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Spectral Analysis of Forest Fire Noise for Early Detection using Wireless Sensor Networks

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***Abstract*—Crown fires are extremely dangerous, very difficult to fight and often have a rate of spread over 100 times more than a surface fire. Therefore, it is important to determine the type of forest fire in the early detection based on wireless sensor networks (WSNs) to adopt the proper strategy to fight the fire. It is shown that this could be done analyzing the noise power spectrum of forest fires: surface fires noise spectrum can be modeled as the red noise (gradual increase of trend line amplitude toward lower frequencies), while for crown fires noise spectrum trend line has an almost bell-shaped (Gaussian) type. The noise frequency range is relatively narrow for crown fires and ranged from 250 to 450 Hz. The intermediate type of fires (strong surface fire and incipient crown fire) has a transient noise spectrum from broadband red to narrowband Gaussian. The article presents the spectrums of 9 different forest fires. The different trend line of the forest fire noise power spectrum is the parameter that can be used to determine the type of forest fire in WSNs.**

Keywords—surface fire; crown fire; early detection of forest fire; wireless sensor network; acoustic emission; spectral analysis

I. Introduction

The problem of wildfires early detection to restrict their spread quickly is very urgent all over the world. Rate of spread of forest fire is strongly influenced by atmospheric conditions, weather, winds, forest type, land cover and topography.

However, rate of spread is one of the fire characteristics that allow classifying two types of forest fires: crown and surface fires. Surface fires (litter fire, herbaceous fire, and undergrowth fire) have a low rate of spread of about 0.5 m/min. Crown fires are extremely dangerous, very difficult to fight and often have a rate of spread approximately from 100 to 200 m/min. Wind may increase this rate.

Therefore the rate of spread is a key component in planning forest fire fighting, and even in taking decisions for conducting prescribed fires and suppressing wildfires. Therefore, it is important to know the type of fire when a fire alarm is triggered [1], whether it is given by a person or by an automated system for forest fire detection (e. g. [2]).

Wireless Sensor Networks (WSNs) is one of the most reliable tools for early detection of forest fires. WSNs consist of tiny, cheap and low-power sensor devices that have ability to measure the environment characteristics.

There are a large number of review articles on the WSNs and their recent developments in terms of technology and research, spanning more than two decades. Some examples of forest fires early detection using WSNs can be found in [3– 9]. However, the sensors used in wireless sensor networks for early detection of forest fires are not able to determine the type of fire. As an example, Fig. 1 shows sensor of the Spanish company Libelium [8].

Fig. 1. Sensor Waspmote for a forest fire early detection by Wireless Sensor Networks of the Spanish company Libelium [9].

This sensor measures four parameters every five minutes: temperature, relative humidity, carbon monoxide, carbon dioxide. If some of these measured parameters is above the configured thresholds, the system analyzes the information and reacts sending an alarm to the firefighters or to the operators devoted to forest fire monitoring. They will know instantly that there is a fire and where it is with accuracy, because each Waspmote can integrate a GPS receiver.

However, the fire type remains unknown, although the information regarding the type of the fire is invaluable for the rapid deployment of fire fighters. Therefore, additional parameters and algorithms to determine the type of fire are needed, and the sensors must measure and compute them.

II. Research Objectives

The aim of this study is to find a simple criterion of instantaneous classification between crown and surface forest fires to be used in WSNs for early detection.

The use of acoustic emission as an early indicator of a hidden structural fire has been already investigated in article by

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Grosshandler et. al. [10]. It was found that the number of emissions/minute varies for a given material in a way similar to the energy.

However, the absolute number of emissions cannot be predicted a priori because the number of defects and the moisture content are highly variable for heterogeneous materials [10].

Strong (e. g. crown) fire has another acoustic emission combustion process. The basic noise is generated by turbulent vortices from burning treetops that begin to dominate.

Therefore, aim of this work was to study the various fire noises to identify a parameter by which to determine the forest fire type. Of course, this parameter is not intended to replace existing sensors, but only to supplement the measured parameters of existing sensors, making the monitoring operation more detailed and exhaustive.

III. Research Methodology

The research method is simply based on the 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. A MATLAB® software was used for the first computations made for this paper. Veracity of calculations was checked by Mathcad® software.

Records of wildfire noises were taken from open sources available on internet [11 – 13]. Accompanying video allowed us to pre-classify the fire on sight. The Fast Fourier Transform (FFT) allows to obtain the necessary noise power spectrum from the recorded sound waveform.

The method of the trend line computation is then used. We calculate the trend line coefficients a_i by polynomial fitting:

$$P(f) = \sum_{i=0}^{n} a_i f^i, \tag{1}$$

where $P(f)$ is a power spectrum of the forest fire noise; f is an instantaneous frequency; i is a current degree of polynomial. A fitting curve of chart shows a qualitative behavior of the forest fire spectrum that may to determine the fire type.

We used in formula (1) maximum polynomial degree n from 3 to 10 for different cases. We restricted degree n if higher coefficients a_i were near zero.

IV. Research Results

More than four dozens of wildfire sound records were analyzed. The article presents results of the analysis of the 15 most characteristic records for different types of forest fires, starting from incipient surface fire to strong crown fire (the so called “firestorm”).

As reported in the scientific literature we expected power spectrum of surface fire sounds similar to white noise spectrum in range from 100 to 4000 Hz. The heat produced by a fire overload will cause the surrounding materials to expand. If the affected components are constrained in a structure, the stressed material may emit sound at frequencies up to 500 kHz when the stress is suddenly relieved [10].

In practice, we got the noise spectrum with gradually increasing trend line toward lower frequencies. This is typical for red noise. Fig. 2 shows the power spectrums and the trend lines in red for surface wildfires noise in wide range (on the left) and with the zoom in a narrow range of frequencies (on the right).

According to our opinion, we expected that power spectrum of crown fire noise will translated toward low frequencies. "The distant murmur had grown into a low moaning over the tree-tops" (Curwood 1926, The Flaming Forest). In practice, the results exceeded expectations. Fig. 3 shows the power spectrums and the trend lines for crown fire noise in wide range (on the left) and with the zoom in a narrow range of frequencies (on the right).

As you can see, the power spectrum trend line of the crown fire noises has a distinct bell-shaped (Gaussian) type. The frequency range is relatively narrow for the crown fires and ranged from 250 to 450 Hz. A specific dominant frequency in the spectrum is not present, but there is global maximum of the power spectrum computed trend line.

This bell-shaped distinct can be used to determine the type of forest fire for early detection using Wireless Sensor Networks made by sensors equipped capable to record forest fire noise.

We also investigated the noise of intermediate types of fire (e. g. strong surface fire and incipient crown fire). The power spectrum of these noises confirms our proposed hypothesis and their trend lines are intermediate between red and Gaussian noise.

It has been found a supplemental parameter to help to determine the type of forest fire: the trend line of the power spectrum of a forest fire noise. This parameter, together with the alarm detected by other systems and other specific algorithms, allows firefighters and qualified operator to immediately assess the rate of spread and potentially take appropriate action.

A patented method of using this parameter on systems for early detection and monitoring of forest fires was described [14]. Sensor includes a thermoswitch and a microphone with transmitter additionally. When the measured temperature goes above the configured threshold, the thermoswitch turns on and connects the microphone to the data transmission system. The noise is transmitted to the fire monitoring center where noise spectral analysis is performed and type of fire is determined. A code for standard PC can be used for the spectral analysis.

The spectral analysis apparatus can be also placed inside the smart sensor, e.g., in [15]. In this case, the network traffic can be considerably reduced and it is sufficient that each sensor is equipped with DSP where the algorithm to compute the trend line for the noise power spectrum.

Conclusion

The results of spectral analysis of the of forest fires noise on the 15 records from various sources are shown. The power spectrum is calculated in a wide range (from 100 to 4000 Hz) and a narrow range (from 100 to 600 Hz).

It is shown that surface fire noise spectrum can be assimilated to the red noise spectrum (gradual increase of the trend line amplitude toward lower frequencies). For what concern crown fires noise spectrum, its trend line has an almost bell-shaped (Gaussian). The frequency range is relatively narrow for the crown fires and ranged from 250 to 450 Hz. One dominant frequency in the spectrum is not found, but there is global maximum of the power spectrum trend line.

The power spectrum of intermediate types of fire (from strong surface fire to incipient crown fire) presents intermediate characteristics between red and Gaussian noise.

The different trend line of the power spectrum can be used to determine the type of forest fire for early detection using WSN.

As told before, the proposed parameter is not intended to replace existing sensors, but only to supplement of measured parameters of existing sensors.

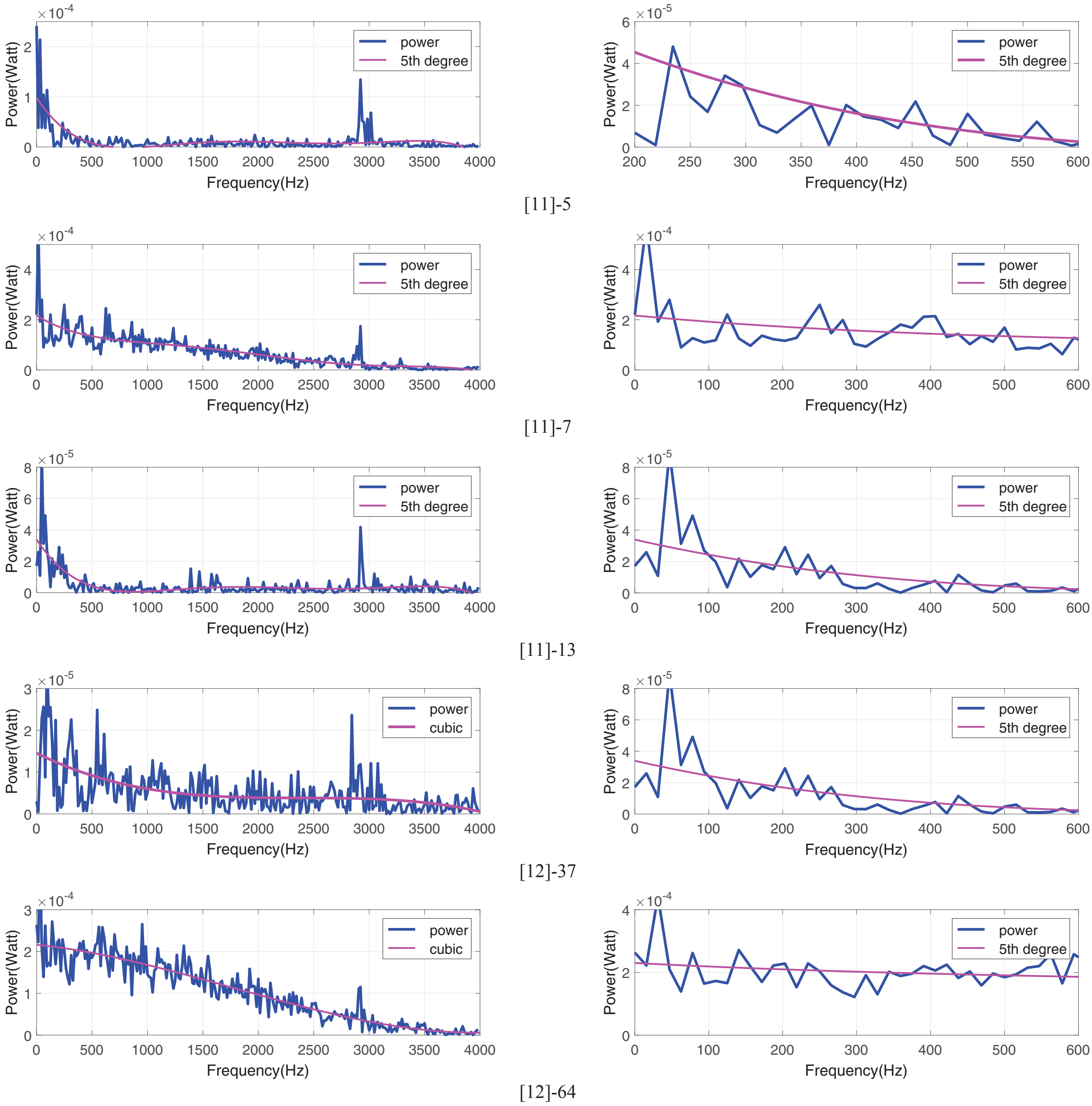

Fig. 2. The power spectrums (in blue) and the trend lines (in purple) for surface wildfire noise in wide range (on the left) and with the zoom in a narrow range of frequencies (on the right). The source of the sound record is marked under the figure.

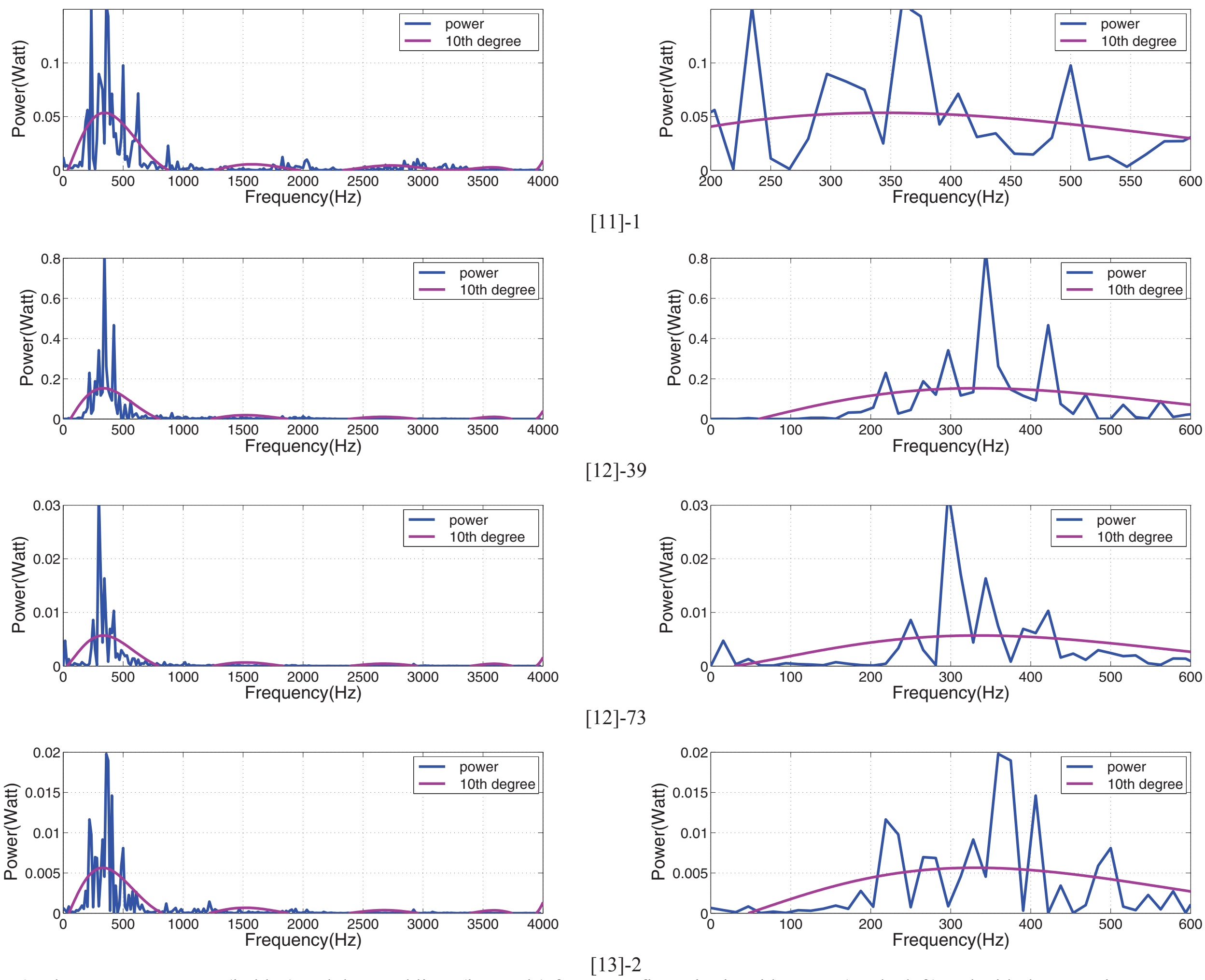

Fig. 3. The power spectrums (in blue) and the trend lines (in purple) for crown fire noise in wide range (on the left) and with the zoom in a narrow range of frequencies (on the right). The source of the sound record is marked under the figure.

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