Multi-Factor Spread Simulation of Forest Fire Based on CA Model

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***Abstract*—Forest fire is a natural disaster which can cause great economic losses and make eco-environment seriously disordered. In this paper, with Cellular Automata(CA) on its features of simulating complex phenomenon, the influential factors for forest fire are divided into two categories in accordance with the condition that whether the factors are alterable during burning. Forest fire spreading model applicable for the situation in Inner Mongolia is designed and realized.**

Keywords: Forest fire; Cellular Automata; Spread, Simulation

I. INTRODUCTION

Forest in Inner Mongolia occupies a total area of 14.066 square kilometers, which have the reputation of "National Forest Treasure". However, forest is very easy to catch fires due to the dry and windy weather or other unfavorable factors. Forest fire will cause tremendous economic losses and threaten people's safety. If the forest fire and its spreading can be predicted in advance, the decisions will be made in time, which is of great value for forest fire extinguishing.

Cellular Automata(CA) is not only a discrete system in time and space, but also a local grid dynamics model of both spatial interaction and time causality. CA has great advantages in the functions of spatial modeling and figures processing, it can simulate complicated dynamic systems with the consideration of space and time. At present, The CA models have been applied for the modeling research of biological evolution, traffic conditions and city systems, etc. And significant research achievements have been obtained

II. CA MODEL DESCRIPTION

CAs consisting of four basic units, including cells, cell space, neighbors and rules. As well as the cell state. According to specific rules, cell state will change from time to time.

A. Cell Space Division

CAs can be any dimension In theory. The article used a two-dimensional CA, named Moore neighborhood. In this case of the neighbourhood of the (i,j) cell consists of the (i,j) cell itself and of all eight cells which are adjacent and diagonal to it. As shown in Fig 1.

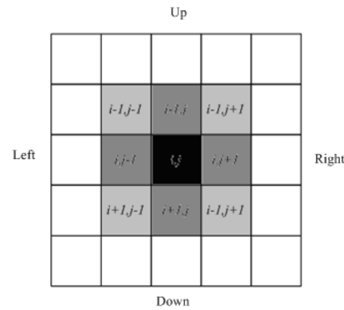


Figure 1. Moore neighborhood

The forests are divided into a matrix of identical square cells, with side length L, and it is represented by a CA. The smaller of this value, the more clearly of the fire details., but that will increase the quantity of computation and data, slowing down the simulation speed.

B. Fire Spread Rate

To combine improved Wang zhengfei forest fire model, given the initial rate of fire spread by(m / min):

$$R_{i,j} = aT + c \quad (1)$$

Where $R_{i,j}$ is the rate of fire speed allocated to the (i,j) cell, without wind, slope and fuel type. T is temperature(□); a is a coefficient equal to 0.053; c is a constant equal to 0.275. At each cell of the CAs is allocated a rate of fire spread, it determines the time needed for a cell to be fully burned out[3].

C. State Function of the Cell

1) State of the cell at time t: The state of (i, j) cell at time t is defined as the ratio of the burned out cell area to the total cell area:

$$S^{t}_{i,j} = A_a / A_b \quad (2)$$

Where, A_a is the burned out (i,j) cell area,
A_b is the total (i,j) cell area.

If A_a= 0, then $S^t_{i,j}$= 0, means the state of the unburned cells is zero; $0<A_a<A_b$, then $0 < S^t_{i,j} <1$, means the state of the burning cells may take any value in berween 0 and 1; A_a= A_b, then $S^t_{i,j}$=1, means the state of the burned out cells is 1. Besides, We can add the state and the attributes of the cells, which based on actual requirements. Attributes are invariable, such as slope, heterogeneous forests, etc, affecting the simulation of forest fire spread.

2) Update the state of the cell: The state of a particular cell after a single time step depends on the state of other cells. In a flat homogeneous forest when on wind blows, the state of a cell at time t+1 is affected by its own state and the state of all eight cells in its neighbourhood at time t. The function of the CA local rule can be expressed as Formula(3).

978-0-7695-3687-3/09 $25.00 © 2009 IEEE
DOI 10.1109/NISS.2009.88

$$S_{i,j}^{t+1} = F(S_{i-1,j-1}^{t}, S_{i-1,j}^{t}, S_{i-1,j+1}^{t}, S_{i,j-1}^{t}, S_{i,j}^{t}, S_{i,j+1}^{t}, S_{i+1,j-1}^{t}, S_{i+1,j}^{t}, S_{i+1,j+1}^{t}) \quad (3)$$

Where, $S^{t}_{i,j}$ and $S^{t+1}_{i,j}$ are the states of the (i,j) cell at time t and at time t+1,respectively.

If a state of the (i,j) cell is unburned and only one of its adjacent neighbour is completely burned out, then the (i, j) cell will be completely burned out after a time step T (s):

$$T = L / R_{i,j} \quad (4)$$

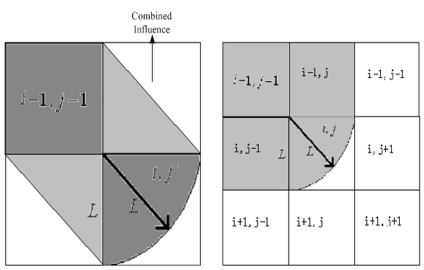
Where L is the cell length (m). Assumed that only one of its diagonal neighbours is completely burned out, the (i,j) cell will be completely burned out after a time step T':

$$T' = \sqrt{2}L / R_{i,j} = \sqrt{2}L \quad (5)$$

Where $\sqrt{2}$ is the length of the diagonal of the cell.

As mentioned above, if the state of only one diagonal cell is 1, at the next time step, its the state will be a quarter section of area of a circle. As shown in Fig 2, after a time step T, the burned out area of the (i,j) cell is $\pi L^2/4$. The state of the (i,j) cell given by Formula(6).

$$S_{i,j}^{t+1} = \pi L^2 / 4L^2 \approx 0.785 \quad (6)$$



(a) (b)

Figure 2. The burned out area of the (i, j) cell after a time step T

If the state of more than one cells in the neighbourhood are in state 1, then the state of the (i, j) cell will be 1. Consequently, the CA local rule can be expressed as Formula(7). It is possible the value of $S^{t+1}_{i,j}$ to be greater than 1. In this case, $S^{t+1}_{i,j}$ is taken to be equal to 1.

$$S_{i,j}^{t+1} = S^{t}_{i,j} + (S_{i-1,j} + S^{t}_{i,j-1} + S^{t}_{i,j+1} + S^{t}_{i+1,j}) + 0.785(S_{i-1,j-1} + S^{t}_{i-1,j+1} + S^{t}_{i+1,j-1} + S^{t}_{i+1,j+1}) \quad (7)$$

Mentioned above,I used visual basic integrated MapX to develop the spread system. Assuming that forest is a flat homogeneous forest when no wind blows, the shape of the fire front would be a circle, as shown in Fig 3.

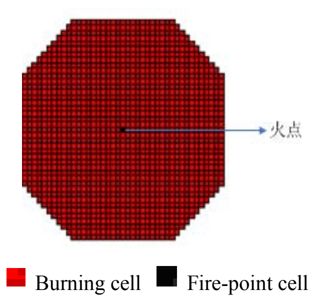


Figure 3. A fire front under an ideal condition

Fig 3 is under the perfect state,but there's no forest like this in the world.We must consider all foctors influenced the forest fire.

III. EFFECT FACTORS OF FOREST FIRE SPREAD AND THEIR CALSSIFICTION

Just considering the meteorological, terrain and fuel type factors influenced fire spread to simplify the CA model. Besides, the barriers such as lake, river and rocks prevented fire spread also acted in the combustion processes. We joined all these factors into the basic CA model to improve it.

A. *Effect of the Variable Factos*

On one hand, the temperature, wind speed and wind direction are variable during the combustion processes and their impacts on fire are externally and continuously. The effect of the temperature has already included in the fire spread formula. On the other hand, the wind speed and wind direction can be regarded as the constants in an infinite small region and time. In order to make the spread model to operate efficiently, we represent the wind speed and direction with a set of discrete date. The density of values of these discrete dates will affect the accuracy of the entire model. However, in real world, when the density of values are large enough, the deviation caused by them often can be ignored.

In order to join the effect of the wind factor into the CA local rule, endowing with a wind weight in each cell state at time t. If there is no wind, all parameters are equal to 1. In the actual conditions, the wind weights vary from time to time. Here, the CA local rule can be expressed as：

$$S_{i,j}^{t+1} = S^{t}_{i,j} + (uS^{t}_{i-1,j} + dS^{t}_{i+1,j} + lS^{t}_{i,j-1} + rS^{t}_{i,j+1}) + 0.785(luS^{t}_{i-1,j-1} + ruS^{t}_{i-1,j+1} + ldS^{t}_{i+1,j-1} + rdS^{t}_{i+1,j+1}) \quad (8)$$

Where u, d, l and r is the wind weights of four adjacent cells in the four directions, which are up, down, left and right, respectively. lu, ru, ld and rd represent the wind weights of four diagonal cells in the diagonal direction.

B. *Effect of the Invariable Factors*

Slope, fuel type and barriers are the inherent attributes of the forest region. These factors would not vary during the combustion processes. For a certain time and place, these factors are assumed to be constants during the combustion processes. The fire spreads slowly when it burns upward the slope while spreads fast when it burns down the slope.

$h_{i,j}$ is the height of the central (i, j) cell. And the (k,l) cell is the adjacent cell of the (i, j) cell, whose height is $h_{k,l}$ Given the difference in height by Formula(9):

$$H_{i,j} = f(h_{k,l} - h_{i,j}) \quad (9)$$

$H_{i,j}$ is the slope coefficient, reflecting the effect which the slope of the adjacent cell influence on the central cell.

s is a correction coefficient, which is used to represent the combustion possibility. Wang zhengfei forest fire spread model aimed at Da Hinggan region. The vegetation is divided into 3 types of fuel, meadow, secondary forest, coniferous forest. The correct values of these fuels are 1.0,0.7,0.4, respectively.

Barriers can effectively prevent forest fire spread. Defined the state of barrier region is -1. If the state of the cell is -1, then the cell will never be burned.

In a word, the CA local rule given by:

$$
\begin{aligned}
S_{i,j}^{t+1} = {} & sS^{t}_{i,j} + (uH_{i-1,j}S^{t}_{i-1,j} + dH_{i+1,j}S^{t}_{i+1,j} + \\
& lH_{i,j-1}S^{t}_{i,j-1} + rH_{i,j+1}S^{t}_{i,j+1}) + 0.785(luH_{i-1,j-1}S^{t}_{i-1,j-1} \\
& + ruH_{i-1,j+1}S^{t}_{i-1,j+1} + ldH_{i+1,j-1}S^{t}_{i+1,j-1} + rdH_{i+1,j+1}S^{t}_{i+1,j+1})
\end{aligned} \tag{10}
$$

IV. SIMULATION RESULTS

Assuming that forest is influenced by meteorology, topography, fuel type and barriers. Fig4(a) is shown the result under an ideal condition with barriers; Fig 4 (b) is the picture that CA is influenced by multi-factor,the wind is blowing from right towards left, the weights were set to the following values:

Fire_Wind_l=0.8	Fire_Wind_r=1.3
Fire_Wind_d=1	Fire_Wind_u=1
Fire_Wind_dl=0.6	Fire_Wind_ul= 0.8
Fire_Wind_dr = 0.8	Fire_Wind_ur = 1.1

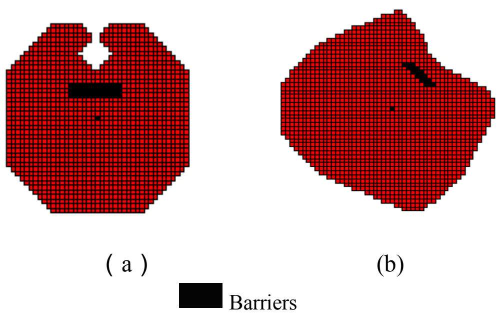


Figure 4. Synthetical simulation results

Specific to request of display terminal, it can be added one more state. As shown in Fig 5, it shows different colors to expressed burning cell and burned out cell.

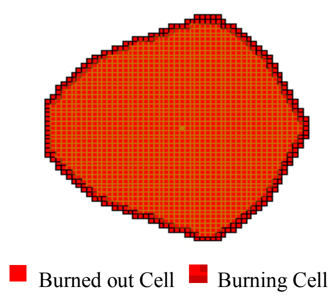


Figure 5. A fire front added a new cell state

Final, combine with decision-making for forest fire rescue platform, the user interface as shown in Fig 6.

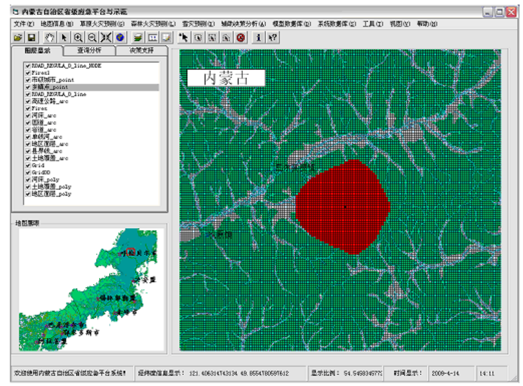


Figure 6. User interface of the forest fire decision-making rescue platform

V. CONCLUSION

The article integrated the CA model and factors influenced forest fire together, and also discussed the way these factors acted in the CA model. Combined the grids generated by Mapx, we make use of VB and Mapx as the further development tool to design and implement the spread system of forest fire based on CA.This model can be adjusted according to the actual situation, and also provide the decision-making for forest fire rescue platform.

ACKNOWLEDGMENT

Project Sources:National Key Technology R&D Program in the 11th Five Year Plan of China:Inner Mongolia Autonomous Region Public Emergency Command Platform Project.

Project Number: 2006BAK01A32.

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