Application of the Levinson filter to predict the state of the environment affecting the occurrence of forest fires

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Abstract. The article is devoted to the application of the Levinson filter for the formation of an input sample in the already existing methods for assessing forest fires. This will allow you to plan in advance measures to minimize the risks of fire hazardous situations. The properties of cross-correlation of elements of the matrix of transition coefficients are applied to find the matrix of transition coefficients. The article provides an example of testing the application of the Levinson filter in the form of an application program. The results described in the article make it possible to judge the applicability of the chosen method of forestry area management.

1. Introduction

Forest fires in our country are one of the most dangerous natural disasters. In accordance with the legislation of the Russian Federation, forest fires are classified as emergency situations and as a phenomenon are subject to continuous monitoring and forecasting.

One of the factors in the spread of forest fires is hydrometeorological conditions. Such factors can significantly affect the intensity and distribution of emergency forest fire situations. It is obvious that climate changes have an impact on their frequency, intensity, direction of propagation and spatial scale.

To determine climatic phenomena and changes in environmental parameters in modern meteorology, forecasting is used both in the short term and in the long term.

Monitoring and forecasting of forest fires in Russia is carried out at the following levels:
- federal;
- regional;
- local [1];

To predict the possible occurrence of a dangerous phenomenon in the form of a forest fire, the following are taken into account: fire hazard class, data on the terrain, the presence of potential fire sources, the results of a retrospective analysis of the distribution of fires in time and the current meteorological situation together with a short-term forecast. This approach to forecasting makes it possible to assess the risk of fire hazardous situations in areas where such situations have already occurred, and the assessment of the meteorological situation is used as an auxiliary parameter to obtain information on how an already arisen hazardous phenomenon will behave. Forecasting the occurrence of emergency forest fire situations in the long term using meteorological data is not used in modern practice. At the same time, it is obvious that meteorological conditions are one of the main factors in the likelihood of fires in nature and long-term forecasting would reduce the risk of forest fires and reduce possible damage [2].
Various methods are used to solve the indicated problems. One of the methods of long-term forecasting is mathematical models. As a central model, it is proposed to use Levinson's recursive algorithm[3, 4], the calculation results of which can be used as input parameters into the already established practice of monitoring and controlling forest fires. Consider the features and feasibility of using this algorithm in the tasks.

2. Methods and Materials
The entire forest fund of the Russian Federation is enshrined in monitoring objects at the legislative level. Monitoring and control of such a dangerous phenomenon includes:
- observation, collection and processing of data on the degree of fire hazard in the forest according to weather conditions;
- assessment of the degree of fire hazard in the forest according to weather conditions according to general or regional scales of fire hazard.

Controlled parameters on the territory of the forest fund:
- air temperature;
- dew point temperature;
- amount of precipitation;
- wind speed and direction.

To assess the degree of forest fire hazard depending on meteorological conditions, the forest fire index is used, which is a comprehensive indicator of fire hazard in a forest, the Nesterov index [1].

To calculate the complex indicator $G$ of fire hazard in the forest according to weather conditions, the following data are required:
- air temperature and dew point ($^\circ$ C) at 12 o'clock local time;
- amount of precipitation (mm) for the previous day, i.e. for the period from 12 noon of the previous day local time (precipitation up to 2.5 mm per day is not taken into account).

The air temperature is determined by the dry thermometer of the psychrometer, the dew point temperature is determined by the psychrometric tables based on the readings of the dry and wet bulb thermometers. The amount of precipitation is determined by the rain gauge. The air temperature and dew point are measured with an accuracy of 0.1 $^\circ$ C, the amount of precipitation - with an accuracy of 0.5 mm.

The complex indicator for the current day is calculated using the formula [1]:

$$G = \sum_{i=1}^{n} T_i d_i, \quad (1)$$

$$d_i = T_i - r_i. \quad (2)$$

here, $T$ is the air temperature ($^\circ$ C) at 12 noon local time; $r$ - is the dew point at 12 noon local time ($^\circ$C); $d$ - dew point deficit; $n$ - is the number of days since the last rain. Dimension $G$ is ($^\circ$C) 2 days.

3. Results and Discussion
Levinson's algorithm is designed to assess the criterion of natural and climatic conditions based on the calculation of the matrix of transition coefficients $A$, used in the linear forecast of the state of the system. Minimization of the mean square error between the predictive estimate and the actual state of the system is occupied by the leading purpose of the matrix of transition coefficients and is determined by the formula 2.

$$E = \sum_{n=n_0}^{n} \left( \sum_{i=0}^{k} a_i y_{n-i} \right)^2 \rightarrow \min, \quad (3)$$
where, $k$ - calculated coefficients, $a_i$ - $i$-th coefficient of the multi-pole model (vector containing the coefficients of the linear prediction coding), $y$ - step of the forthcoming calculation.

The resulting system of equations, after the necessary simplifications, is not deterministic. In this case, the matrix of autocorrelation coefficients is reduced to the Toeplitz matrix [5, 6]. Let us bring the solution of the system of equations to the form:

$$
\begin{bmatrix}
R_0 & R_1 & \cdots & R_k \\
R_1 & R_0 & \cdots & R_{k-1} \\
\vdots & \vdots & \ddots & \vdots \\
R_k & R_{k-1} & \cdots & R_0
\end{bmatrix}
\begin{bmatrix}
a_1 \\
a_2 \\
\vdots \\
a_k
\end{bmatrix}
= 
\begin{bmatrix}
E_k \\
0 \\
0 \\
\vdots \\
0
\end{bmatrix},
$$

(4)

where, is the solution to the problem. Since the matrix characterizing the state of the system is presented in the form of the Toeplitz matrix, to find the matrix of transition coefficients $A$ apply Levinson's recursive algorithm.

Applying the properties of cross-correlation of the elements of the matrix of transition coefficients inherent in Levinson's approach, we find that the computational problem is reduced to finding at each step the correlation coefficient of transitions $\lambda$ and sequential correction of the elements of the vector $A$. The calculations of the first step are reduced to:

$$a_i = -\frac{E_i}{R_0},$$

(5)

$$E_1 = R_0 + a_1 R_1$$

(6)

At each subsequent step $k$ of the correlation coefficient of transitions and transformation of matrix $A$, we obtain (4) and (5).

$$\lambda = -\sum_{j=0}^{k} a_j \frac{R_{k+1-j}}{E_k},$$

(7)

$$A_{k+1} = U_{k+1} + \lambda V_{k+1}$$

(8)

Applying the obtained expressions, the final solution at each subsequent step $k$ will take the form:

$$E_{k+1} = E_k + \lambda \sum_{j=0}^{k} a_j R_{k+1-j} = (1 - \lambda^2)E_k$$

(9)

The matrix obtained in the course of solving the problem is used as the coefficients of the FIR (finite impulse response) - a filter for linear prediction of the state of the system under study.

Analysis of the results of applying Levinson filtering. To forecast meteorological data, an application program in C ++ was implemented and the criterion “extreme natural and climatic conditions” was applied.

As the climatic investigated parameter, the parameters were chosen - temperature and relative humidity of the air for the period from 10.02.2008 to 10.02.2021. The coordinates of the study point are 62 3N and 59 1E. Data taken from systems: NOAA NCEP-NCAR CDAS-1 DAILY.

The obtained meteorological data of the research point are the input parameters of the developed software application.

The predictive model for assessing the criterion of extreme natural and climatic conditions shows a very positive result. As seen in the graphs (figures 1 and 2). The graph shows baseline meteorological indicators (blue), forecast (yellow) and difference (red). Filter settings allow you to adjust the accuracy.
of the output (predictive) parameters. As soon as the filter has finished analyzing the input data, its recursive system has adjusted - at the output, one can observe, in some cases, similar predictive data in relation to the original.

![Figure 1. Comparison of the actual and predicted temperature obtained using the Levinson algorithm.](image1)

![Figure 2. Comparison of actual and predicted relative air humidity obtained using the Levinson algorithm.](image2)

The data approbation showed that over a number of months there are 100% similar results between the initial and predictive data; nevertheless, in some months there is an error, but within the established norms for long-term forecasting [7, 8].
4. Conclusions
From the presented results, it can be concluded that it is possible to use Levinson filtering for long-term forecasting of meteorological conditions and its use in the methodology for calculating a complex indicator of fire hazard in a forest based on weather conditions [9]. Submitting an initial series of 10 years as an input, at the output we get a predictive estimate of 5 years, which is half the depth of the filter system, in turn, from the point of view of climatology, this is a long-term forecast. The positive component of the algorithm used is the filter depth. This parameter is directly related to the obtained predictive data and is exactly half the filter depth. It is obvious that the number of variables in the original series directly affects the depth of filtration.

The difference in the result obtained is due to the complexity of describing all stochastic natural processes by a mathematical model for future forecasting. The presence of such an error, the model made it possible to form a long-term forecast with an accuracy within acceptable values [10-12]. Based on the data obtained, the Levinson's algorithm model is applicable to this problem; in the future, it requires more thorough research and analysis as an input parameter in the method for calculating the complex indicator of fire hazard in a forest based on weather conditions.

References
[1] GOST R 22.1.09-99 1999 Bezopasnost' v chrezvychajnyh situaciyah. Monitoring i prognozirovanie lesnyh pozharov. Obschchie trebovanija. (Moscow: IPK Izdateľstvo standartov)
[2] Gordeev V S and Smirnova T V 2019 Prognozirovanie lesnyh pozharov na osnove nejrosetevyh tehnologij Materialy 19-j mezdunarodnoj nauchnoj konferencii p 297
[3] Frazho A E 2001 Kalman and Levinson Filtering AdAE 567 Lecture Notes Purdue University p 238
[4] Speakman N O and Bullock T E 1984 Kalman filter design using the Levinson algorithm and output statistics The 23rd IEEE Conference on Decision and Control, Las Vegas, NV, USA, doi: 10.1109/CDC.1984.272053.
[5] Marple S L Jr 2019 Digital Spectral Analysis: Second Edition Courier Dover Publications, p 432
[6] Petrov O A 2003 Ispol'zovanie algoritma Levinsona-Durbina dlya resheniya sistemy linejnyh uravnenij Infokommunikacionnye tehnologii 1
[7] Kolbina O N, Stepanov S Yu, Sidorenko A Yu and Istomin E P 2015 Analiz modelej i sistem obrabotki heterogennyh dannyh dlya ispol'zovaniya v prikladnyh GIS Nauchnyj vestnik 4(6) pp 53-62
[8] Istomin E, Sidorenko A, Stepanov S, Petrov Y and Martyn I 2020 Application of Kalman-Bucy filter for vessel traffic control systems in the northern sea route IOP Conf. Ser.: Mater. Sci. Eng. 817 012012
[9] Istomin E P, Nigmatulin TA, Petrov Ya A, Sokolov A G, Yagotinceva N V 2020 Ontologiya sistemy upravleniya razvitiem social'no-ekonomicheskikh sistem i territorij Estestvennye i tekhnicheskie nauki 12 (150) pp 209-215
[10] Martyn, I., Petrov, Y., Stepanov, S., Sidorenko, A. 2020 Spatial-temporal variability of ice cover of the Bering sea IOP Conference Series: Earth and Environmental Science 539(1) 012198
[11] Petrov Y, Istomin E, Stepanov S, Sidorenko A and Vagizov M 2020 Development of a conceptual GIS model to support management decision making IOP Conference Series: Earth and Environmental Science 574(1) 012062
[12] Istomin E, Martyn I, Petrov Y, Stepanov S and Sidorenko A 2020 Study of intra-day dynamics of currents in the area of the navigable strait of Baltiysk to adjust the movement of water transport IOP Conference Series: Materials Science and Engineering 817(1) 012013