnel evacuation path becomes longer, leading to longer evacuation time. While no obstacles in the case of all the personnel evacuation time is

the shortest. It can be concluded: the structure characteristics of buildings to have certain effects on the evacuation efficiency, recommend setting the compartment or placing large goods shelves the best position and exit locations relative in large buildings, when a fire or emergency occurs when the person can judge on the outlet position. If unable to set up inside the building structure, can increase the incentives for staff to find the outlet position.
(2) The simulation process of evacuation exits in different directions.

Have different effects on different export settings May evacuation will be, for export in the simulation process in different directions when the evacuation.

1) Setting export position

Set the outlet position in before simulation, setting area in system parameters, set the corresponding parameters. Consider two kinds of export setting mode, a two outlet is arranged on the diagonal position coordinates of the center for export: $(x_1, y_1) = (30, 0.5)$; $(x_2, y_2) = (0.5, 30)$. Another is the outlet is arranged at the boundary of the same side.

2) Simulation and results of evacuation exits in different orientation analysis

Simulation of evacuation process: a fire evacuation process simulation are respectively arranged on two kinds of exports, many simulation results show that, in each outlet is arranged under each personnel evacuation time difference, fire occurs all the evacuation process time by using a comparison of two export settings, fire occurs all the evacuation process used in time comparison table that two kinds of export settings, as shown in Table 2.

Table 2. Two Export Position All the Time Table of Evacuation

Random simulation times	In the diagonal (seconds)	Located on the side (seconds)
1	29.5	32
2	28.5	34.5
3	28.5	33
4	28	33.5
5	27	32
6	28.5	33
Average (seconds)	28.3	33

It can be concluded: the process of evacuation settings will be medium-sized shopping malls and other buildings of the outlet position of influence, proposed in the large building exports to set too dispersed, finally can be arranged in a diagonal, two planar region, when the fire or emergency personnel to evacuate in the shortest possible time.

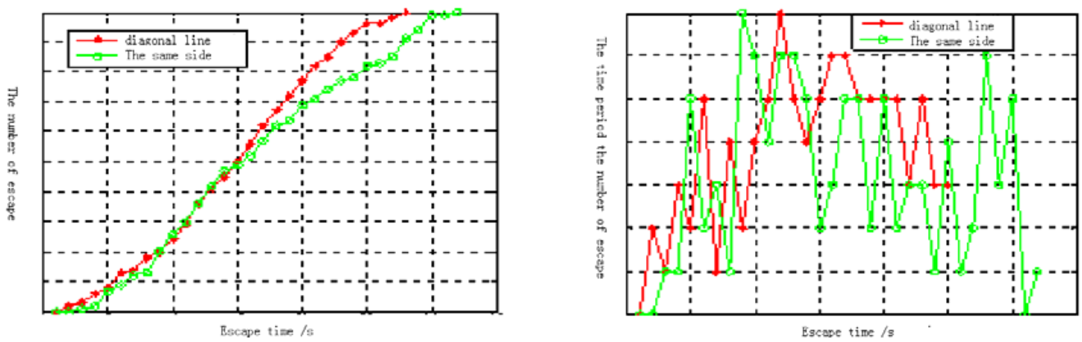


Figure 4. Relationship between the Number and Time of Different Escape Outlet Position

At the same time can increase the incentives for staff to find the outlet position.

Table 2 and Figure 4, experiments that two kinds of export settings in a fire exist all the time difference between the evacuations. In the diagonal export settings because the majority of staff can be selected as the target near an exit, so this way all the evacuation time is the same side outlet is arranged in less time-out coordinates:

$$(x_1, y_1) = (27.5, 30)\ ;\ (x_2, y_2) = (1, 30)\ ; \tag{22}$$

5. Conclusion

The experimental results show that, the same in public places, different internal environment and obstacles in the layout of the evacuation of personnel greatly influence efficiency.The results show, the same size of the public places within the accessibility, personnel flow and average speed generally maintained at a relatively low level, but in this scenario, the pedestrian evacuation efficiency is the highest. Analysis and summary of the above phenomenon reflect the corresponding formulas and rules introduced in the paper the results are in line with reality can be for pedestrians were evacuated to provide a good reference in the real scene. At the same time also provides some experience for optimizing public evacuation plan, in addition to allow pedestrians to take in an emergency evacuation process proper evacuation rules, but also for public construction layout, internal environment settings were optimized. From the study of evacuation medium-sized mall building model of this paper can be seen, the fire and the fire spread is the key factor to influence the efficiency of pedestrian evacuation.

Therefore, in a public place items, as some flammable and explosive articles placed away from the export position, at the same time, fire prevention measures, according to the actual situation to establish some safety isolation in public places, in order to prevent the occurrence of fire, due to the rapid combustion ceiling, electrical equipment, as well as decorative materials flammability and disaster destruction of a larger area, causing a greater loss than loss. In addition, in public places should be equipped with exhaust system is good, in order to prevent pedestrians as the best evacuation routes and blocking due to the spread of fire, had to detour ahead, resulting in delays due to more time to make the danger. In addition, keep the passages and export in public places is smooth, effectively ensures the rapid evacuation of safety protection for pedestrians.

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