University of Amsterdam

Assignment 4

Modeling and Simulating (the Spread of) Forest Fires

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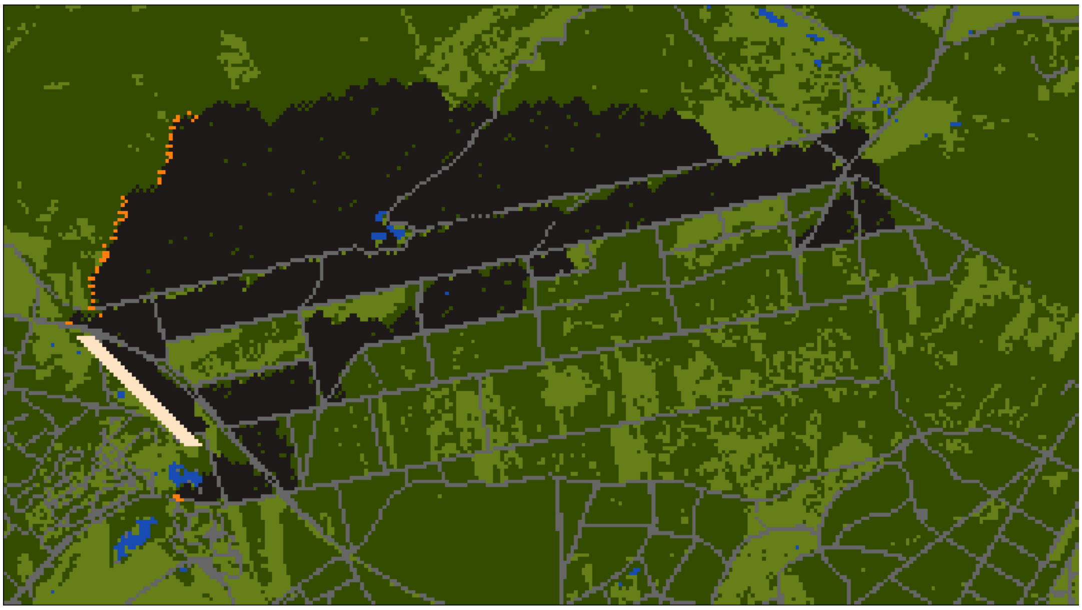


1 Introduction

Forest fires are a serious issue and knowing how they behave is crucial in fighting them or at least minimising the consequences. Simulations can be a great way to find out how forest fires behave without actually setting a forest ablaze. In this report, a newly implemented two dimensional model will be discussed along with the results and findings of the simulations that have been run on this model. The model is based on a forest fire that broke out on Monday 20th of April 2020 at about 1300 hours in National Park 'De Meinweg', the Netherlands. A few mitigiation techniques are discussed and experimented with, namely the usage of a stop line and the deployment of firefighters.

2 Model definition and implementation

2.1 Cell states

The model is implemented as a non-deterministic cellular automaton that makes use of individual two-dimensional cellular automata. Each individual cellular automaton can be in one of four states at any time: fuel/vegetation, fire, burnt or empty/road. A cell with a fuel state can be ignited if certain conditions are met — these conditions will be coverd in the next section. When a cell with a fuel state is ignited, it will transition to a fire state the next time step. After a cell with a fire state has been burning for one time step, it will transition to a burnt state. A cell in a burnt state will stay in the burnt state until the simulation ends, i.e. the cell will not contain fuel or fire anymore during the rest of the simulation. A cell with an empty state does not contain vegetation and therefore can not be ignited.
The model adopts two types of vegetation that grows on the fuel cells: trees and moorland. In addition, the model represents the roads/dirt paths and water bodies in the National Park as empty cells.

Figure 1: Cell states of all tiles of the model

2.2 Probability function

The forest fire propagates according to a certain probability function. This probability function determines the chance that a cell with a fuel state will be ingited by a neighbouring burning cell. The model adopts the probability function as used by Alexandridis et al. (2008) and is implemented as follows: $P_{burn} = P_h(1 + P_{den})(1 + P_{veg})P_w$.

2.2.1 Components of the probability function

- P_h: The probability that a cell with fuel neigbouring a burning cell will ignite at the next time step under no wind conditions. This probability is the complement of the humidity in the forest, i.e. $P_h = (1 - humidity)$.
- P_{dens}: The probability based on the density of the vegetation of a certain cell. For any fuel cells with a normal density, this probability is set to 0 while this probability takes the value of 0.4 for dense fuel cells. These values are based on the work of Mutthulakshmi et al. (2020)
- P_{veg}: Probability based on the type of vegetation of a fuel cell. This probability for the vegetation type moorland and trees is 0 and 0.4 respectively.
- P_w: Probability that is affected by the wind direction and speeds. This probability is calculated using the following formula: $P_w = f_t e^{C_1 V}$ with $f_t = e^{VC_2(\cos\theta - 1)}$. In these formulas V denotes the wind speed, θ corresponds with the angle between the wind direction and the direction of the fire propagation and C_1 and C_2 are both constants. The values of these constants are 0.045 and 0.131 respectively as used by Alexandridis et al. (2008)

3 Fitting the model parameters

To simulate the forest fire in the National Park De Meinweg as closely to the reality as possible the model parameters are fitted using several online resources. Data regarding the weather conditions and the location of the starting fire was gathered from a report written by the Dutch fire department. (Stoevelaar et al. 2020) Data regarding the spatial layout (data about roads, waterbodies, vegetation, etc.) of the forest was gathered from satalite images and vegetation maps (*Kaarten* 2018).

3.1 Weather conditions

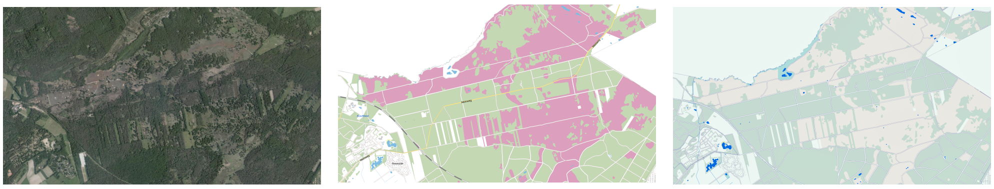
Based on the data gathered by the Dutch fire department, the wind direction parameter was set to 50°. The average wind speed at De Meinweg during the forest fire was approximately 10.2 m/s, however, due to the fast wind gusts it was decided to set the wind speed parameter to 12 m/s. The humidity parameter was set to 43%, the average measured humidity at De Meinweg during the forest fire.

April 20	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
Wind direction	50°	60°	50°	50°	50°	50°	50°
Wind speed	9m/s	10m/s	11m/s	11m/s	11m/s	10m/s	10m/s
Maximum wind gust	12m/s	14m/s	14m/s	14m/s	16m/s	16m/s	15m/s
Humidity	50%	46%	44%	42%	41%	41%	40%

Table 1: Weather conditions at De Meinweg on the 20th of April 2020

3.2 Spatial layout

Three different kinds of maps were used to determine the kind of cells needed to fit the model according the spatial layout of De Meinweg. A satelite map, a roadmap and a waterbodies map were used to determine which cells were supposed to be fuel cells, empty/road cells and empty/water cells respectively.



Satellite   Roadmap   Waterbodies

Figure 2: Original imagery, taken from (*Kaarten* 2018)

For the satellite image an Otsu filter was used to seperate the trees from the moor landscape. Below the threshold is moor landscape and above is considered trees. As you can see in the first image of 3 the trees in the satellite image are well represented. Furthermore the national park contains some roads. These also affect the spreading of fire. Since they are not clearly visible on the satellite photo a road map was taken from (*Kaarten* 2018) as well, as visible in 2. This was converted to grayscale after which a dilation and skeletonize algorithm with threshold returned the bitmap. Result of this is visible in the second image in 3. The last bitmap is the water body. The blue value is filtered out of the image with a threshhold and a bitmap created from it, visible in the last picture.

All images were downscaled by a factor of 5 as 1460x810 cells would take up too much resources to run experiments of sufficient sizes. The bitmaps are read in and the configuration is initialized by only Moor landscape. Trees are placed, roads are placed and water is placed based on the bitmaps. The Meinweg forest fire situation is now properly configured.

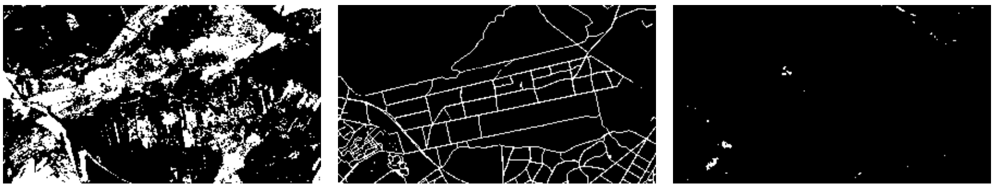


Figure 3: Resulting bitmaps of trees, roads and waterbodies, respectively.

3.3 Comparison reality

A comparison has been made to check if the current model parameters are correctly fitted so that the model reflects the reality as closely as possible. To make this comparison, a simulation has been made with the fitted parameters. The result of this simulation has been laid next to a map with indicators of the fire direction made by the Dutch fire department. After comparing the model with this map the model was found to be a accurate representation of the reality.

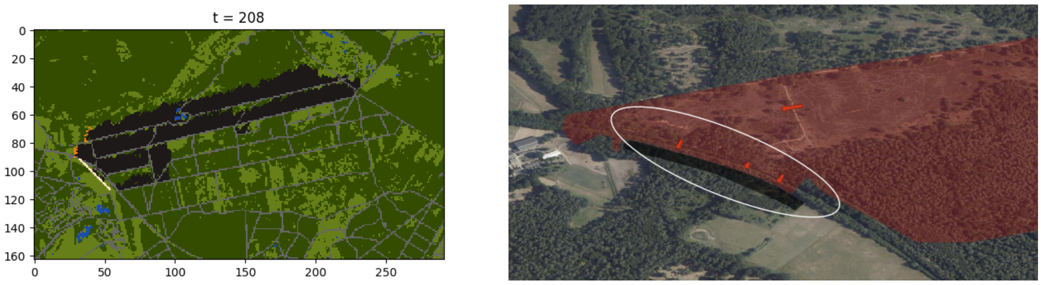


Figure 4: Comparison model and de Meinweg forest with firebreak

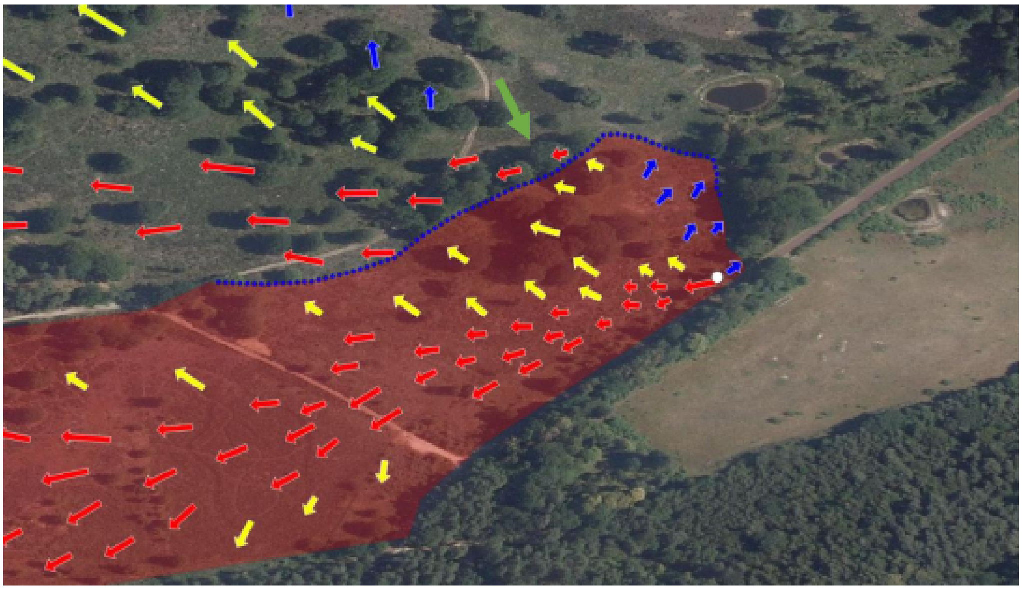


Figure 5: Map with indicators of fire direction. Red = parallel the wind direction, yellow = perpendicular to wind direction, blue = against the wind direction

4 Experiments and analysis

4.1 Experiments

The goal of the first experiments was to research the **critical density** of the model. To research this, several experiments have been run. These experiments consist of calculating the percentage of burnt vegetation out of the total vegetation over 210 simulations. Since the fire propagation largely depends on the humidity, all model parameter except the humidity were set to the same value for each experiment. The values for the humidity, however, ranged from 0 to 1 with increments of 0.05. For each value for the humidity, the model has been run 10 times. Because of the fact that this expirement critical density deemed to research the critcal density as objectively as possible, each simulation was run in a randomly generated forest. These forests had the following characteristics: width = 150, height = 150, vegetation density = 0.9 and tree/moorland ratio = 0.7.

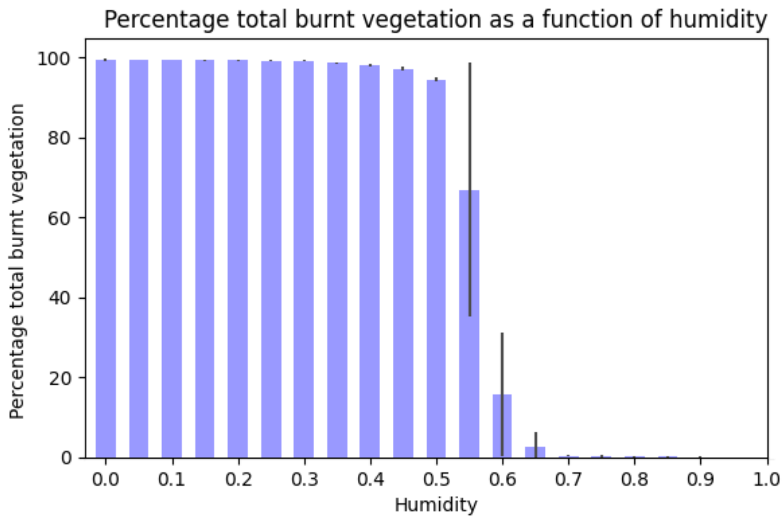


Figure 6: Average percentage total burnt vegetation as a function of humidity.

For the second set of experiments inspiration was taken from the mitigation technique used in the forest fire at Herkenbosch (Stoevelaar et al. 2020). Vehicles from the Dutch Ministry of Defence created a firebreak (or stopline as directly translated). Military tanks completely cleared a large strip of its vegetation. Therefore there is no fuel anymore for the fire to spread. In the casus we examined the firebreak line was placed just below the railroad. It is placed perpendicular to the wind direction for maximum effect. Just like the first set of experiments, the second set of experiments consist of calculating the percentage burnt vegetation out of the total vegetation over 300 simulations. However, in the second set, the forest used in the simulations is the De Meinweg model. In the expirements, a total of four different chosen placements of the firebreak were simulated. For each different placement, the length of the firebreak took a total of five different values (10, 20, 30, 40 and 50 tiles). Each placement and length pair was then run 10 times.

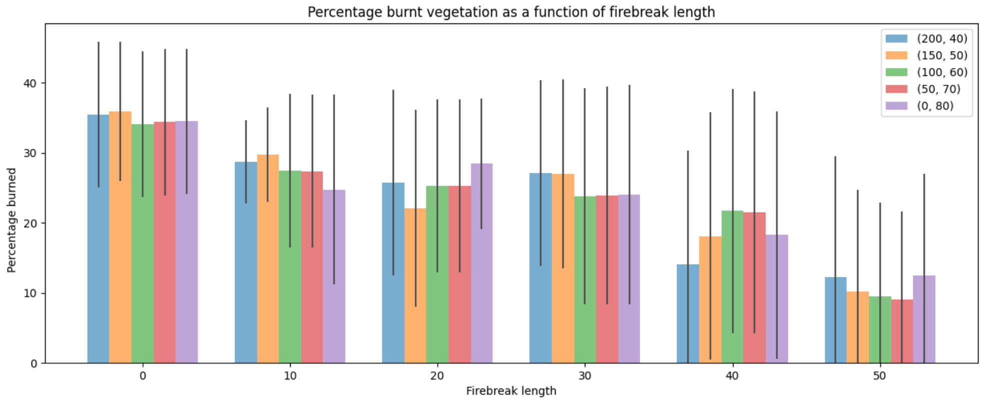


Figure 7: Average percentage total burnt vegetation as a function of firebreak length.

4.2 Analysis

From the results of the first set of experiments, it can be noticed that somewhere between the values 0.5 and 0.6 for the humidity, the percentage of burnt vegetation dramatically decreases. Thus, the results empirically imply that the critical density of the humidity in the model is 0.55 ± 0.05

The results of the second set of experiments implies that a different location of the firebreak has a relatively small impact. Furthermore, it can be noticed that increasing the firebreak length leads to smaller portion burnt forest.

References

Alexandridis, A. et al. (2008). "A cellular automata model for forest fire spread prediction: The case of the wildfire that swept through Spetses Island in 1990". In: *Applied Mathematics and Computation* 204.1, pp. 191–201. ISSN: 0096-3003. DOI: https://doi.org/10.1016/j.amc.2008.06.046. URL: https://www.sciencedirect.com/science/article/pii/S0096300308004943.

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Mutthulakshmi, K. et al. (2020). "Simulating forest fire spread and fire-fighting using cellular automata". In: *Chinese Journal of Physics* 65, pp. 642–650. ISSN: 0577-9073. DOI: https://doi.org/10.1016/j.cjph.2020.04.001. URL: https://www.sciencedirect.com/science/article/pii/S0577907320300873.

Stoevelaar, H. et al. (2020). *Natuurbrandonderzoek de Meinweg Herkenbosch 29 en 30 mei 2020.* URL: https://www.vrln.nl/application/files/1416/0441/5652/Rapportage_NBO_De_Meinweg_2020.pdf.