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APPLYING THE MATHEMATICAL MODEL OF FOREST FIRE IN THE SOFTWARE CREATED FOR SUPPORTING THE DECISIONS IN EXTINGUISHING ACTIONS

Zastosowanie modelu matematycznego pożaru lasu w oprogramowaniu wspomagania decyzji w akcjach gaśniczych

Summary

The paper presents the assumptions for the computer simulation of a forest fire in accordance with digital topographic map of forests and short-term weather forecast. To conduct the simulation, a software has been created. The software includes deterministic mathematical model of a forest fire. Input data have been extracted from the short-term weather forecast and the digital forest maps. The application range covers both planning of a controlled fire, e.g. in cases when the fires are intentionally started by the forest services to get rid of accumulated forest material, as well as to plan extinguishing actions and to plan appropriate disposal of resources during the extinguishing of a forest fire. Creation of the described simulation environment arises from the need of optimum planning of the extinguishing actions in local fire service centers. The initial risk assessment in the stage of planning the extinguishing action, will allow efficient management of equipment by the local units. It also prevents from repeating wrong decisions made in the early stages. This need imposes limiting the use of equipment platforms to medium class PC's. The outcomes of the paper provides accessibility of a tool supporting the decision making process and assessing the damages in the high risk conditions of a forest fire. Furthermore, conducting a simulation allows to estimate the need for fire fighting equipment in the case of total and border extinguishing of a fire, for different weather conditions, considering fire density.

Streszczenie

W pracy przedstawiono założenia do symulacji komputerowej pożaru lasu, w oparciu o dane cyfrowe topografii lasów i krótkoterminową prognozę pogody. Do przeprowadzenia symulacji zostało wykonane oprogramowanie, w którym zawarto deterministyczny model matematyczny pożaru lasu. Dane wejściowe pozyskiwane są z krótkoterminowej prognozy pogody, oraz numerycznych map lasów. Obszar zastosowań dotyczy zarówno planowania kontrolowanego pożaru, gdy pożary są celowo wywoływane przez służby leśne w celu pozbycia się nadmiaru nagromadzonego materiału leśnego, jak również planowania akcji gaśniczych i dysponowania zasobami podczas gaszenia pożaru lasu. Stworzenie wymienionego środowiska symulacji poparte zostało potrzebą optymalnego planowania akcji gaśniczych w lokalnych ośrodkach straży pożarnej. Wczesna ocena ryzyka na etapie planowania akcji gaśniczej umożliwi wydajne gospodarowanie zasobami przez lokalne jednostki, oraz zapobiega propagowaniu się błędów decyzyjnych na wczesnych etapach. Powyższa potrzeba narzuca ograniczenie stosowania platform sprzętowych do komputerów PC średniej klasy. Wynik pracy zapewnia dostępność narzędzia wspomagającego podejmowanie decyzji oraz szacowania strat w warunkach podwyższonego ryzyka zagrożeniem pożaru lasu. Ponadto przeprowadzenie symulacji pozwala oszacować zapotrzebowanie środków gaśniczych gaszenia całkowitego i gaszenia obrzeża dla różnych warunków pogodowych, z uwzględnieniem obciążenia ogniowego danego terenu.

Keywords: forest fire, simulation
Słowa kluczowe: pożar lasu, symulacja

Introduction

The forecast of potential fire behaviour is the key element of decision making during extinguishing of forests fires. The problem of simulation of forests fires is not a new issue. For the complexity of the content, the problem is not completely solved to date. Previous results of works carried out abound with simulation programs which were developed for the purpose of work in a different geographical specificity. These programs are still of developmental nature and contribute in favour of increasing fire safety in forests.

Mathematical models usually consist of range of function which as results gives numerical values for spatial, time development of one or more variables such as speed of dissemination, level of flame, risk of ignition or usage of fuel. More or less detailed description of behaviour of the phenomenon is obtained in this manner. Depending on the type of function computer programs base on selected models of forests fires simulation:

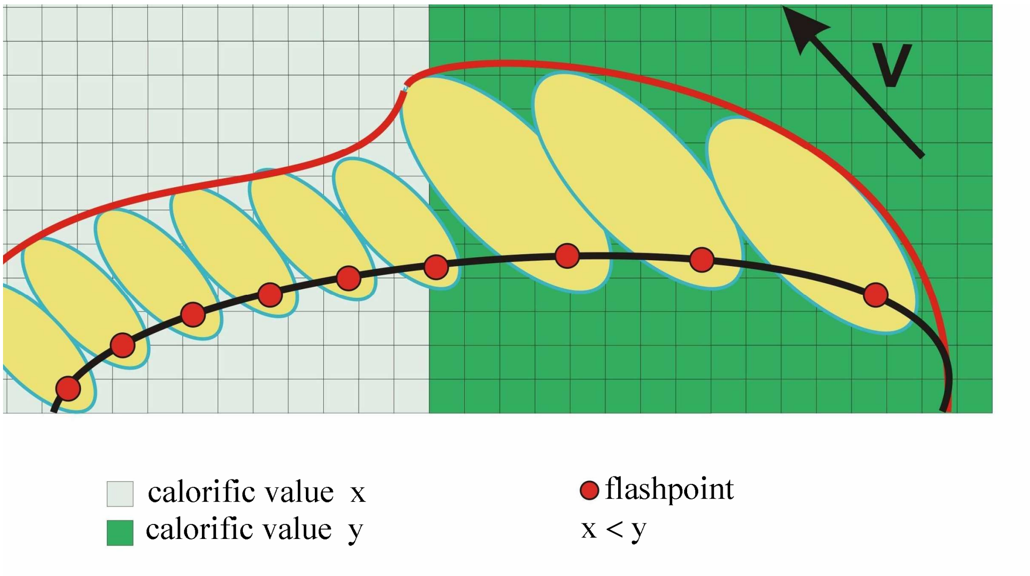
- theoretical models – generated from the principles of fluid mechanics, combustion and exchange of heat. Verification of these types of models is extremely intractable despite they can be extrapolated for various fire situations;
- deterministic models – built on the basis of experiences and fire researches which already took place. Such models apply merely for systems in which conditions are the same as the ones used during formation and testing of models;
- semi-deterministic models – theoretical and performed by experimenting. Exploration of these models is proper in situations similar to the ones used in order to obtain experimental data. There are less difficulties during evaluation of these models than in case of theoretical ones [Pastor et al. 2003];

- probabilistic models – using known distributions of probability for occurrence of phenomena accompanying fires.

Despite large number of models, there are only few of them which are successfully used in practice.

Materials and methods

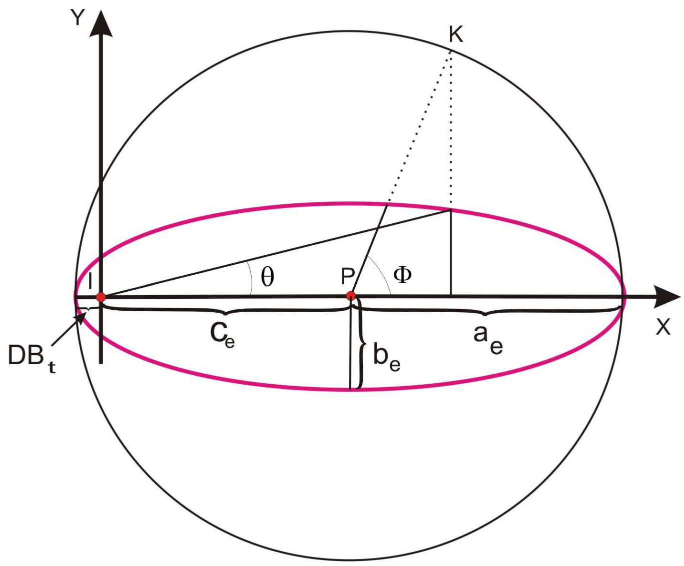
This thesis presents deterministic simulation model of fire dissemination which was elaborated in the aim of facilitating the analysis of probable destruction and water demand necessary for fire extinguishing. Computer simulation is based on the cellular model using Fermat's rule with a matrix of spatial representation in which a single cell of two-dimension matrix represents a projection on a surface of actual area with a shape of a square. It is assumed that conditions prevailing in one cell are homogenous similarly to average conditions prevailing in a projected area. Square cells are commonly used for simulation of natural phenomena. Propagation of fire may follow exclusively by neighbourhood of cells, in this case – cells adjacent by sides and vertices. In the accepted model of fire dissemination the Huygens' rule was used which is known as of light waves propagation. This rule which is used for applications of fire simulation was adopted by Sanderlin and Sunderson for the first time in 1975. It is assumed that a shape of fire can be reflected by an envelope of particular ellipsoidal segments of fraction simulation. Each inflamed cell constitutes a new source of propagation of fire wave. The front of fire wave constitutes the envelope of ellipsis of partial simulation. For the fact of raster nature of space representation, actual ellipses cannot be used. The envelope of progress of fire in every step of simulation is approximated to the nearest vertex as coordinates of location can only take values of whole numbers [Knifht et al. 993].



Picture 1. Propagation of fire with the use of ellipses in differential environment
Ryc.1. Propagacja ognia z zastosowaniem elips w zróżnicowanym środowisku

In homogeneous environment under conditions in which there is no wind, the shape of wandering fire from the point of ignition is assumed to be round. On the other hand, when homogeneous wind blows, the shape of fire from the point of ignition takes the shape of an ellipsis [Lopes et al. 2002, McAlpine 1989, Pastor et al. 2003, Richards 1993] (picture 1, 2). A simple mathematical interpretation and the easiness of service in the scope of entrance data have made contribution to general acceptance of such shape for computer models simulation of dissemination of forests fires. Accepted model, in accordance with Huygens' rule, best illustrates reality taking into account invariability of conditions. Despite the direction of wind may change in reality, with respectively small time interval step of simulation the variability of wind is of marginal importance.

Transfer from windless conditions into conditions with wind factor are shown in the Picture 2.



Picture 2. Transformation of dissemination speed depending on vector wind speed in relation to spatial system.

Ryc. 2. Transformacja prędkości rozprzestrzeniania się ognia w zależności od wektora prędkości wiatru do układu przestrzennego

Point P is an origin of the fire for windless conditions; point K is the position of fire accession for given time Δt. Angle Φ is contained between the direction of wind and the straight line PK. To include wind there should be made transformation of position of point K, recumbent at the circle, with the point located at the circuit of ellipsis in the dissemination model. This point will be located at the intersection of the straight line located under the angle θ to the direction of wind. Source of the fire P is of the same actual coordinates as point I. Section DB_t is the distance which will be covered by fire in the opposite direction to wind. Designation of angle Φ allows application of pattern 1.

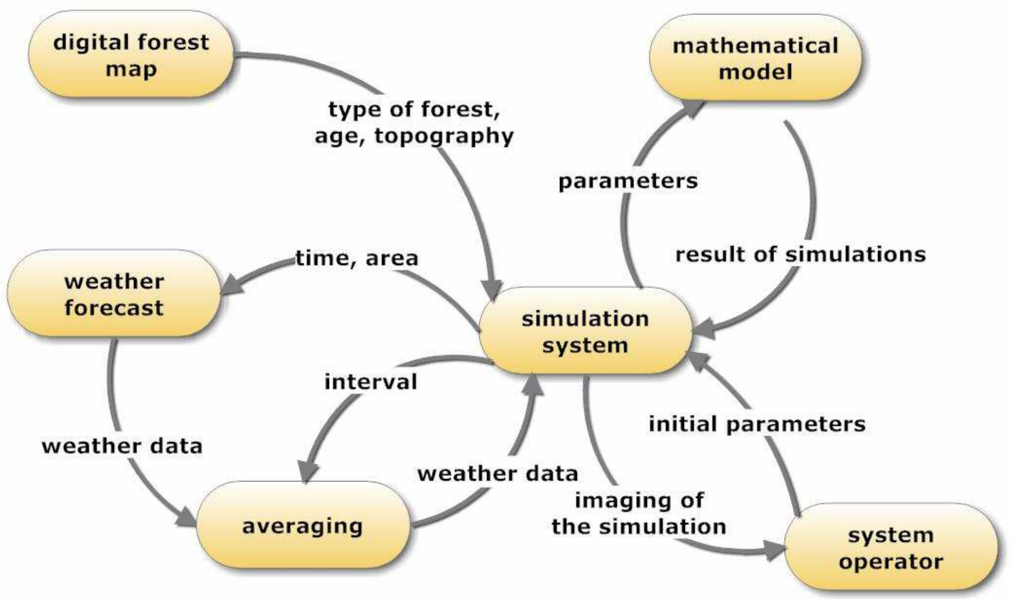
$$\Phi = \cos^{-1} \frac{\left(b_e \cos\theta \left(b_e^2 \cos^2\theta + \left(a_e^2 - c_e^2\right)\sin^2\theta\right)^{0,5} - a_e c_e \sin^2\theta\right)}{b_e^2 \cos^2\theta + a_e^2 \sin^2\theta} \qquad [1]$$

It is known [Lopes et al. 2002, McAlpine 1989, Pastor et al. 2003, Richards 1993, Willer 2007], that not only changes of the speed and direction of wind but also other factors such as kind and fuel type, asymmetry of changes (topographical conditions) influence the shape of fire dissemination. Coefficients of ellipses are conditioned on fuel type and speed of fire. Proportions are also influenced by humidity and type of forest bed. Designation of speed of dissemination allows application of pattern 2.

$$V_p = \frac{b_e(c_e \cos\Phi + a_e)}{\sqrt{b_e^2 \cos^2\Phi + a_e^2 \sin^2\Phi}} \quad [2]$$

Simulation

On the basis of the model the software which uses spatial data as well as short-term weather forecast was developed. Entrance data are obtained from numerical maps of forests and short-term weather forecast (picture 3).



Picture 3. Context diagram
Ryc.3. Diagram kontekstowy programu

As the speed of wind which is input from a short-term weather forecast is of a discrete character, with a certain interval of time which cannot be changed, it was for the aim of simulation to allow obtaining this value at any time of simulation. Therefore, the value of speed of fire is averaged with adjacent forecasted value for any time of simulation within the scope of validity of weather forecast. The same mechanism also covers direction and a sense of forecasted wind.

From the digital map of forests the significant impact have: kind of forest, age of forest, precinct of forest, obstacles in relation to fire (access roads fire, rivers, etc); places of special danger.

For the execution of the simulation it is necessary to introduce 4 initial parameters.

1. location of the fire source,
2. simulation time of the beginning and the end,
3. the time interval of an individual simulation time,
4. raster of area.

Simulation is being carried out iteratively. The number of iterations necessary for execution of simulation is stipulated by time of end, time of beginning and raster time. Parameters are determined by an operator. During conducting a simulation a matrix is created in which results are kept. Dimensions of matrix define length and width of size of the area. The size of matrix X,Y depends on raster area. After each iteration scores are overwritten in particular cells. Each iteration requires mathematical modelling of each cell of matrix and saving data to its neighbours. A single cell of matrix keeps data like:

- direction and speed of wind,
- fuel type,
- vectors of speed of fire for neighbours of a cell,
- state,
- passage of time in a state of ignition.

During a simulation a picture of process of fire is generated according to the condition of cells (picture 4).

Picture 4.Graphical illustration of the course of the fire
Ryc.4. Prezentacja graficzna postępującego pożaru

For the aim of calculation of water demand necessary for extinguishing the fire total number of inflamed cells should be counted – for the complete extinguishing, and respectively – the number of inflamed cells within the circuit of fire for a given width of extinguishing rim.

Demand for water for full extinction *isw* was determined based on [1].

$$isw = \frac{P \cdot W_{op} \cdot f_c}{CCP}$$

were:

P- fire surface [ha]
f_c- complete combustion coefficient – 0,7
CCP- water evaporation heat [kJ/kg]
W_{op}- calorific value [kJ/m^2]:

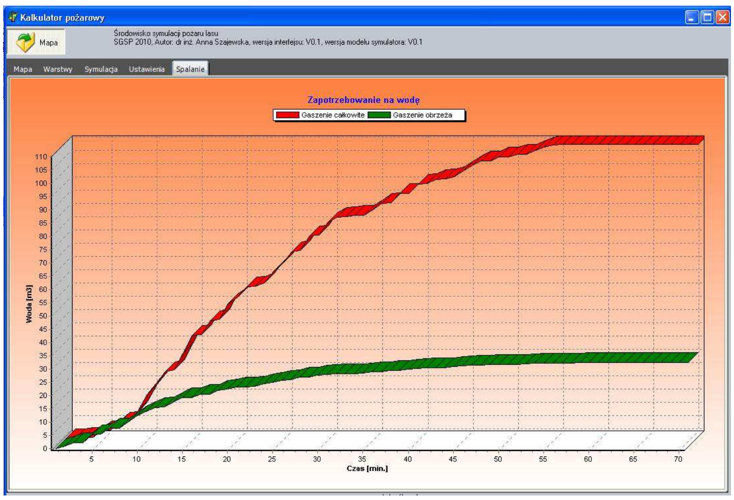
$$W_{op} = Q_d \cdot (4982 - 52{,}2 \cdot w_s) \cdot 4{,}1868$$

were:

Q_d - fire load kg/m^2 (the value taken from a digital forest map)
w_s - material humidity [%]

For the purpose of determining demand for water to extinguish fire rim, the surface of the rim knowing the width is calculated, complete combustion coefficient is exchanged for flame combustion coefficient which is dependent on fire load Q_d.

Having known the current location of a fire, duration, time necessary for arrival of extinguishing units, it is possible to estimate a water demand for a certain existing situation by firemen reaching a place of fire (picture 5). Application of computer simulations can in a simple manner facilitate planning of extinguishing actions.



Picture 5. Graphical illustration of water demand for full extinguishing and extinguishing of the rim area

Ryc.5. Prezentacja graficzna zapotrzebowanie na wodę do gaszenia całkowitego i gaszenia obrzeża

Summary

This program has educational and training aspect for analysts and civil safety services. Computer program was developed with the usage of programming tool RAD including the package of Delphi compiler. Application which was obtained in this manner is adapted for launching within PC's with operational system Windows. With the aid of the developed program, simulations under variable conditions can be carried out within different forest areas.

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