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, ecademic 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 the reason of it not only can represent 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 divided 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 fire spreading. This paper presents a fire spread model for Drum-Tower District of Tianjin based on cellular automaton.

III. MODEL DESCRIPTION

A. Cell size

The narrow streets and densely-builting houses is the character of old places. In Drum-Tower District, building 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 one cell, the average properties are used which generated by the area method or the power method specially to handle with average proxy. Of course there will be different situations, we will treat differently. The area method means that the cell characteristics were determined by the largest material area in one cell. The cell characteristics are the most important materials in this cell in the power method. In the CA model, each house is regarded as an agent. We assume the fire can have nine possible action directions.

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[3].

(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 develop, more and more modern buildings are now being built with many new buildings being built with a 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 places. 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 $P(t_{kl})$.

$$\begin{align*}
pt(i,j) &= \begin{cases} 
0.6 & \frac{t_1 - t_{ij}}{t_e - t_{ij}} \leq t(i, j) \leq \frac{t_1 - t_{ij} + t_1}{5} \\
0.2 & t(i, j) \leq \frac{t_1 - t_{ij}}{t_e - t_{ij}} \\
4/5 & t(i, j) \geq \frac{t_1 - t_{ij} + t_1}{5}
\end{cases} \\
t_e &= (3 + 3a/8 + 8d/21) / (6 + 0.1u) \\
t_{ij} &= (\sqrt{H/A_i} - 5.5 / V) \\
D &= 1.15(5 + 0.5V)
\end{align*}$$

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 $[k,l]$ 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 unfix variable, will changes according to the time and conditions. For a given certain wind speed, $D$ is the fire can spread farthest distance, and calculated by

$$D = 1.15(5 + 0.5V)$$

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, $A_i$ is the average open places in each floor. For each floor in one building, $A_i$ 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](image)

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 now burned out. As we know, the transitions of the fire situation have a fixed order. When the fire was caught in a cell, the state of the cell’s state will transitie to state (2). The state of the cell 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:

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

where $N(i+\Delta i,j+\Delta j)$ denotes the number of the houses in the aisles, where the fire of the lattice $(i,j)$ passes the cell $(i+\Delta i,j+\Delta j)$ and arrives the left (right), here, $\Delta i = \pm 3$, $\Delta j = \pm 3$. If the neighboring 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 $F_d$ determine the cell’s change probability. Cells with different characteristics have different $F_d$. The indexes for cell-materials are based on the weather and cell characteristics.

Building rule: $F(i,j) = S_j \cdot P_j \cdot W_i \cdot \text{pt}(i,j) \cdot \alpha \cdot w^2$ (5)

Here, $S_j$ 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 $P_j$. 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, $\gamma$, which determined the range and direction of the fire spreading, also is an suitable parameter to wind. In each cell, $W_i$ 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 $\alpha=0.2$, $D=12.0$, $\beta=1.1$, 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 affect 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.

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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