Development of Trained Algorithm Detection of Fires for Multispectral Systems Remote Monitoring

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Abstract. The paper describes research of a trained threshold algorithm for analysis of the fire situation using multispectral remote sensing data. The algorithm is based on application of sub-satellite information about the fire on the territory covered by a satellite image. Thresholds are selected for each of the spectral bands for the determination of known fire threshold and then are used to select all thermal anomalies in the picture. According to study of the algorithm the informative spectral channels are defined for detecting fires. Combination of the results from the multiple channels spectroradiometer MODIS for increasing the probability of correct detection is demonstrated.

Keywords: Forest fires, MODIS spectroradiometer, MOD14 algorithm, trained threshold algorithm, spectral channels, probability of fire detection

1 Introduction

Data of the earth remote sensing (ERS) is widely used for forest fire detection. In this case, pictures of Imaging Spectroradiometer MODIS [1], which is a part of equipment of American Terra and Aqua satellites, are intensively used now. An operative receiving of information from MODIS is carried out by personal receiving ground stations, one of which (UniScan-24 [2]) is set at the Ural Federal University.

The MODIS data are formed in 36 spectral bands and characterized by a wide swath (2300 km) and high frequencyof udate (up to several times a day). However, these images have low spatial resolution (1 km in the most of the infrared spectral channels) that does not allow one to detect reliably fires in a fraction of a hectare under various observation conditions (surface fire, lack of fire intensity, poor weather conditions, *etc.*).

2 Problem formulation and development of trained threshold algorithm

Complexity of solving the problem of detection of the forest fires using remote sensing data may be shown by presence of a large number of Russian and foreign Internet services. This information about the fires differs not only from the actual, but, also, among the sources. The evidence of this is confirmed [3] by analysis of the fire in State Nature Reserve "Denezhkin Kamen" (Fig. 1) in 2010 according to the data of several online fire detection and monitoring services.

Information from these services is based on the MODIS sensor data that are processed by the MOD14 fire detection algorithm and its modifications [4].

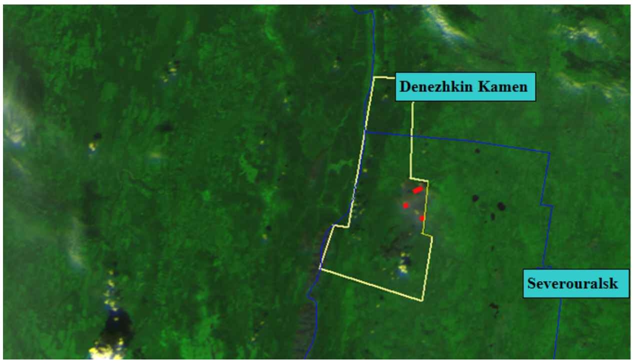

Fig. 1. Daily snapshot MODIS 31.07.2010 combined with mask fires and the boundary of the reserve "Denezhkin Kamen"

This algorithm uses the temperature data of the pixels at two infrared spectral channels: 4 μm (21 channel) and 11 μm (channel 31). The brightness temperature of a "hot" pixel in channel 21 should be higher 312K by day and 305K by night. In addition, if the temperature difference of a pixel between the 21 and 31 channels and the difference between channel 21 and the environment temperature are larger, the probability that the pixel belongs to the fire is higher. Pre-image is also evaluated under presence of clouds using masks clouds and global clouds; and the pixels belonging to the solar flare are eliminated. As a result, the mask of fires is built that contains the so-called "thermal points", *i.e.*, the pixels exceeding the preset temperature thresholds.

It should be noticed that this algorithm is currently the basis for a number of specialized software tools for processing remote sensing data, such as the program product ScanEx Image Processor [5]. In the fact, efficiency of the MOD14 is insufficient in areas with high forest vegetation, and it can detect only relatively large fires. This factor is caused by fixed values of temperature thresholds that do not take into account specific conditions of the observation.

To increase the likelihood of a correct detection of temperature anomalies, we have proposed [6] to train our threshold algorithm on the basis of sub-satellite information about the current fire. Selection of the threshold level was made using channel 21 of the spectroradiometer MODIS for pictures dated by July 28 (night) and July 29 (day), 2010. The training was based on the known fire in the reserve "Denezhkin Kamen". For this purpose, a part of the Sverdlovsk region was cut and converted to a range of brightness from 0 to 255, and after that the detection thresholds were determined. It is also supposed (Fig. 2) that there is the area free from fire adjacent with another seat of fire, the area of 1 pixel size (gray area) separated from the fire at the distance about 0.5 – 1.5 pixels is the boundary region part, which can be occupied with the fire (white square) round the seat of fire (a dark oval). In our case (Fig. 2), when the seat of the fire is in the pixel with coordinates (X = 217, Y = 193), this means that "hot" pixels are absent at the points X = 215–219 when Y = 191 and Y = 195 and at the points Y = 191–195 when X = 215 and X = 219.

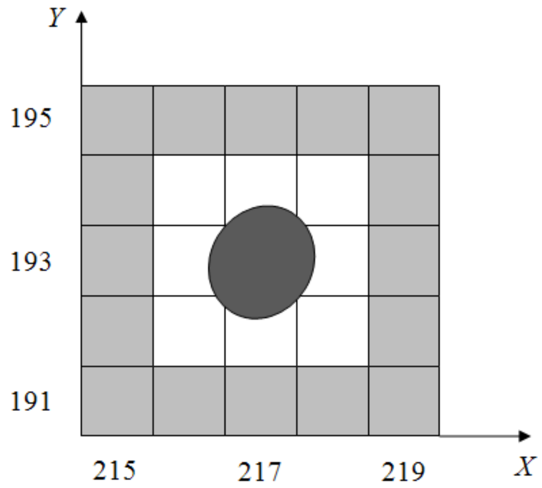

Fig. 2. The definition of adjacent area to the fire

The threshold in spectral channel 21 (I_{POR}) is defined as the average of the luminance values of pixels from the known fire hearth (I_{OI}) and the adjacent region (I_{SI})

$$\begin{aligned} I_{\mathrm{POR}} &= (I_{\mathrm{OImin}} + I_{\mathrm{SImax}})/2, \\ I_{\mathrm{OImin}} &= \min(I_{\mathrm{OI}}), \\ I_{\mathrm{SImax}} &= \max(I_{\mathrm{SI}}). \end{aligned} \tag{1}$$

Here, I_{OImin} is the minimum brightness of a pixel of the source area with known fire, I_{SImax} is the maximum brightness of a pixel of the adjacent area. In this case, ($I = 1$) are pixels (correlated with the fire) in the image (I) exceeding this threshold

$$I = \begin{cases} 0, & if\ I < I_{POR}\,, \\ 1, & if\ I \geq I_{POR}\,. \end{cases} \quad (2)$$

3 Research of the trained algorithm

Study of the proposed algorithm was performed using MODIS imagery territory of the Sverdlovsk region 28–29 July, 2010 and 01.08.2012. The actual fire situation was determined by the summary of the Ministry of Emergency situations posted the Internet. In the night picture, the threshold of detection of fire in the reserve "Denezhkin Kamen" in channel 21 MODIS (in relative brightness values 0–255) was determined in the range $B_{21NIGHT}$ = 59–69. After selecting the middle value $B_{21NIGHT} = 64$, the mask of detected fires (Fig. 3) was constructed. The fire figures (black dots) are visible in the reserve "Denezhkin Kamen", Garinsky, and Sosvinsky counties.

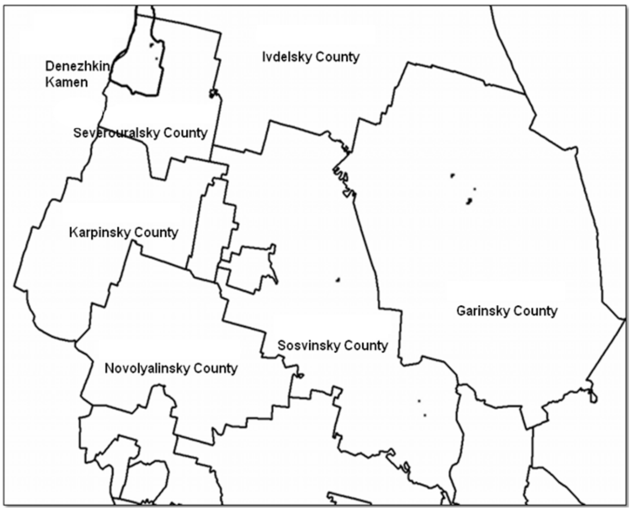

Fig. 3. Mask fires of the trained algorithm for the night snapshot, 28.07.2010; the black dots are selected thermal points

Table 1 presents information about known fires and the results of detection of the thermal points obtained (using the night MODIS image) by the proposed algorithm and the MOD14 algorithm with selected (from the condition of maximum detection of existing fires) value $T_{21NIGHT} = 300$K.

The chosen threshold value $T_{21NIGHT} = 300\text{K} = 270\text{C}$ was lower than the value $T_{21NIGHT} = 305$K, which is considered as the boundary for the recognition of the pixel to be the thermal points. It is quite realistic to suppose that this was the night temperature of crowns of trees in the Northern part of the Sverdlovsk region. Note that the proposed algorithm has demonstrated its efficiency, but it showed slightly worse results compared to the MOD14 with selected thresholds in channels 21 and 31.

Table 1. Detection of fire by the night snapshot 28.07.2010; the number of thermal points in each snapshot is given in parentheses

County	Actual fires	MOD14 (selected thresholds)	Trained algorithm
reserve "Denezhkin Kamen"	1	3 (4; 3; 1)	2 (3; 1)
Severouralsky	11	2 (1; 1)	no
Sosvinsky	15	6 (2; 3; 4; 2; 2; 12)	3 (3; 1; 1)
Ivdelsky	9	1 (1)	no
Garinsky	10	10 (1; 1; 1; 2; 1; 1; 2; 3; 2; 7)	3 (6; 3; 1)

When applying the proposed methodology on a daily snapshot, it took to use as a training standard the fire in Garinsky county because the creeping fire in the reserve "Denezhkin Kamen" failed to be detected due to its masking by the canopy of trees. In this case, the average value of the threshold $B_{21DAY} = 43$ for channel 21 fires in Sosvinsky, Garinsky, Krasnoturinsky, Serovsky, Kachkanarsky, and Karpinsky counties were detected.

In this experiment, the threshold value $T_{21DAY} = 320$K was selected by the condition of maximum detection of existing fires and was slightly above the recommended ($T_{21DAY} = 312$K) to reduce the number of false thermal points. Analysis (Table 2) has determined that the false "hot" pixels were detected in Kachkanarsky county, and the fires in the reserve "Denezhkin Kamen", Severouralsky, and Ivdelsky counties were skipped. According to the above data, the trained algorithm showed approximately the same results as MOD14 with thresholds chosen to the highlight of known fires. In general, the results of a daily snapshot for both algorithms were slightly worse than for the night ones because of the influence of surface temperature and possible specular reflections from water surfaces and edges of the clouds.

Verification of the trained algorithm was carried out using the daily MODIS image of the Sverdlovsk region dated 01.08.2012. In this case, the fire at Krasnouralsky county was selected as "training". The comparison of the results obtained here for the trained algorithm with the actual number of fires, as well as, with the MOD14 algorithm with a threshold chosen for the situation in 2010 is given in Table 3.

The obtained result demonstrates the effectiveness of the proposed algorithm (selected only one false fire) compared to the MOD14 algorithm where the threshold was selected for the snapshot of the same territory made two years earlier (with a precision of 3 days), where lots of false fires were found.

Table 2. Detection of fires on a daily snapshot 29.07.2010; the number of thermal points in each snapshot is given in parentheses

County	Actual fires	MOD14 (selected thresholds)	Trained algorithm
reserve "Denezhkin Kamen"	1	no	no
Severouralsky	12	no	no
Sosvinsky	15	2 (1; 1)	1 (1)
Ivdelsky	9	2 (1; 1)	no
Garinsky	11	6 (1; 2; 2; 2; 3; 5)	4 (5; 2; 1; 1)
Karpinsky	7	1 (1)	2 (3; 1)
Krasnoturinsky	3	no	2 (8; 1)
Serovsky	1	2 (1; 1)	1 (11)
Kachkanarsky	1	1 (12)	2 (15; 12)

Table 3. Detection of fires on a daily snapshot 01.08.2012

County	Actual fires	MOD14 (the thresholds selected for the 29.07.2010 snapshot)	Trained algorithm
Krasnouralsky	1	1	1
Kachkanarsky	no	2	1
Sosvinsky	no	1	no
Ivdelsky	no	7	no
Severouralsky	no	1	no
Krasnoturinsky	no	1	no
Karpinsky	no	2	no

Further improvement of accuracy of fires detection using MODIS data can be done by integration of the detection results obtained by processing a series of images (especially day and night) received at the same or next day. However, at the time of the next shooting, some fires can be extinguished, and some new fires may appear. Shooting conditions can also change. Therefore, the most expedient way is to extract information about the fire according to the other spectral channels of a single snapshot. Thus, parameters of the signal passing through the atmosphere from a thermopoint are various for different spectral channels (depend on a condition of the atmosphere, temperature of a thermopoint and temperature sensitivity of the channel). So we conducted research of temperature sensitivity of different channels.

In contrast to our previous publications [3], [6], this paper shows the results that were received using pictures 28.07.2010 (night) and 29.07.2010 (day) with the subsequent association of results in spectral channels. Results for the MODIS channels that are informative to find thermal anomalies are presented in Table 4. The appearance of the sign "–" for channel 24 means that it is uninformative during the day because it could not allocate any points of real fires. In addition, the reserve "Denezhkin Kamen" is a part of Severouralsky county, and the table presents aggregated information about fires in these area.

Table 4. Results of study of the spectral channels reliability

The channel number		20	21	22	23	24	25
County	Actual fires (night/ day)	Fires found (night/day)					
Severouralsky (reserve "Denezhkin Kamen")	11/12	2/0	2/0	2/0	2/0	2/–	2/0
Sosvinsky	15/15	6/0	3/0	3/0	4/0	6/–	5/0
Ivdelsky	9/9	0/6	0/0	0/0	0/0	13/–	0/0
Garinsky	10/11	3/3	3/2	3/3	3/3	3/–	3/2
Karpinsky	0/7	0/0	0/0	0/0	0/0	0/–	0/0
Krasnoturinsky	0/3	0/2	0/0	0/0	0/0	0/–	0/0
Serovsky	0/1	0/0	0/1	0/1	0/1	0/–	0/1
Kachkanarsky	0/1	0/1	0/1	0/2	0/1	0/–	0/0
Taborinsky	0/0	0/0	0/0	0/0	0/0	0/–	0/2
The channel reliability night/day (P_{RN}/P_{RD})		0.244/ 0.203	0.178/ 0.068	0.178/ 0.085	0.200/ 0.085	0.444/–	0.222/ 0.051

Analysis of the obtained data allows one to determine the probability of a false detection of the thermal points as the ratio of the total area of the false "hot" pixels to the area of the territorial county where they are found. The area of the MODIS pixel in the selected channels is 1 km^2, so, the probability of false detection of a fire by daylight shots in Kachkanarsky and Taborinsky districts was equal to $3 \cdot 10^{-3}$ and $2 \cdot 10^{-4}$, respectively. Similarly using the night shot of four non-existent fires were found (13 discovered and reported 9) at Ivdelsky district. So, the probability of false detection of fire is $2 \cdot 10^{-4}$.

The probability of correct detection of the thermal point (P_R) in the spectral channel (the reliability of the channel) was determined as the ratio of the total (around snapshot) number of the detected fires in the channel to their actual number. So, the actual number of fires on territories at the night snapshot 28.07.2010 was 45, and number of thermal points found at the channel 20 is 11. As for the day shot, 59 points are actual fires and 12 are detected. So, the reliability of the channel 20 at the night is $P_{RN} = 0.244$, and at the day its P_{RD} = 0.203. Similarly, reliability of the remaining (21,...,25) channels (Table 4) was calculated.

Combining the results of several spectral bands, it is possible to was estimate the probability of correct fires detection based on remote sensing data and application of the proposed algorithm. For example, if one of the pixels on the night image of the Garinsky district exceeded trained 20,...,25 channels thresholds, the probability that it belongs to the fire is

$$P_{RN} = 1 - \prod_{k=20}^{25} (1 - P_{RNk}) = 0.823. \tag{3}$$

Using information of only one channel, you can get the reliability of the fire detection not more than $P_{RN24} = 0.444$. If the pixel at the day image of the Garinsky district exceeded the threshold of 20,...,23, and 25 channels, the probability that it is thermal point is $P_{RD} = 0.410$. And finally, if it is the same pixel on both daylight and night shots, the probability that it belongs to the fire is

$$P_R = 1 - (1 - P_{RN})(1 - P_{RD}) = 0.896. \tag{4}$$

Comparing our algorithm with well-known ones, for example [7], [8], we should say that in them information about statistical characteristics of fire and background pixels is used to define a threshold of detection. But we suggest the approach that doesn't assume any initial allocation of potentially hot pixels for definition of distribution function of probability density for brightness of fire-fighters and the pixels surrounding them. It is based on the fact that detection of thresholds is performed at spectral channels on the basis of allocation of the known fire in the picture, according to the subsatellite information. In this case, it is possible to exclude an uncertainty in temperature of a surface and, partially, in the atmosphere parameters.

The conducted experimental study of our algorithm, which is based on the existing fire, allows one to conclude that the results received with its help aren't worse than ones of the well-known algorithm MOD14. Similar results are received in papers [7], [8] that allows one to judge efficiency of our algorithm in comparison with ones offered there. We plan to conduct further researches using more extensive actual material for receiving adequate quantitative estimates. Combination of our results with ones received by the mentioned algorithms will allow increasing probability of the forest fires correct detection.

The further increase of probability of the correct fire detection according to MODIS is possible by exception of reflections from stationary natural (water) and anthropogenous (industrial and civil constructions) objects, and, also, from nonstationary objects (edges of clouds).

4 Conclusion

The paper presents description of the trained threshold algorithm that uses the true ground information about one of the fires and builds an effective procedures for analysis of the fire situation on the basis of the territory shot obtained by the spectroradiometer MODIS. Study of the proposed algorithm was implemented for the forest fire detection using data by 21 spectral channels of one night and two daylight MODIS images. Good coincidence of the results of the fires detection with the ground true data and results of work of the well-known MOD14 algorithm was obtained. Informativity of the MODIS spectral channels for forest fire detection using the trained algorithm was analyzed. The example shows that approximately double increase of the probability of correct detection of fires (up to 0.896) is possible by combining the results of spectral bands 20,...,25 of the night and day shots.

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