FOREST FIRE SIMULATION USING 2D CELLULAR AUTOMATA

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ABSTRACT: Since many decades different parts of world's forest environment undergo depletion because of many factors but major depletion is due to random forest fires - a state, process, or instance of combustion in which fuel or other material is ignited and combined with oxygen, giving off light, heat and flame. This causes destruction of a building, town, forest etc. In Andhra Pradesh the forest area to geographical area is about 23.2% with dense forest occupying 23,048 km², open forest 19,859 km² and mangrove vegetation of about 383 km². Most dominant forests are dry deciduous and moist deciduous forests. Forecasting the fire spread in forest environment by graphical simulation is useful for prompt fire-fighting and to save natural forest environment of the country. In order to understand the growth and speed of the fire, a simulation is carried out using Cellular Automata.

In this research, we have proposed an ideation to develop an Android based application that simulates the fire spread in the forest environment. For this purpose, 2D-Cellular Automata (CA) is used. Using CA one can forecast the spread of fire and the possibilities of self arresting capability, in a short duration. To achieve this, the map data of the forest area is necessary, which would be obtained by lattice map generation using available methods. The effectiveness of this simulation application depends on the generated map. As a case study 1972 m² area of the Nallamala Forest is modelled and the simulation is carried out by giving several options of the ignition points and results are compared.

1. INTRODUCTION

Globally, large area of forest environment is getting depleted by several factors including forest fire as a major concern. Forest fires affect all the components of natural forest ecosystem (such as species composition, natural vegetation, etc.) and consequently cause irrecoverable damage to the natural forest environment of the country. In order to preserve the natural forest environment of country, better understanding of the factors that causes depletion is needed and necessary management techniques should be exercised. Fire spread simulation is used to understand and to forecast the possible fire behaviour in the forest environment. Fire simulations are used in implementing different aspects of forest fire management schemes. Several forest fire spread simulations have been proposed throughout the world. The method described in this paper is based on 2D-CA.

Presently, with the invention of high performance mobile devices the need of innovation in disaster management in the country has become one of prime importance. The high performance mobile devices is being used for several purposes which includes communication (anytime, anywhere), entertainment, photography, internet access, banking, photography, etc. These devices can also be used effectively in simulating any natural systems. When a forest fire happens, the forest environmental conditions changes drastically with fire spreading rapidly, causing huge damages and casualties. At present most of the forest fire simulations are based on CA approach incorporating the factors that influence fire environment but these simulations are not mobile. To implement the visual simulation in mobile devices, in this research, the spread of fire in forest environment is simulated using 2D-CA approach and ideation to develop an Android based mobile application is proposed.

2. STUDY AREA

The Nallamala Forests show in Figure 1, are a section of the Eastern Ghats which stretch primarily over Kurnool, Mahabubnagar, Guntur, Prakasam and Kadapa districts of the state of Andhra Pradesh, India. They run in a nearly North-South alignment parallel to the Coromandel Coast for close to 430 km between the rivers, Krishna and Pennar. Its northern boundaries are marked by the flat Palnadu basin while in south it merges with the Tirupathi hills. The Nallamala Forests are probably the largest stretch of undisturbed forest in South India apart from the Western Ghats and which covers an area of about 5,161 Sq.Kms in which percentage of plain and hilly area are 34.4% and 61.6% respectively. To carry out the forest fire simulation, a portion of Nallamala Forest area of about 1972 sq.m is modelled, simulated and the results are obtained.

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3. CELLULAR AUTOMATA

Cellular automata were originally proposed by John von Neumann as formal models of self-reproducing organisms (Palash, 2000). CA is a collection of coloured cells on a grid of specified shape that evolves through a number of discrete time steps according to a set of rules based on states of neighbouring cells. CA is a discrete space-time model that can be used to model many complex systems (Unknown). A CA is characterized by four features as shown in Figure 2.: the geometry of underlying medium which contain the cells; the local transition rule; the states of the cell; and the neighbourhood of a cell (Palash, 2000).

4. FOREST FIRE SIMULATION

For the purpose of simulation of the spread of fire in the forest environment, 2D-CA is used. To achieve the simulation of spread of fire, the lattice map data of the forest area under study is generated using an available method which is described in detail. The effectiveness of this simulation depends on the generated map. The possible number of states and state transition rules are formulated and is applied on the lattice map generated, and forest fire simulation is carried out with the help of computer program.

4.1 Lattice Map Generation

The lattice map data of the forest area under study is generated by conventional manual method; that is, the initial state (colour) of each cell in the forest lattice map (grid) is manually input based on the spatial distribution of combustible and incombustible materials (fuels). The lattice map generated by the above described method in this paper restricts the number of possible states (i.e., global state) that a cell can attain in the given grid is 3; that is combustible, incombustible and burnt state. The forest maps considered for the study contain (a) continuous distribution of combustible material (b) discontinuous distribution of combustible and incombustible material varying horizontally. In case of discontinuous distribution of the combustible/incombustible materials (fuels), the state of the cell varied visually; that is the nature of the state of the combustible/incombustible materials (fuels) remains same. The map generated is shown in the figure 3(a), 3(b).

![Figure 1. Nallamala Forest Location Map](image1)

![Figure 2. Cellular Automata Features](image2)

![Figure 3(a) Lattice Map with fuel(s) continuity](image3a)

![Figure 3(b) Lattice Map with fuel(s) discontinuity](image3b)
introduced to differentiate the materials present. The colour of each state is as described below.

- Burning / Burnt State
- Incombustible / Unburnt state (Rock)
- Incombustible / Unburnt state (Water body)
- Combustible state (Grass type – 1)
- Combustible state (Grass type – 2)
- Burning / Burnt State (Vegetation type – 1)
- Burning / Burnt State (Vegetation type – 2)

4.2 Forest Fire Environment

The Forest Fire environment controls the behaviour of fire and its components. Forest fire behaviour can be defined as the manner in which fuels ignite, flames develop, and fire spreads and exhibits other characteristics. The three components of fire environment that control fire behaviour include weather, topography and fuels. In this paper the effect of weather and topography of the forest area is considered to be uniform and the effect of fuel(s) distribution on the rate of spread of fire is studied (i.e., horizontal continuity and discontinuity of fuel distribution) and simulated. For the simulation purpose, the time taken for the fuel to acquire ignition temperature from its normal temperature is taken randomly and the simulation is carried out. Ignition temperature is defined as the temperature which the material must attain to produce self-sustaining combustion. The Ignition time for different material types are taken as given in Table 1.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Ignition time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass type – 1</td>
<td>1.0</td>
</tr>
<tr>
<td>Grass type – 2</td>
<td>1.2</td>
</tr>
<tr>
<td>Vegetation type – 1</td>
<td>3.0</td>
</tr>
<tr>
<td>Vegetation type – 2</td>
<td>4.0</td>
</tr>
</tbody>
</table>

4.3 Forest fire spread transition rule

The spread of forest fire is considered as radial neglecting the effect of weather and topography; that is the fire spreads equally in all the directions. In CA there are several types of neighbourhood, which should be selected based on the physical phenomenon which is to be simulated. In order to simulate the phenomenon of fire behaviour using 2D-CA, the type of neighbourhood selected in this paper is Moore neighbourhood shown in Figure 4. The Moore neighbourhood is a simple square grid (usually 3x3 cells) consisting of 9 cells with the output cell (N9) is at the centre. The state of the output cell depends on states of its surrounding neighbouring cells (N1, N2, N3, N4, N5, N6, N7, and N8); which, in terms of fire spread i.e. spread of fire from one location to another in 2D lattice, depends on the surrounding neighbouring locations. The Transition rule for fire spread is mathematically formulated as shown below.

\[
T_{t+1} = T_r(S_c, S_{n(c)}^{t+1})
\]

Where,

- \( T \) - Finite set of state transition rules
- \( T_{t+1} \) - State of the output cell at time ‘t+1’
- \( T_t \) - State of the output cell at time ‘t’
- \( S_{n(c)}^{t} \) - State of the neighbourhood at time ‘t’
- \( S_c^{t+1} \) - State of the output cell at time ‘t+1’

A CA with S possible states and N neighbourhood (including itself), has \( S^N \) number of possible transition rules. The fire spread transition rule formulated in this paper to simulate forest fire is described as: at least one of the neighbourhood of output cell should be in burning or burnt state at time step ‘t’, to change the state of the output cell from the previous state to burning/burnt state at time step ‘t+1’ as shown in Figure 5.
5. FOREST FIRE SIMULATION OF NALLAMALA FOREST AREA & RESULTS

5.1 Forest Fire Simulation of Nallamala Forest Area – With Fuel Continuity & Discontinuity

The forest fire simulation is carried out for the Nallamala forest area considering various points of ignition, for the following cases and the results are obtained.

5.1.1 Case 1: Fuel continuity with uniform fuel loading

The forest fire simulation is started by choosing the fire ignition point as shown in the Figure 6, and the snapshot of the simulation captured at different time steps \( t = 0, 1, 15, 25 \) are shown in Figure 7, 8, 9, 10 respectively.

5.1.2 Case 2: Fuel Discontinuity with uniform fuel loading

Similarly as the previous case forest fire simulation is started by choosing the fire ignition point as shown in the Figure 11, and the snapshot of the simulation captured at time steps \( t = 0, 1.2, 14.29, 15.49, 23.9, 26.9 \) are shown in Figure 12, 13, 14, 15, 16, 17 respectively.
The above simulated forest fire cases considers only the fuel continuity and discontinuity without considering the weather and topography elements which also influences the rate of spread of fire in the forest environment. The results obtained from the simulation are discussed in the following section.

5.2 Forest Fire Simulation Results

In this study, the lattice map is generated for above discussed two cases and the forest fire simulation is carried out neglecting the effect of weather and topography. A comparative study is carried out to understand the effect of fuel continuity on the fire simulation, since the fuel is also one of the important factor that influence the rate of fire spread in forest environment. The Figure 18 shows the graph plotted between the No. of cells burnt during the simulation and the time steps.

In the first case study, the lattice map generated consists of single fuel type (i.e. Grass type – 1) distributed throughout the forest area considered for study. The time taken for the ignition of the cells is same throughout the lattice (i.e. for the Grass type – 1, the ignition time is randomly taken as 1 s). The simulation time for the spread of fire throughout the forest area is estimated as 34s.

In the second case study, the lattice map generated consists of different types of fuels and incombustibles (such as water body, rock, etc.) distributed randomly throughout the forest area considered for the study. The time taken for the ignition of cells varies depending on the type of cell (refer Table 1 in section 4.2). The simulation time for spread of fire throughout the forest area is estimated as 71s; that is, the simulation is delayed for nearly 36.9s from the simulation carried in the first case study as shown in the above plot. The delay of the simulation is primarily due to the fuel discontinuity - that is different materials ignite at different ignition temperature, which affects the overall ignition time, affecting the rate of spread. Consequently, the simulation produced may be less compatible compared to the reality because of assumptions made and constraints therein.
6. IDEATION FOR DEVELOPMENT OF ANDROID BASED APPLICATION FOR FOREST FIRE SIMULATION

Invent of high performance mobile operating system for electronic devices and in-built GIS feature inspired this study to extend further to ideate the development of Android based mobile application to simulate the forest fire spread. Based on the several survey information the android is known to be the most widely used mobile operating system in India. Development of Android based mobile application to simulate forest fire spread introduces mobile disaster management facility across the globe.

6.1 Ideation

Initially the efforts are put to develop an Android based application based on the simulation algorithm described previously in the study. Earlier for the purpose of theoretical study of simulation C-Programming Language was used in forest fire simulation. To develop Android based application the previous simulation algorithm is to be recoded using Java programming language. The apt user interface is to be designed for the application to make it user friendly that simulates the forest fire spread based on the previous simulation algorithm. The input to the application is lattice map data of the forest area with finite number of states, and the ignition location. For the purpose of generating the lattice map data, modern methods such as electronic housing map, etc. is to be used for improved results.

7. CONCLUSION

In this study, the effect of fuel continuity on rate of fire spread is examined through the forest fire simulation of Nallamala forest area using 2D Cellular Automata. The lattice map is generated by conventional method; that is the information of the forest area is input manually. Two simulation cases such as fuel continuity and discontinuity are considered for comparison and it is found that the rate of spread of fire reduces when there is fuel discontinuity. The simulated results are less compatible with the reality due to some assumption and constraints. Future work on extending the same simulation algorithm by introducing new parameters that incorporate the topography, weather, and other effects were taken into account.

Invent of high performance mobile operating system for electronic devices and in-built GIS feature inspired this study to extend further the ideation of the development of Android based mobile application to simulate the forest fire spread based on the previously discussed simulation algorithm.

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