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An algorithm of the wildfire classification by its acoustic emission spectrum using Wireless Sensor Networks

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Abstract. Crown fires are extremely dangerous as the speed of their distribution is dozen times higher compared to surface fires. Therefore, it is important to classify the fire type as early as possible. A method for forest fires classification exploits their computed acoustic emission spectrum compared with a set of samples of the typical fire acoustic emission spectrum stored in the database. This method implies acquisition acoustic data using Wireless Sensors Networks (WSNs) and their analysis in a central processing and a control center. The paper deals with an algorithm which can be directly implemented on a sensor network node that will allow reducing considerably the network traffic and increasing its efficiency. It is hereby suggested to use the sum of the squares ratio, with regard to amplitudes of low and high frequencies of the wildfire acoustic emission spectrum, as the indicator of a forest fire type. It is shown that the value of the crown fires indicator is several times higher than that of the surface ones. This allows classifying the fire types (crown, surface) in a short time interval and transmitting a fire type indicator code alongside with an alarm signal through the network.

1. Introduction

Wildland fires still cause severe harm to ecology and economy of many countries worldwide despite the technology onrush. Nowadays, the technological techniques for forest fires detection can be divided into two groups:

- Photographic survey in visible and/or infrared bands of a forest surface area and autosensing of the fire evidence (smoke, thermal field) by stationary field cameras or LIDARs placed on control towers or mobile cameras fixed on any flying vehicle (plane, UAV, air balloon, satellite);
- Measurements and monitoring of environmental parameters (temperature, humidity, smoke content, etc.) using sensors located in the controlled forest territory, together with their transfer to the tracking center through a network.

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The first group mostly covers methods based on automatic recognition of a smoke through the image processing [1]. The second group of technological methods of fire detection implies placing temperature and/or smoke sensors in an administered territory [2], which is desired to be controlled; this technology has been known for a long time and is widely used in various buildings and facilities. Such systems are marked by low cost of their operation, speed of fire detection and high integrity (false alarms are hardly possible).

However, unlike fire detection systems installed in buildings, sensors that are used in large forest areas by far require wireless technologies. An autonomous fire detector is a miniature electronic package combining position location capability possibly using the Global Positioning System (GPS), communications (packet or voice-synthesized radio), and fire detection capability (thermal, gas, smoke detector) into an inexpensive, deployable package. Such detector can report fire-related parameters, like temperature, carbon monoxide concentration, or smoke levels via a radio link to firefighters [3].

At present, one of the most advanced wireless technologies that best fit this task is the so called Wireless Sensor Network (WSN), with its different operational and communication platforms and standards (e. g. ZigBee platform is best known and widely used). Some WSNs for forest fire early detection were developed and presented [4]. They are based on IEEE 802.15.4 protocol and are characterized by low energy consumption, low cost and low speed of data transmission.

The main advantages of such networks include easy scalability, low energy consumption due to the possibility to keep the WSN node in the so called “sleep mode”, and their low cost. Among disadvantages, there is low data transmission speed (250 kbps), which may be a constraining factor in implementing large-scale WSNs. Hence, as a rule, the manufacturer of such systems produces a line of radio-transmitting modules with various characteristics contributing to the design of forest fire early detection systems with different configurations.

The main problem of WSNs application in wildfires early detection is a large number of sensors required to cover the whole area of the administered territory.

If temperature and smoke sensors are capable to overcome the triggering threshold and send an alarm signal only close to fire front, the sound of a fire can be detected further from its front.

In solving our task it is essential to differentiate between crown and surface fires as the velocity of surface fires distribution is much lower than of the crown ones and forest fighters should be consequently prepared and equipped [5].

Hence, the purpose of this research is to design a formal algorithm for forest fire types determination and classification (surface, crown, etc.) according to their noise spectrum. Moreover, the algorithm has to be designed in a way to be used not only on the PC in the tracking center, but also within the sensor itself (provided the microprocessor is built-in). In the second case, the amount of transmitted data through the network will be much less than in the first one. It will allow reducing considerably the network traffic and to increase its efficiency.

2. Research methodology

The noise spectrum recorded from dozens of various fires is studied in this work. Accompanying videos allowed classifying all fires type (e. g. surface fire, crown fire). It was shown that noise spectra of surface and crown fires have different forms: a gradual increase of the trend line amplitude towards lower frequencies for the surface fire noise spectrum and the bell-shaped (Gaussian) trend line for the crown fires noise spectrum [6]. These differences can be used in early detection of the forest fire type.
The research method is simply based on noise spectral analysis of different forest fires using the Fourier transform. The purpose of this method is to identify the characteristic of the frequency response of the noise for different forest fire types.

Records of wildfire noises were taken from open sources available on the internet. Accompanying videos allowed us to pre-classify the fire on sight. The Fast Fourier Transform (FFT) allows obtaining the necessary noise power spectrum from the recorded sound waveform.

3. Research results

First of all it should be pointed out that the problem of false alarms was not considered in this paper. It is caused by the fact that, according to the published method of forest fire detection, the spectral analysis of its noise is only made once the surrounding temperature increases above the preset threshold. It means that the event of "Fire" has likely occurred and there is no need to distinguish the fire noise from, for instance, the rain noise in the forest (false alarm), the spectrum of which is very similar.

The known method of forest fire type determined by the noise is based on the comparison of the measured fire noise with spectra of an already known fire noise stored in the database. Such algorithm can be easily implemented in the tracking center, but it is not suitable for a sensor microprocessor.

Thus, in order to achieve the desired objective, the spectral analysis of the surface and crown fire noise was made using the ad-hoc developed software. The analysis demonstrates that there is a considerable and steady increase of the amplitude within the low frequency range, which is only typical for crown fires. A similar difference was also noticed between noise spectra of surface and crown fires.

This difference was used as a technique to define the forest fire type. The classification algorithm can be implemented not only on the PC in the tracking center, but also within a small microprocessor built in the Smart Sensor (SS) itself.

The algorithm can be presented as a sequence of the actions described in the following. The sensor switches from sleep into the operating mode and measures standard parameters, e.g., temperature, humidity, CO content, etc. A predefined threshold (e. g. 70-80ºC) is considered, and if the measured temperature does not exceeds the preset threshold, the measured standard parameters are transmitted through a network and switch back to the sleep mode. Otherwise, the acoustic sensor is activated and used to measure fluctuations of acoustic pressure during a well-defined time interval (e.g. 2-3 seconds). The analog values measured by the acoustic sensor is amplified and converted into a digital code and recorded in the sensor RAM (for example, the RAM of sensors on the Intel Mote 2 platform is 32 MB, which is entirely sufficient to record 24 KB of audio data). At this point the spectrum of the signal recorded in the RAM according to Discrete Fourier Transform (DFT) is computed according to the following equation:

$$C_j = \sum_{k=1}^{m} S_k e^{-i(2\pi j/m)k}, \tag{1}$$

where k and m are the current number and the amount of signal samples (fire noise), S_k is a current value of signal amplitude of samples, j is the index of the current frequency component of a signal, $j = 1\ldots m$.

The next step is to evaluate the sums of squares of the calculated spectrum amplitudes for low and high frequencies and to calculate their relation R (an indicator of the forest fire type) according to equation (3) below:

$$R = \frac{\sum_{j=l_1}^{l_2} |C_j|^2}{\sum_{j=l_3}^{m} |C_j|^2} \cdot \frac{m - l_3 + 1}{l_2 - l_1 + 1}, \tag{2}$$

where l_1, l_2 and l_3 are numbers of signal indications corresponding to the specified range of low (from l_1 to l_2) and high (l_3 to m) frequencies properly selected a priori.

If calculated value R is higher than the preset threshold, the forest fire is classified as a type "crown". If calculated value R is lower than the preset threshold, the forest fire is classified as a type "surface". The information is transmitted through the network together with the measured values of standard parameters.

All the working steps are performed until SS stops functioning due to high fire temperature or the alarm is stopped.

Equation (1) may be replaced with formulas of the Fast Fourier Transform (FFT), thus allowing the reduction of the number of operations for spectrum calculation. A one-dimensional continuous wavelet transform, which is faster in terms of computational load, can also be used instead of the Fourier Transform [7].

Of course, the algorithm does not depend on the number of sensors within a network, it does not require iterative calculations, and, hence, cannot be classified as a high complexity class algorithm.

Besides, after additional study of a fairly large number of forest fire noises, it is possible to determine the values of relation *R* typical for intermediate types of forest fires. For instance, “strong surface fire”, “incipient crown fire”, etc. can be added to the classification schema.

4. Case studies

In order to check the algorithm independent videos of forest fires were selected, according to which it was possible to visually determine the fire type. Figures 1-4 are examples of the basis of video used to prove the validity of the proposed classification algorithm: incipient surface fire (Figure 1), intense crown fire (Figure 2), developed crown fire (Figure 3) and intense crown fire or fire storm (Figure 4). The image on the left shows typical photos of fires. On the right, there is the segment of the fire noise time chart related to 30 ms (above) and the noise spectrum diagram with the fitting curve (purple) calculated related to 5 s (below). Values of relation *R* calculated according to equation (2) are given in captions.



Figure 1. Incipient surface fire [8], $R = 1.15$



Figure 2. Intense surface fire [8], $R = 2.14$



Figure 3. Mature crown fire [9], R = 29.66



Figure 4. Intense crown fire (fire storm) [10], R = 65.06

The plots on the right in the previous figures show that the trend line of the noise spectrum diagram for incipient surface fires gradually increases its amplitude towards low frequencies.

The trend line of the noise spectrum within the range of low frequencies in a bell-shaped, or Gaussian, form is typical for intermediate and crown fires. The stronger the fire is, the more distinctly the bell-shaped trend line is observed. This bell-shaped distinct is used to determine the type of forest fire for early detection/classification by the proposed algorithm. The value of forest fire indicator R, calculated by the proposed algorithm, gradually increases as the fire becomes stronger. The comparison between the incipient surface fire (Figure 1) and the intense crown fire (Figure 4) is of great interest.

5. Discussion

This paper is a step towards the development of a new method of wildfire detection and classification by its acoustic emission (noise). This technology is, first and foremost, aimed at protection of large territories with minimum civilization noise, such as conservation areas and pristine forest areas.

It is wrongly assumed that this technology is able to substitute all existing technologies of wildfire early detection. Most likely, it is only supplementing them with another independent tool, thus making the system of forest fire early detection more efficient.

Sensor nodes like these will obviously cost more compared to regular sensors based on temperature and smoke detection. However, it is possible to combine both (some sensors are simple and the others are smart) in order to pick the best solution for a certain topology of a network ad-hoc designed for a target area to be monitored.

6. Conclusions

This study is based on the previous work on forest fire early detection by spectral analysis of fire acoustic emission. A new algorithm of the forest fires classification and detection by their noise spectrums is presented in this paper. The algorithm does not depend on the number of sensors within a network. In addition, it does not require iterative calculations and, therefore, as already stated before, cannot be classified as a high complexity class algorithm. It can be implemented not only in a central processing center, but also on board of the network node, provided the microprocessor is built-in.

The paper suggests using the relation of the sum of squares of low and high frequency amplitudes of a fire noise spectrum as a forest fire type indicator. It is shown that the value of this indicator is several times higher for crown fires than for surface ones. This allows defining the fire type immediately and transmitting a fire type indicator code alongside with an alarm signal through the network, which is crucial information for the corresponding training of firefighters and potentially intervention over the burned area.

A set of known and previously recorded data of real records of wildfires demonstrates good performance of the algorithm used to classify the forest fire type.

7. References

[1] Cetin A, Merci B, Günay O, Töreyin B and Verstockt S 2016 *Methods and Techniques for Fire Detection* (Academic Press: New York)

[2] Hefeeda M and Bagheri M 2009 Forest Fire Modeling and Early Detection using Wireless Sensor Networks *Ad Hoc & Sensor Wireless Networks* vol 7 (Philadelphia: Old City Publishing) pp 169–224

[3] Kremens R, Faulring J, Gallagher A, Seema A and Vodacek A 2003 Autonomous field-deployable wildland fire sensors *Int. J. of Wildland Fire* vol 12 (Clayton South VIC: CSIRO Publishing) pp 237–244

[4] Solobera J 2010 Detecting Forest Fires using Wireless Sensor Networks *Libelium World (Electronic Materials)* (Zaragoza: Libelium)

[5] Bertoldo S, Corgnati L, Losso A and Perona G 2012 Safety in forest fire fighting action: a new radiometric model to evaluate the safety distance for firemen working with hand-operated systems *Proc. 3rd Int. Conf. on Modelling, Monitoring and Management of Forest Fires 2012* vol 158 (London: WITpress) pp 3–12

[6] Khamukhin A A and Bertoldo S 2016 Spectral analysis of forest fire noise for early detection using wireless sensor networks *2016 Int. Siberian Conf. on Control and Communications (Moscow)* (New York: IEEE) pp 1–4

[7] Chilo J and Lindblad T 2008 Hardware Implementation of 1D Wavelet Transform on an FPGA for Infrasound Signal Classification *IEEE Transactions on Nuclear Science* vol 55 no 1 (New York: IEEE) pp 9–13

[8] Surface fire documentary 2010, http://www.youtube.com/watch?v=VlmSqdvDsz8

[9] Crown fire documentary 2010, https://www.youtube.com/watch?v=euRsJuqJeeU&feature=youtu.be&t=23

[10] Crown fire documentary 2016, https://www.youtube.com/watch?v=0-hu1BUBQDQ