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MATHEMATICAL MODEL FOR CALCULATING A FIRE CIRCUIT

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Abstract: The problem of forest fires and fire safety of forests is devoted to a large number of experimental and theoretical works. The main factors, the knowledge of which determines the fire extinguishing tactics and the choice by the fire extinguishing manager of the ways and means to deal with it, are the outline of the forest fire and its parameters, as well as the direction of its most dangerous spread. The work is devoted to the study of the construction of a theoretical model that allows you to calculate the contour of the fire at different points in time and modeling the dependence of this speed on the main factors in the development of fire

Keywords: fire safety, forest fire, fire circuit

Existing theoretical models for determining fire propagation factors can be very roughly divided into two classes: microscopic and phenomenological models.

In microscopic models [5, 6], an attempt to take into account a large number of heterogeneous parameters that affect the dynamics of the fire circuit makes it necessary to solve difficult differential equations, the solution of which is even more difficult often with uncertain initial and boundary conditions.

Greater success can be achieved in phenomenological (analytical-geometric, geometric, semi-empirical) approaches [1-4, 7]. Based on the known average empirical or theoretical values of a small number of the main parameters of forest fires and not going into the subtle physical details of the fire development process, relatively simple models can be studied that describe the spread of the edge of the fire.

However, despite numerous and often fruitful efforts [1-4], at present, there is no sufficiently simple, reliable, and practically applicable mathematical model for the development of a forest fire. The difficulties of creating such a model have been repeatedly discussed in the literature [4, 6].

In our opinion, an ideal, in the sense of practical use, mathematical model should satisfy the requirements considered below and solve such a problem.

Let us have a topographic map that reflects the relief of a possible fire in this forest. From this map you need to find a function $F_1(x,y)$ that describes the given relief, where x, y – are the coordinates of the plane. Let us further indicate (at least approximately) the distribution of the combustible material and its moisture content. These quantities determine two more functions $F_2(x,y)$ and $F_3(x,y)$. Setting the location and shape of the fire source is described by a function $F_4(x,y)$, that determines the initial condition. In addition, information on the direction and speed of the wind is necessary. Based on these basic input data [1-5], it is necessary to calculate with some accuracy the most probable contour of the fire, its perimeter and area, as well as the direction of its most dangerous spread at any given time. Such a model should be simple enough to carry out these calculations in real time in the field. An important factor should also be the flexibility of the model, which would allow taking into account current information about the fire circuit at the current time and replace the function $F_4(x,y)$ in the calculations with some new function.

This article is devoted to some stages of the implementation of this program.

First of all, we note that such a phenomenological approach involves solving two interrelated tasks. One of them consists in constructing a theoretical model that allows calculating the contour of the fire at different points in time. The solution to this problem involves the use of a speed of movement of the edge of the fire defined in some way at each given point in the terrain. Therefore, the second task is to simulate the dependence of this speed on the above-mentioned main factors of fire development.

Based on the assumptions that the fire circuit is continuous, that the fire develops in a homogeneous environment and that the fire circuit can be considered as an isothermal curve on the plane, we obtained the following equation:

$$\frac{\partial f}{\partial t} + \vec{V}\vec{\nabla} f = 0, \tag{1}$$

where $\vec{V} = d\vec{r}/dt$ – is the speed of the fire circuit, and the function $f = f(\vec{r},t)$ describes the fire circuit at a point $\vec{r}$ at time t. Note that in [4, 5], with the use of additional hypotheses (such as the Huygens hypothesis in optics), equation (2) is obtained in various forms and attempts are made to solve it.

Equation (1) can be given a form convenient for solution. To do this, it is enough in the expression for the contour $f(x,y,t)=const$ and in equation (1) to pass from the Cartesian coordinates x,y to the polar coordinates ρ,φ. Then, for the contour we get the expression $\Phi(\rho,\varphi,t)=const$. Solving the last equation with respect to ρ, we obtain $\rho=\rho(\varphi,t)$. Performing the corresponding transformations of equation (1), introducing the concepts of radical velocity $V_r(\varphi)$ and taking into account the relationship of velocities, V_x, V_y and $V_r(\varphi)$, $V_\varphi(\varphi)$, we can obtain a solution to equation (1) in the form

$$\rho(\varphi,t) = \rho_0(\varphi) + \int_{t_0}^{t} V_r(\varphi,t)dt \quad , \qquad (2)$$

where the function $\rho_0(\varphi)$ describes the contour of the fire at the initial moment of time t_0 (the above function $F_4(x,y)$). In addition, it was taken into account in (2), that the velocity V_r can, generally speaking, depend on time t. Note that the authors of [2, 4, 5], after long and complex reasoning, ultimately arrive at a similar result.

Thus, to describe the geometry of the fire $\rho(\varphi,t)$, it is sufficient to know the contour $\rho_0(\varphi)$ and be dependent $V_r(\varphi,t)$ on the polar angle φ and time t. To obtain the dependence $V_r(\varphi,t)$ on φ let us temporarily omit the dependence on t and use the expressions for the propagation velocities of the frontal V_{fr}, flanking V_{fL}, and rear edges V_{re} of the fire relative to the direction of the wind velocity $\overrightarrow{V_w}$ obtained in [1]. These simple expressions depend on V_w and the parameters associated with the specific heat of combustible materials, their composition and humidity.

Based on the values of V_{fr}, V_{fL} and V_{re}, we use a simple geometric model and make a natural [2-5] assumption that the dependence V_r on φ can be described by an ellipse that is elongated along the direction of the wind. Then we get [8]

$$V_r(\varphi) = (V_0 + kV_в)\frac{2\alpha Cos\varphi + (1+\alpha^2)\sqrt{Cos^2\varphi + (1-\alpha^2)Sin^2\varphi}}{Cos^2\varphi + (1+\alpha^2)^2 Sin^2\varphi} \quad , \qquad (3)$$

where φ – is the polar angle measured from the direction of the wind, $\alpha = V_в / \sqrt{V_в^{\;2} + C^2}$, V_0, k and C are the parameters of the theory determined from the experiment [1-3]. Note that the origin in (3) is chosen in such a way that $V_r(0)=V_{fr}$, $V_r(\pi)=V_{re}$, and the minor axis of the ellipse (3) is equal V_{fL}.

Formulas (2) and (3), in principle, solve the problem as a first approximation.

Further directions of development of the proposed model are seen by us, primarily in the following. In the formulas of [1] for V_{fr}, V_{fL} and V_{re}, and in (3), it is necessary to introduce explicit and, in principle, known dependences on humidity W (function $F_3(x,y)$) and the angle θ – terrain inclination. Further, to describe the features of the relief (hills, depressions, slopes, climbs, hollows, ridges, water and other obstacles, etc.), enter the functions $F_i(x,y)$ to find in an appropriate way $F_i(x,y) = \sum F_i(x,y)$.

Knowledge $F_i(x,y)$ will allow using the known gradient $\overline{\nabla} F_i(x,y)$ calculate the value of the angle θ at each point of the contour. It is also of interest to study the effect of fluctuations of various parameters of the theory (for example, V_w) on the contour of a fire.

The product of the final implementation of the considered model will be a software package designed for the practical use and training of forest firefighters.

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