Waldemar Wójcik[1], Andrzej Kotyra[1],
Tomasz Golec[2], Mariusz Duk[1]

[1]Technical University of Lublin, Dept. of Electronics, Nadbystrzycka 38a, 20-618 Lublin, Poland
[2]Institute of Power Industry, Augustówka 5 Str., 02-981, Warsaw, Poland

COMPRESSION OF SIGNALS OBTAINED FROM THE FIBRE-OPTIC FLAME MONITORING SYSTEM

Keywords: wavelet transform, signal compression

In the article, we present application of wavelet transform and Fourier transform in compressing signals obtained from the flame monitoring system. The results of compression are compared by function of relative error vs. compresion ratio.

INTRODUCTION

The digital system supervising a power block enables current controlling of its state through analysing signals of various sensors and transducers. By simultaneous measurement of different physical quantities such as temperature, pressure, displacement etc., it is possible to determine the current state of power block. In the case of 200MW power block at "Kozienice" power plant, which was taken into consideration, the number of measuring point exceeds 1000. The proper interpretation of the signals could be done not only through its actual values, but also through the former values. This imposes the necessity of storing the data. The other reason is analysing of possible malfunctions of important devices, which would have taken place in the past. That is why all the signals are stored by the period of one year.

Storing such a huge amount of data would be difficult if proper compression algorithms would not have been applied. Especially it concerns quick-variable signals such as, flame pulsation signals, which contain sudden amplitude changes.

We have applied wavelet transform based lossy compression, which is especially efficient in the case of such signals.

THE FLAME MONITORING SYSTEM

Signals taken under consideration are output signal of flame monitoring system. The system was elaborated at Department of Electronics, Technical Univ. of Lublin and its scheme shown on Fig.1. The system is designed to work at industrial conditions and consists of following main parts [1]: multichannel head, high-temperature optical fibers, photodetectors and electronic blocks.

A part that in the highest degree influences on the proper operation of the whole device, is the head [1]. It is placed inside the combustion chamber of the power boiler and works at temperatures exceeding 450°C with high dustiness and vibrations. The multichannel head receives radiation emitted by certain flame zones ensuring the suitable temperature to the optical fibres that are placed inside. The head's front is designed so as to work for a few months without the necessity of manual cleaning. Optical signals that correspond to particular flame zones are transmitted via high-temperature optical fibres to the optoelectronic part of the whole device, which is placed at comparatively low temperature conditions. The signals are converted into electrical form and then readjusted to the standards required by power block's computerised supervising system.

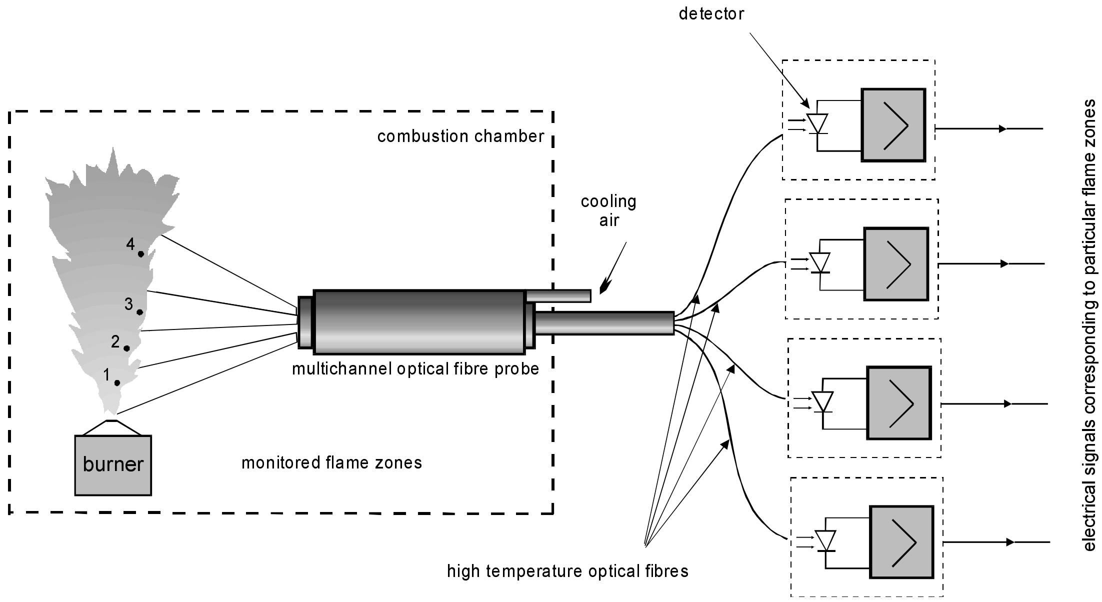


Fig. 1. Schematic diagram of the flame monitoring system

The output signals of each optoelectronic block (Fig.1) are flame radiation intensity signal and flame flickering signal. The signals are highly nonstationary for the turbulent flow of air/fuel mixture and turbulent flame. In order to obtain information of such a process through an analysis of the mentioned above signals, one have to utilise a sophisticated methods of signal processing.

WAVELET TRANSFORM

Wavelet transform becomes more and more popular signal processing technique as opposed to Fourier transform. It decomposes finite energy signal f(t) into a series of wavelet coefficients $\gamma(s,\tau)$ [2], [3]:

$$\gamma(s,\tau)=\int f(t)\cdot\overline{\psi_{s,\tau}(t)}dt \quad (1),$$

where: $\psi_{s,\tau}(t)$, $\overline{\psi_{s,\tau}(t)}$ – set of base functions (wavelets) and conjugated functions respectively,
s, τ – scale and translation coefficients respectively
t – time.

The elements of the set of base functions $\psi_{s,\tau}(t)$ are obtained from a single prototype function by its continuous dilation and translation in time domain:

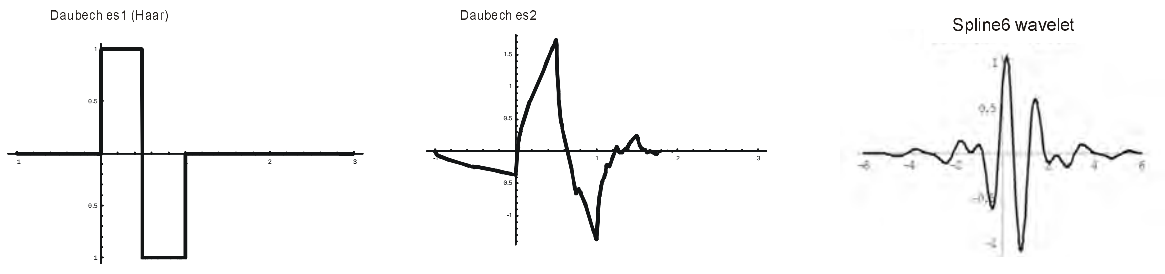
$$\psi_{s,\tau}(t)=\frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \quad (2)$$

As opposed to Fourier transform, wavelet transform can represent a signal in time domain simultaneously at different resolutions. Moreover, the prototype function can be any function. However, it should have good localization in time (which means vanishing at $t\rightarrow\pm\infty$ and vanishing of its Fourier transform at $\omega\rightarrow\infty$ and $\omega\rightarrow 0$). Wavelets must fulfill admissibility condition [2]

$$\int \frac{|\Psi(\omega)|^2}{\omega} d\omega < +\infty \tag{3}$$

where: $\Psi(\omega)$ is the Fourier transform of $\psi_{s,\tau}(t)$. The admissibility condition is the necessary condition of existence of the inverse transform. Because wavelet possesses localization both in time and frequency domain, from eq. (3) it follows that function $\psi(t)$ has at least a few oscillations. Thus, the word “wavelet” means just a “small wave”.

Examples of some wavelets are presented on Fig. 2



a) b) c)

Fig. 2. a), b) Some of Daubechies wavelets of 1st (also known as Haar wavelet) and 2nd order respectively, c) Spline wavelet of 6th order

DISCRETE WAVELET TRANSFORM

Practical realisation of transform in meaning of (1), would be impossible due to continuity. Thus coefficients s and τ are digitised which leads to discrete wavelet transform (DWT). For the sake of computing optimisation, it is convenient to set these coefficients as follows [2], [3]:

$$s = 2^j,\ \tau = k, \tag{4}$$

where: j, k are integers,
and to set the number of samples N to be integral multiple of power of 2. This leads to $\log_2 N$ decomposition levels.
The signal can be reconstructed through the inverse wavelet transform, which is (in the discrete case) sum of base functions weighted by corresponding wavelet coefficients:

$$\mathrm{f}(t) = \sum_{j,i} c_{j,k} \cdot \psi_{j,i}(t) \tag{5}$$

where: $c_{i,k}$ – wavelet coefficients series.

SIGNAL COMPRESSION

Wavelet based compression consists on decomposition to the appropriate wavelet coefficients and rejecting of the ones, that do not contain significant information. Then, the inverse transformation is calculated over the remaining coefficients. In fact, this is a kind of lossy compression, where some part of a signal is treated as noise and is rejected. To determine which of wavelet coefficients should be omitted, energy contained within c^{th} coefficient is calculated. Introducing a function of cumulative energy $\mathrm{E}(n)$:

$$\mathrm{E}(n) = \sum_{i=1}^{n} |c_n|^2, \qquad |c_n| \geq |c_{n+1}| \tag{5}$$

we can determine energy contained within n largest coefficients. A diagram of such compression is shown on Fig. 3.

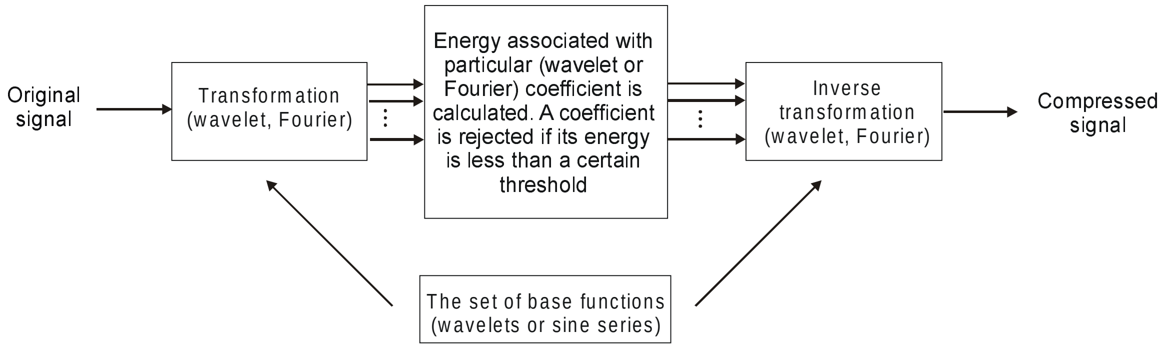


Fig. 3. Block diagram of lossy compression

COMPRESSION RESULTS DISCUSSION

An example signal obtained from the fibre-optic flame monitoring system is presented on Fig. 4. The signal was captured at the speed of 1000 probes/s when a sudden change in air/fuel ratio took place (pointed with an arrow). The signal was transformed into wavelet and Fourier coefficients.

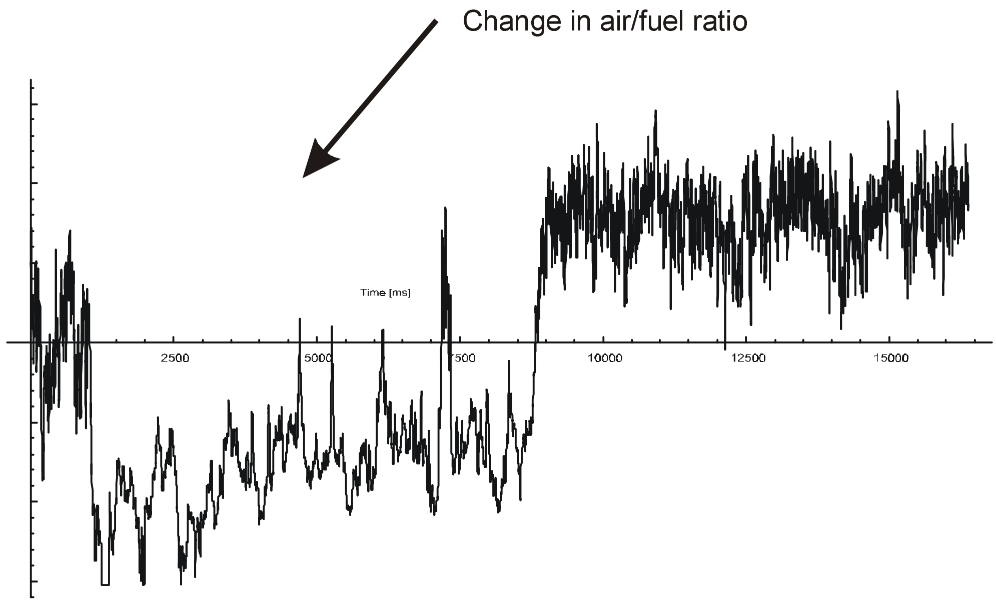


Fig. 4 An exmple signal obtained from flame monitoring system

To compare results obtained with wavelet and Fourier transform, cumulative energy was calculated. The result of an example calculation is presented on Fig. 5. In the case of wavelet transform the Spline6 wavelet was used.

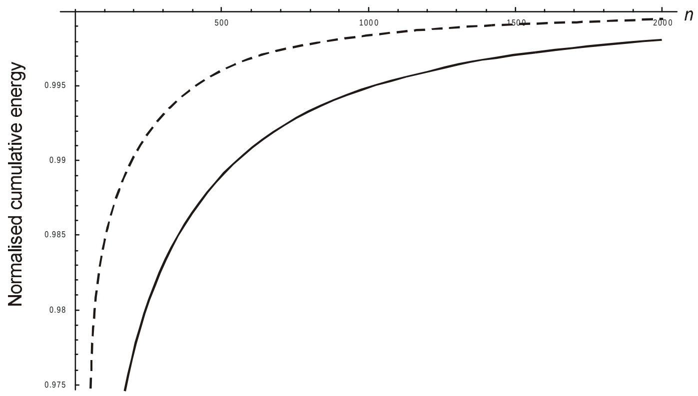


Fig. 6. Normalised cumulative energy for wavelet transform (Spline6) – dashed line and Fourier transform – solid line

We see that the cumulative energy of the Fourier coefficients (solid line) is well below that of the wavelet coefficients (dashed line). For instance, we keep 99% the energy by retaining 590 Fourier coefficients and only 194 wavelet coefficients. This means that in this example the wavelet transform is able to concentrate more energy in fewer coefficients than the Fourier transform, thus requiring fewer coefficients to reproduce the signal.

Often it is desirable to know how the errors change with the compression ratio and we would like to achieve maximum compression for a given allowed error. The compression ratio is defined as N/M, where N is the total number of coefficients before compression, M is the number of coefficients to retain. The relative root mean square error can be calculated according to:

$$\varepsilon = \sqrt{\sum_{k=1}^{N} \left|\tilde{c}_k - c_k\right|^2 \Big/ \sum_{k=1}^{N} c_k^2}\ , \qquad (6)$$

where $\{c_k\}$ is the original data and $\{\tilde{c}_k\}$ is the reconstructed one. Since an orthogonal wavelet transform with periodic boundary conditions preserves the "norm of the data" $\sum_{k=1}^{N} c_k^2$, we can also calculate the error before doing inverse transforms. It can be easily shown that the relative error due to compression with a ratio N/M is given by

$$\varepsilon = \sqrt{1 - \tilde{E}(M)}, \qquad (7)$$

where $\tilde{E}$ is the normalized cumulative energy.

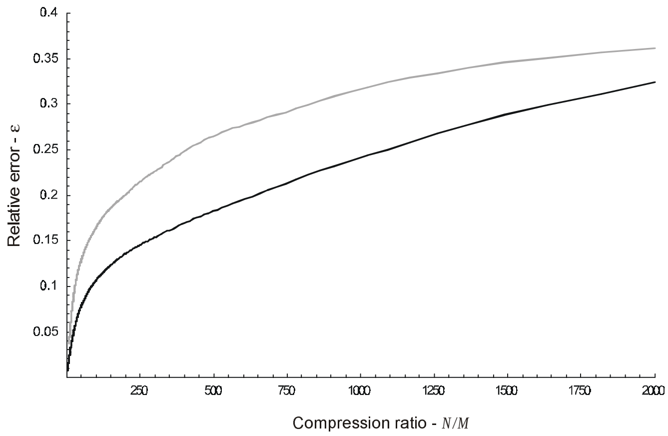


Fig. 7. Relative error vs. compression ratio for: wavelet transform (Spline6) – black line and Fourier transform – grey line

The Fig. 7 shows that for the same compression ratio, wavelet decomposition has less relative error or, for the same error, it can achieve a larger compression ratio.

CONCLUSONS

A problem of choosing the proper compression method for signals obtained from fibre-optic flame monitoring system was presented. Such signals are highly nonstationary, where sudden changes of amplitude take place. Wavelet based compression gives better results comparing to Fourier transform based compression for such signals. The same amount of signal's energy is contained within smaller number of expansion coefficients for the wavelet transform. Moreover, relative errors for the same compression ratios are smaller using the wavelet transform.

A care must be taken choosing the proper wavelet basis [4] in order to achieve as small relative errors as possible.

Wavelet based compression can be applied in real-time with modern DSP processors, the more, so as wavelet transform computed especially, that in the case of Daubechies wavelets, consumes less time than FFT algorithm does.

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Virgil Golumbeanu, Paul Svasta, Ciprian Ionescu

[1]University Politehnica Bucharest, Splaiul Independentei 313, 77206, tel: 2116674, e-mail virgil@cadtieccp.pub.ro

THE REFLECTIONS PRODUCED BY LUMPED LOAD OF DIGITAL SIGNAL LINE

Key words: printed circuit board, reflections, digital circuits, capacitance load.

In interconnection technique of digital circuits in general the matched lines method for reducing the influence of reflections in a view to a good working of interconnected circuits is used. Due to the input capacitance of digital circuits appears a reactance load. Although the matching is very good realized from the viewpoint of the resistive load, there is a reactive mismatching that can produce reflections at high frequency. Using Laplace transformation the reflections produced by parasitic capacitance load will be determined. These reflections will be analyzed depending on the type of the digital circuits and the parameters of the interconnection line. For some types of digital circuits the maximum fanout from this point of view will be determined.

1. INTRODUCTION

In digital systems the designer has to take care of line reflections caused by improperly terminated lines. These line reflections may lead to additional signal distortion which cause