A Fire Spread Model Based on Cellular Automaton

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Abstract—**The Drum-Tower District is a historic site in the Inner place of Tianjin which represents the commercial culture, ecdemic culture, exotic culture and civilian culture of Tianjin. The buildings of this region are usually made of wood and other highly combustible materials. Once there be a fire, the influence will be very serious. The study of fire spread model Drum-Tower District is necessary. In the model of fire spread the cellular automaton rules were used. The effects of the different influence coefficients on the evacuation time were investigated, and the typical characteristics of space-time dynamics were analyzed. The numerical simulations show that the model is very good and can be used as a tool to predict fire.**

Keywords-fire spread; cellular automaton; geographic information system (GIS)

I. INTRODUCTION

Many researches have been procedure by the scholars for the development of building fires, but the point which they investigated mainly within only one building or very small places. Also the model which they used only describe the process fires spreading in one single material and and results of one building[1]. Few researchs concerned with two or more building . Therefore the cellular automaton(CA) model was used here for thereasonof it not only can repres ent the whole process, but can also describe the details of the fire spreading. This paper presents a fire spread model for Drum-Tower District of Tianjin based on cellular automaton.

II. PROBLEM FORMULATION AND PRELIMINARIES

In the model of CA，the analysis area is generally divides into equal - sized cells[2]. Each cell is a basic unit in the fire spread model, and the size of cell is determined by the places studied. Each cell has only one state according to the local circumstances. Each cell has the characteristics of the area it belongs to. The situation can change with time. Cells states can be impacted with each other specially for the neighboring cells according to update rules which are deter min ed from exp erience app lied to all the cells in this system[3]. So a bidimensional CA model can be described for the target area. A two-dimensional grid can be created by dividing the research place. The state of each cell can be occupied by something like an obstacle or a pedestrian, also the state of each cell can be empty. One proxy can only occupy one cell at any time. If a proxy occupies a cell, then this proxy occupies the whole place of this cell. If there are two or more materials exist in one cell, the average prope rties are used which generated by the area method or the po wer method specially to handle with average proxy[4]. Of course there will be different situations, we will treat differently The area method me ans that the cell cha ra cteristics were determined by the la rgest mat eri al area in one cell.The cell characteristics are the most important mat erials in this cell in the po wer method. In the CA model, each house is regarded as an agent. We assume the fire can have nine possible action directions.

III. MODEL DESCRIPTION

A. Cell size

The narrow streets and densely-builting houses is the character of old places . In Drum-Tower District, builting are the same which means the house here are generally 2 m to 4 m wide and 4 m to 7 m long. The streets are generally 2 m to 4 m wide. So In this study，3 m by 3 m cells was adopted for the numerical accuracy and computational efficiency balanced within. the model uses two methods in different conditions, when two or more materials exist in cell. in m ost parts of the places，the area method can be used ； but for the power method，it can be only used to the important places, such as the ancient protected buildings area and other important places. AS we know，in Drum-Tower District，there are many protected building.

B. Cell characteristics

In the study of Murosaki et al ,the fire spread model was advanced .It showed that the fire spread most strongly affect by the weather conditions and the building materials [5].

(1) Factors of buildings

The buildings in Drum-Tower District are mainly built of wood and soil and are generally 1 to 3 floors. But as the city develops, more and more modern buildings are now being built with many new buildings being built with a wi de variety of stuffs. The model must include all these situations and should be adaptable to further conditions. people ,in Drum-Tower District, enjoy their lives for the reason of sun-shine and the Haihe river.So the houses here have larger windows which have 4 m to 6 m in size than other regions and placess. Thus, they receive more sunshine; these large windows at the same time allow the fire's spread. It makes the fire spread more speedily and quickly. The buildings in Drum-Tower District were classified as: (1)

brick buildings which have 1,2, or 3 floors, (2) steel and brick buildings which have 1 , 2 , 3 to 6 floors, (3) steel buildings which have 2 to 9 floors, (4) earthen buildings which have 1 or 2 floors, (5) wooden buildings have 1 to 5 floors,and (6) other buildings. The different buildings have different building parameters S and ratios of wood P. Except for the structural factors, the different buildings have different ways to get fire . The equation given by Wakamatsu was used to calculate $P(t_{kl})$.

$$pt(i,j) = \begin{cases} \frac{4.0}{t_2 - t_1} t(i,j) + \frac{0.2 t_2 - 4.2 t_1}{t_2 - t_1}, & t_1 \leq t(i,j) \leq \frac{t_2 - t_1}{5} + t_1 \\ \frac{5}{4(t_2 - t_1)}(-t(i,j) - t_2), & \frac{t_2 - t_1}{5} + t_1 \leq t(i,j) \leq t_2 \end{cases} \quad (1)$$

$$t_1 = (3 + \frac{3a}{8} + \frac{8d}{D})/(1 + 0.1v) \quad (2)$$

$$t_2 = (w_f/5.5)/(A_w\sqrt{H}/A_f) \quad (3)$$

where *pt (i,j)* is the capability for the cell [i,j] to catch the fire to spread. The time t_1 is looked as the cell [kl] starts burning to when it began to spread of fire after catch fire. *a* is the length of one cell ,which usually is 4 m. *d* , which is an unfixed variable, will changes according to the time and conditions[5,6]. For a given certain wind speed , *D* is the fire can spread farthest distance, and calculated by[6]

$$D = 1.15(5 + 0.5V) \quad (4)$$

where *V* is the wind velocity.

For the cell [i,j], the time from the cell get fire to the cell burned out is defined as t_2. The fire load can be presented by w_f . According to the investigation made by the authors, w_f for wooden structures or buildings is 60.0, the fire load of earthen structures or buildings is 45.0, the fire load of brick structures or building is 20.0, and for others structures or building that do not catch fire is 0.0. For doors and windows， A_w is the average open places in each floor. For each floor in one building , A_f is the area and *H* is height of it.

(2) Weather conditions

In the study of Jirou and Kobayashi， the farthest fire spreading distance equation was presented in 1997 [7] . The equation is a function of only the wind direction and velocity. Fig. 1 shows the effect of the wind.
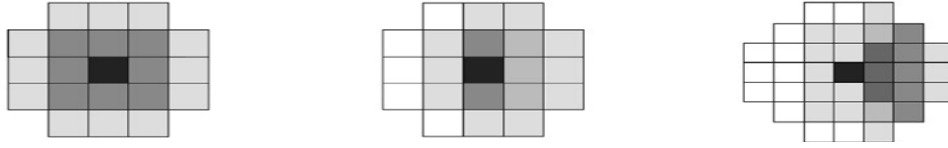

Fig. 1 Effect of wind

C. Cell state

In each cell, the fire situations are: (1) can not be burned; (2) just begun burning, but at that time not able to spread; (3) cells are not burning, but are able to burn; (4) are now burning greatly, and are now beginning to spread, (5) are burned out;. As we know,the transitions of the fire situation have a fixed order. When the fire was catched in a cell , the state of the cell's state will transitie to state (2). The state of the cell will changes from situation(2) to situation (4),sometime after got fire. And also the situation of the cell will never change if the cell is in the situation of (1) or (5).

D. danger degree

When the target cell is chose, we may consider the value of the field of the aim cell and the local density distribution. Here, the total danger degree is defined as follows:

$$D(i + \Delta i, j + \Delta j) = (1 - \beta) \times \frac{G(i + \Delta i, j + \Delta j)}{\sum_{\Delta i'}\sum_{\Delta j'} G(i + \Delta i', j + \Delta j')} + \beta \times \frac{N(i + \Delta i, j + \Delta j)}{\sum_{\Delta i'}\sum_{\Delta j'} N(i + \Delta i', j + \Delta j')} \quad (4)$$

where $N(i+\triangle i,j+\triangle j)$ denotes the number of the houses in the aisles, where the fire of the lattice *(i, j)* passes the cell *(i+△i,j+△j)*and arrives the left (right) , here, *△i=±3, △j=±3)*. If the neighbouring lattice not occupied by a house or others, the values of *G* and *N* are 0, the influence coefficient reflecting the strength of catching fire after the local density distribution is considered, and $0 \leq \beta \leq 1.0$.

IV. SIMULATION AND VISUALIZATION

A. Simulation

The model of fire spreading must know whether the changes of cell[i,j] have between state (2) and (3). The fire spreading judgment index F_{ij} determinthe cell's change probability. Cells with different characteristics have different F_{ij} . The indexes for cell-materials are based on the weather and cell characteristics.

Building rule:$F(i,j)=S_{ij} \cdot P_{ij} \cdot W_{ij} \cdot Pt(i,j) \cdot \alpha \cdot w^\gamma$ (5)

Here, S_{ij} is a building parameter, for wooden places， it be set to 1.0, for steel buildings or places， it be set to 0.0, and for other material， it be set from 0.0 to 1.0. In the materials, the ratio of wood is presented by P_{ij} . And, according to the distance from the burning grid, the wind effect in each cell is presented by w which varies from 0.0 to 0.6. $\alpha(0<\alpha 1)$ is a parameter which it's value can adjust. That's means that it's value is changed to wind effects when the

spreading velocity is small. γ, which determined the range and direction of the fire spreading, also is an suitable parameter to wind. In each cell, W_{ij} is the loading for ability of easy to burn. When $F(i,j)$ is larger than a random value (between 0 and 1),the change between state (2) and state (3) of the situation for the cell will be happen, and having got fire for the cell is defined . When got fire time is more than t_1 , the cell state will be changed to situation (4). When the the cell situation's got fire time is more than t_2 ,it will be changed to situation (5).

B. Simulations result

Based on the GIS model, we developed the Drum-Tower District fire spreading DLL(Dynamic Link Library). The parameters were α =0.2, D =12.0,β =1.1, and d =2.5. For wooden structure w_f =55.0 , P =1.0, for half combustible stuffs w_f =40.0，P=0.7, for almost not combustible stuffs w_f

=15.0 ，P=0.3, and for not combustible stuffs w_f =0.0,P=0.0. Figure 3 shows the Drum-Tower District fire spreading process . The wind was assumed to be from east direction, and the level of it is 3-4 . burning cells be represented by the light gray and the burned out cells be represented by black gray.

Figure 2a shows that the fire has broken out. In Fig. 2b the fire has spread over 1260 m^2. Here, the wind direction is mainly affected the fire spread direction . In Fig. 2c at t =150 min, the fire has burned from cell-buildings to other thinks with 1218 m^2 burned out. Once the other things like trees got fire, the fire spreads become quickly, as shown in Fig. 2d at t=210 min. Therefore, the fire scope and velocity depends on the cell characteristics and some extra conditions.
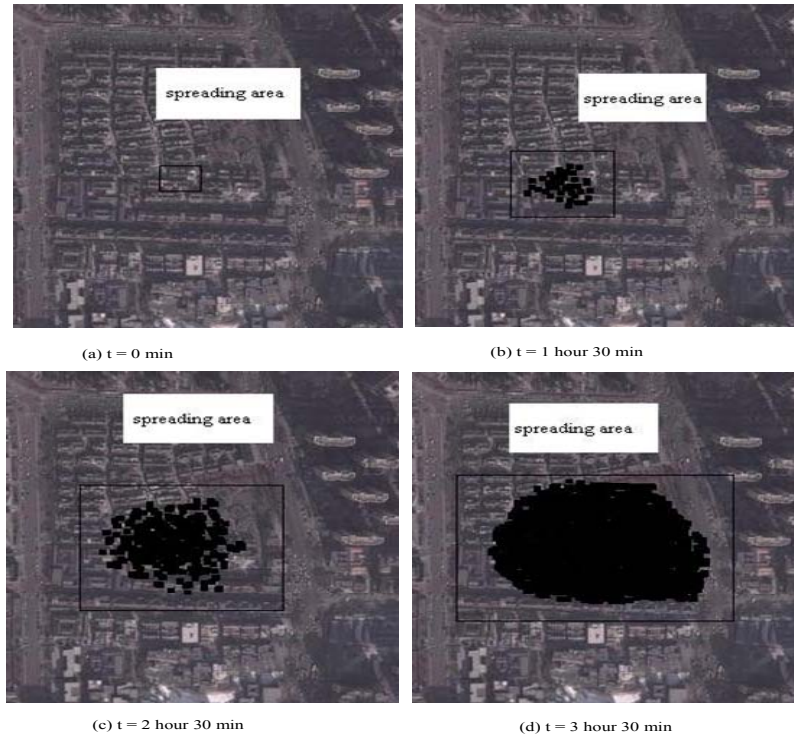

(a) t = 0 min

(b) t = 1 hour 30 min

(c) t = 2 hour 30 min

(d) t = 3 hour 30 min

Fig. 2 Process of fire spreading in Drum-Tower District

V. CONCLUSIONS

This paper introduces a fire spread model for Drum-Tower District in Tianjin, based on a model of CA. According to recommended values in Drum-Tower District, the cell parameters are cell's characteristics, cell's states , and cell's size . The results of simulation in Drum-Tower District show that the model can provide a useful prediction for the fire spreading in Drum-Tower District. Future study be process in future by considering of more parameters such as humidity and the air condition to improve the accuracy.

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