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COMPUTER SIMULATION OF FOREST FIRE ON THE BASIS OF DIGITAL MAPS AND WEATHER FORECAST

In the article the elements of the computer simulation system in terms of fire spreading during the fire of barn litter were described. The characteristics of certain programs used to predict the spread of fire were described and summarized.

Key words: computer simulation, fire modeling system, forest fire, digital maps of forest

1. Introduction

The problem of simulation of forest fires is not a new issue. There are many computer programs but most of them are developed to model large forest fires, which are very rare in Poland. Simulation programs are created primarily for the specific conditions prevailing in the area, taking into account the topography and the combustible material. Therefore, there is a need to develop tools which will enable a simulation of forest fire in Polish conditions.

In 2004 Poland implemented a system of numeric maps of forests, which, in combination with a digital weather forecast map can provide the necessary input for computer simulation for a mathematical model [11].

Range of usage of the software is applicable to both the planning of controlled fire, for example, when the fires are deliberately set by the forest service to get rid of the accumulated material, as well as planning firefighting by local fire brigades for most efficient use of resources. This work has also an educational value for analysts and civil security services. This limits the program's hardware requirements to those of mid-range PCs.

2. Materials and methods

A deterministic forest fire model will be used to create the simulation environment. Input data are obtained from a digital weather forecast and from digital forest maps (fig. 1).

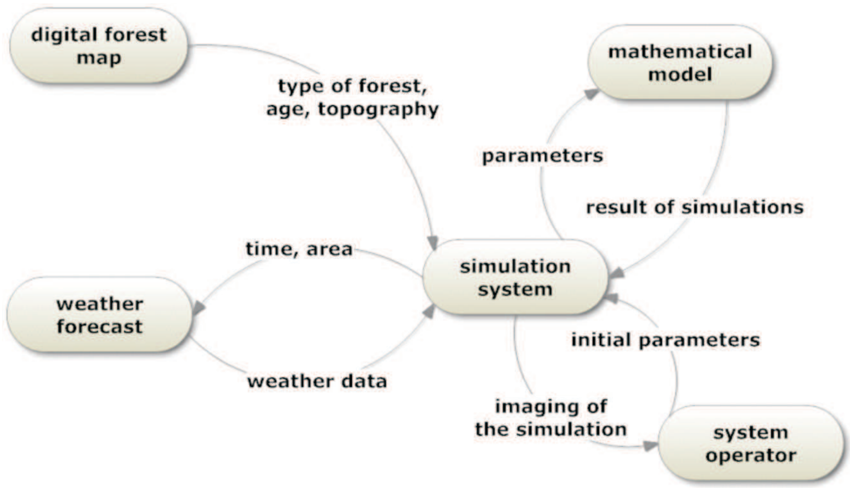

Fig. 1. *Context diagram*

Factors which have the biggest impact on the speed at which a fire spreads have been extracted from a digital weather forecast, and are as follows:

- wind speed and direction,
- humidity of bedding,
- air temperature,
- precipitation.

Since the function of the wind speed extracted from the short-term weather forecast is discrete within the given, unchangeable time interval, for the purpose of simulation one should be able to extract the factor at any period of the simulation time. Therefore the wind speed is averaging from contiguous, forecasted values for any period of the simulation time. The same mechanism is used for the direction of the wind and its change.

The air temperature parameter, precipitation has a significant impact on humidity of flammable material. Yet, precipitation which occurs concurrently with a fire may prove to be beneficial to the course of events.

In the mathematical model the factor of precipitation would not be taken into account, with the pessimistic scenario adopted, which is rationally justified for planning of an extinguishing action.

In the event of widespread and long-lasting fires secondary factors occur, which also affect the further progress of a fire, and namely:

- change in wind speed,
- change in wind direction,
- local temperature change [2].

Owing to the fact that those phenomena occur only in the event of fires with a very large area they have not been allowed for in the discussed model [9].

From the data contained in the digital map of forest the ones that have significant impact on the speed of the spread of fire are:

- forest type,
- forest age,
- forest border,
- obstacles for a fire (fire routes, rivers etc.),
- particularly endangered places.

2.1. Elements of the computer simulation system

The simulation, in terms of the fire spreading, has used the Huygens principle [5]. It was assumed that the fire spreads similarly to the waves. It was assumed that each lit cell in a cell space model is a new source of fire that spreads round in windless conditions. Experiments show that in the constant wind and a homogeneous environment, this shape is similar to an ellipse [3, 6, 7, 9, 10]. Ellipse coefficients a_e, b_e, c_e (fig. 2) depend on: wind speed, fuel type, humidity and type of litter. DB_t section is a section of the path, which fire pases in the direction opposite for the direction of the wind [3].

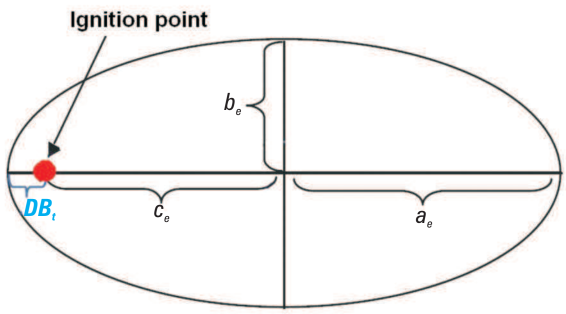

Fig. 2. *Ellipse coefficients*

Speed of fire V_p from the point of inflammation to surrounding cells can be calculated from the formula (1):

$$Vp = \frac{b_e(c_e \cos\Phi + a_e)}{\sqrt{b_e^2 \cos^2\Phi + a_e^2 \sin^2\Phi}} \tag{1}$$

Φ angle can be calculated using the formula (2), where the Φ angle is the angle in the Cartesian coordinate system included between the wind velocity vector and the straight line connecting the combustion point adjacent to the selected cell:

$$\Phi = \cos^{-1} \frac{(b_e \cos\theta(b_e^2 \cos^2\theta + (a_e^2 - c_e^2)\sin^2\theta)^{0,5} - a_e c_e \sin^2\theta)}{b_e^2 \cos^2\theta + a_e^2 \sin^2\theta} \tag{2}$$

Where the θ angle is included between the wind velocity vector and the straight line connecting the point of inflammation and the point lying on the circumference of an ellipse for which reach the speed of fire is calculated. The coefficients a_e, b_e, c_e ae have been adapted to Polish conditions. At the digital terrain map of forests the cellular model map is applied. Each cell is equipped with additional information on combustible material, fire barriers, and time indexes upon which the time of burning of a single cell can be calculated.

Simulation is performed iteratively as follows:

1) Conditions and limitations of simulation (simulation start and end time, interval, raster, map, weather forecast) are determined.
2) On the basis of data on wind speed and direction from interpolated array forecasts the coefficients a_e, b_e, c_e are determined for the prevailing conditions of tested terrain cells.
3) On the basis of fixed angles $\Phi_1 \ldots \Phi_n$ the speed of fire reaching the cells in the vicinity of the point of inflammation is calculated. If the time of transfer to the cell Kn is less than or equal to the interval, then the cell is lit with the appropriate setting of the time indices.
4) After analyzing the entire cell matrix which represents the area, the state of the cells is layered on a map and then displayed.
5) Demand for water for extinguishing of fire and overall margins is calculated. The results are shown on a graph.
6) The next iteration is performed with an increase of the simulation of fire for the duration of the interval of a single step.
7) When a simulated duration of the fire reaches a certain value simulation is completed.

It should be noted that the simulation relates to the fire of barn litter, which significantly predominates in actual fire-fighting actions in Poland. Method of determining the coefficients of the ellipse has been developed for this type of fire. For complete fire one uses a simplified model, however, the simulation results are subject to greater error because it does not take into account additional factors such as e.g. secondary currents [4].

$$V_p = k_1(w_s) \cdot w + k_2(w_s) \tag{3}$$

V_p [m/s] – speed of fire front,
k_1, k_2 – coefficients saved in the interpolated panel, dependent on material humidity w_s,
w – wind speed [m/s].

***Fig. 3.** Graphical display*

If the current fire location, duration and time necessary for arrival of fire service units are known, it is possible to evaluate the water demand in a situation found by the firemen arriving to the location of the fire. The application of a computer simulation may in a simple way facilitate planning of extinguishing actions.

3. Comparison of the systems

During the last couple of years many support softwares were design. The most important features, determining the way of operation, are as follows:
- type of input and output data,
- way of modeling,
- equipment,
- weather and spacial conditions.

The following table (Table 1) summarizes the characteristics of certain programs used to predict the spread of fire [1].

Table 1. Properties of some programs to predict the spread of fire

Property/ program	Fire Simulator	BehavePlus	FlamMap	Farsite	FSPro
Type of input	digital forest map, weather forecast, humidity of bedding	data entered manually through the user interface	map of spatial (GIS), fuel type, terrain, other data	map of spatial (GIS), fuel type, terrain, other data	map of spatial (GIS), fuel type, terrain, climate data, the well--known fire perimeter, other data
Type of output	map of the damage after the simulation, the amount of demand for fire-fighting measures	tables, charts, simple diagrams	map of the damage, the minimum time to reach a fire risk areas	the increase in fire--damaged area	fire probability map for each computation al cycles
Changing the input data during the simulation	changing weather conditions	conditions unchanged	conditions unchanged	changing weather conditions	changing weather conditions
Simulation time	simulation time in min inflicted	combustion time elapsed for a given distance defeated by fire	simulation time in min inflicted	time simulation inflicted in the days and hours	time simulation inflicted in the days and hours
Equipment	Personal Computer	Personal Computer	Personal Computer	Personal Computer	"high end" computer with computer access by authorized analysts
Modeling	embedded deterministic model	model library FBSDK	model library FBSDK	model library FBSDK	possessed set of probabi-listic models
Spatial conditions	topography	uniform	topography	topography	topography

It should be noted that programs such as BehavePlus, FlamMap and Farsite, use in their actions the same set of libraries, "Software Development Kit Fire" (FBSDK), which is a collection of C + + functions and classes implementing the various fire algorithms. Library FBSDK is available under the GNU. Compared to existing solutions essential feature is the ability to cooperate with the available formats of input data such as maps of forests and numerical weather forecasting. In addition, the model includes the age of the forest taken directly from the numerical maps of forests. The program is easy to operate and has a low hardware requirements [1].

The disadvantages of software are as follows:

- it does not take into account the changes in the topographical data,
- the knowledge of moisture content of forest litter is needed. Parameter does not exist in weather data and must be carried out manually,
- the result of simulation may be affected by an error due to differences between actual conditions and outdated data derived from digital maps.

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SUMMARY

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COMPUTER SIMULATION OF FOREST FIRE ON THE BASIS OF DIGITAL MAPS AND WEATHER FORECAST

The article presents the integration of digital topographic map of forests and short-term weather forecast allowing to conduct a computer simulation of forest fire. To execute a simulation, a software was produced. The software includes deterministic mathematical model of forest fire, programmed on the basis of developed assumptions. Creation of mentioned environment simulation was based on a need for the optimum planning of extinguishing actions in local fire service centres.