3 XI 2003

INSTITUTE OF FLUID-FLOW MACHINERY
POLISH ACADEMY OF SCIENCES

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

113

Selected papers from the International Conference on *Turbines of Large Output* devoted to 100th Anniversary of Prof. Robert Szewalski Birthday, Gdańsk, September 22-24, 2003

WYDAWNICTWO IMP PAN

GDAŃSK 2003

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY Appears since 1960

Aims and Scope

Transactions of the Institute of Fluid-Flow Machinery have primarily been established to publish papers from four disciplines represented at the Institute of Fluid-Flow Machinery of Polish Academy of Sciences, such as:

- Liquid flows in hydraulic machinery including exploitation problems,
- Gas and liquid flows with heat transport, particularly two-phase flows,
- Various aspects of development of plasma and laser engineering,
- Solid mechanics, machine mechanics including exploitation problems.

The periodical, where originally were published papers describing the research conducted at the Institute, has now appeared to be the place for publication of works by authors both from Poland and abroad. A traditional scope of topics has been preserved.

Only original and written in English works are published, which represent both theoretical and applied sciences. All papers are reviewed by two independent referees.

EDITORIAL COMMITTEE

EDITORIAL BOARD

INTERNATIONAL ADVISORY BOARD

EDITORIAL AND PUBLISHING OFFICE

IFFM Publishers (Wydawnictwo IMP), Institute of Fluid Flow Machinery, Fiszera 14, 80-952 Gdańsk, Poland, Tel.: +48(58)3411271 ext. 141, Fax: +48(58)3416144, E-mail: esli@imp.gda.pl http://www.imp.gda.pl/

Terms of subscription

Subscription order and payment should be directly sent to the Publishing Office

Warunki prenumeraty w Polsce

Wydawnictwo ukazuje się przeciętnie dwa lub trzy razy w roku. Cena numeru wynosi 20,- zł + 5,- zł koszty wysyłki. Zamówienia z określeniem okresu prenumeraty, nazwiskiem i adresem odbiorcy należy kierować bezpośrednio do Wydawcy (Wydawnictwo IMP, Instytut Maszyn Przepływowych PAN, ul. Gen. Fiszera 14, 80-952 Gdańsk). Osiągalne są również wydania poprzednie. Prenumerata jest również realizowana przez jednostki kolportażowe RUCH S.A. właściwe dla miejsca zamieszkania lub siedziby prenumeratora. W takim przypadku dostawa następuje w uzgodniony sposób.

ISSN 0079-3205

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 113, 2003, 3-4

Editorial

These Special Issues of the *Transactions of Fluid-Flow Machinery*, Nos. 113 and 114 contain selected papers from the International Conference on *Turbines of Large Output* devoted to commemorate 100th Birthday Anniversary of Prof. Robert Szewalski. The conference was held in Gdańsk, Poland on September 22-24, 2003.

The Conference is a continuation of previous conferences held at the Institute of Fluid-Flow Machinery PAS in former years dedicated to technology of steam turbines. Series of conferences bearing the same name took place in the years 1962, 1965, 1968, 1993. In 1997 organised has been a conference on steam turbines and related topics, but with a slightly amended title – *Problems of Fluid-Flow Machinery.* At present at the Institute of Fluid Flow Machinery there are conduced research of fundamental character encompassing both the issues related to steam turbines and fundamentals of power engineering.

Organisers of the present conference have returned to the traditional name, i.e. Conference on *Turbines of Large Output* to mark the respect to the memory of Professor Robert Szewalski (1903-1993), the founder and a director of the Institute of Fluid-Flow Machinery for several years, and initiator of the conference series devoted to the problems of steam turbines.

The Editors are very grateful to the referees of the papers presented in this issue of the *Transactions of Fluid-Flow Machinery*: J. Badur, W. Batko, E. S. Burka, J.T. Cieśliński, P. Doerffer, A. Gardzilewicz, B. Grochal, J. Kiciński, G. Kosman, T. Król, J. Krzyżanowski, J. Mikielewicz, A. Neyman, W. Ostachowicz, R. Puzyrewski, R Rządkowski, J. Świrydczuk, M. Trela, T. Uhl and Z. Walczyk.

We appreciate cordially the manifested authors interest in our conference. Special thanks are conveyed to Ms 'Maya' Bagińska, for her fruitful editorial help related to directing the papers to reviewers and correspondence with the authors of contributions.

Prof. Jarosław Mikielewicz
Editor-in-Chief

Dr Edward Śliwicki
Managing Editor

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 113, 2003, 67-74

GRZEGORZ Ł. AUGUSTYN, WOJCIECH BATKO and JACEK WIERZBICKI*

Context filtering in diagnostics

AGH University of Science and Technology Department of Mechanics and Vibroacoustics, Mickiewicz Av. 30, 30-059 Kraków, Poland

Abstract

The paper presents a new method for filtering signals with use of the Modified Recursive Discrete Fourier Transform. The basic idea of the method is the application of user defined context to the recursive form of the DFT and filtration of data or signals. The context is considered as a pre-defined pattern in frequency domain, like frequency envelope of phenomena, which is being searched for. The method works as tool with scanning amplitude–time–frequency representation in the context of such pattern. In this paper authors present mathematical formulas, example of processing noisy signal with predefined patterns and idea of an intelligent algorithm scheme for intelligent context filtering of signals and data. As the example authors filter by the chosen context a genuine diagnostic signal from a large power turbine, where context is applied as a filter for extraction of certain properties of a diagnostic signal, to obtain knowledge about damages or phenomenas caused by machine dynamics. Future research and possible applications in other fields of research are also discussed.

Keywords: Digital signal processing; Digital filters; Discrete Fourier transform

1 Introduction

Context filtering is the method which uses Discrete Fourier Transform in its original form. Transforming of DFT into the certain formula provides the algorithm enabling observation of a signal spectrum changes at every moment, recording of such information, modifying and preparing of maps of signal changes according to a pattern such as for example spectrum envelope predefined by user. This work describes context filtering with utilization of ADFT (Adaptive Discrete Fourier Transform) and its most simple algorithm.

*Corresponding author. E-mail address: wierzbic@uci.agh.edu.pl

2 Recursive discrete Fourier transaform

Discrete Fourier transform of the signal can be written in the form:

$$X[k] = \sum_{n=1}^{N} x(n+\alpha) e^{-j2\pi k(n+\alpha)/N} \tag{1}$$

for a selection of N samples, taken from the sample α. If we make necessar arithmetic operations on the above formula, we receive – for every α sample th following formula:

$$X_s[k] = -x(\alpha)W^{k\alpha} + \sum_{n=1}^{N} x(n+\alpha)W^{k(n+\alpha)} + x(N+\alpha)W^{k(N+\alpha)} \tag{2}$$

This formula is for calculation of discrete spectrum (ADFT) of a signal, usin information contained in previously calculated spectrum by means of recursiv adaptive method. Now, we are going to present inverse transform for ADFT. T achieve that we have to transform the above formula into the following form:

$$x(N+\alpha)W^{k(N+\alpha)} = X_s[k] + x(\alpha)W^{k\alpha} - \sum_{n=1}^{N} x(n+\alpha)W^{k(n+\alpha)} \tag{3}$$

which can be further cast as:

$$x(N+\alpha) = \left\{ X_s[k] - X[k] + x(\alpha)W^{k\alpha} \right\} W^{-k(N+\alpha)} \tag{4}$$

which gives directly the inverse ADFT (Inverse Adaptive Discrete Fourier Trans form).

The advantage of the transform (IADFT) is maintaning all time–frequency amplitude dependencies and relations, which allows reconstruction of analyze information. The benefits are: simple way to reconstruction and achieving o original signal continuity after processing and modification of spectral nature o the analyzed signal and – more – the ability to analyze highly non-stationar signals.

The kernel of the transform is given below as a part of MATLAB code:

```
%algorithm of the context filtering
for a=1:2000,
for i=1:4,
Xsa(:,i)=ay(:,i).*fft(X(a:N+a-1,:));
ER(1,i)=sum(Xsa(:,i));
[lev_i,num_i]=max(ER);
end
Xs(:,a)=Xsa(:,num_i);
```

```
for k=1:128,
Xs(k,a+1)=X(a,1)*exp(j*2*pi*(a+1)*k/N)+Xs(k,a)*exp(j*2*pi*
(a+1)*k/N)+X(a+N,1)*exp(-j*2*pi*(N+a)*k/N);
end
end
```

ADFT algorithm has also certain limitations. The main reason for these limitations is the Heisenberg uncertainity rule. It is directly caused in the kernel for calculation of the initial spectrum for algorithm, which is the process with the same constraints as in classical Fourier analysis methods. Initial conditions for analysis such as sample length (chunk length for the analysis) and analyzing window – if applied – are critical. These initial conditions depend on the purpose of the analysis. The issue is to find compromise between representation in frequency domain and information contained in the signal.

3 Context

Context allows the signal to be modified in different ways when context is properly shaped in frequency domain due to the application. Context is considered as a spectral pattern which is normalized in such a way that all of its values full into the range between 0 and 1. So, the signal is not analysed with the whole range of harmonic functions in the analysis, but only with these functions with certain weights, which are considered, because of the feature which is being searched.

According to this, the formula for discrete Fourier transform takes a form:

$$X[k] = \sum_{n=1}^{N} x(n) \cdot A_n[k]^{\beta} e^{-j2\pi kn/N} \tag{5}$$

The parameter β allows for spectrum shaping by means of $A_n[k]$ coefficients.

When the above formula is applied to ADFT, we have:

$$Xs[k] = -x(\alpha)A_n[k]^{\beta}W^{k\alpha} + \sum_{n=1}^{N} x(n+\alpha)A_n[k]^{\beta}W^{k(n+\alpha)} + x(N+\alpha)A_n[k]^{\beta}W^{k(N+\alpha)} \tag{6}$$

as showed in [...].

Calculated spectrum, adaptively, sample by sample, follows the changes in spectrum of the signal according to the applied context. Number and shape of contexts chosen to analysis is optional. In this way it is possible to extract any feature from the noisy environment, filtrate any information, examine amplitude changes and - as the result of inverse ADFT – to have time representation of a modified signal.

Return to the time domain can be done by a simple modification of the inverse ADFT transformation.

If we use several patterns at once, algorithm can estimate also several features at once due to this complex context.

4 Context filtering

Let's assume that we have the base of several contexts:

$$m = \max\left\{\sum_{k=1}^{N} X_1[k],\ \sum_{k=1}^{N} X_2[k], ...,\ \sum_{k=1}^{N} X_i[k]\right\}. \tag{7}$$

where:
i – number of contexts,
m – number of the context with the best fitting.

The simplest way of evaluation of the fitting of a feature to the chosen context is sumation and comparison of all values across the frequency axis. The spectra with the most nearest value of the sum have the maximum probability, that they are the best fitting context.
This algorithm is showed below as a part of MATLAB code:

```
%context database creation
AN=[AN1 AN2 AN3 AN4];
%context database creation in frequency domain
ANTF=(abs(fft(AN(1:N,:))));
for i=1:4,
ay(:,i)=(ANTF(:,i)./max(ANTF(:,i))).^(1);
end
(...)
for a=1:2000,
for i=1:4,
Xsa(:,i)=ay(:,i).*fft(X(a:N+a-1,:));
ER(1,i)=sum(Xsa(:,i));
[lev_i,num_i]=max(ER);
end
Xs(:,a)=Xsa(:,num_i);
(...)
```

In effect we obtain the following formula:

$$X_{iS}[k] = -x(\alpha)A_{in}[k]^{\beta}W^{k\alpha} + \left[A_{in}[k]^{\beta} \cdot DFT\{x(n+\alpha)\}\right] W^{k(n+\alpha)} + \tag{8}$$
$$+x(N+\alpha)A_{in}[k]^{\beta}W^{k(N+\alpha)}$$

which provides ADFT algorithm with implemented context. Index "i" denotes the number of the analyzing pattern. It gives a number of applied contextes.

The disadvantage of this way of extraction of a feature is the necessity of having context base given a priori. We can also apply the maximum likelihood estimation methods, correlation methods, coherence function or application of neural networks as a decision making systems for fitting evaluation.

In analogy to the IADFT, and using the IDFT, we have:

$$y'(N+\alpha) = \left\{ Y_s[k] - Y[k] + (IDFT\{X_\alpha[k]\})W^{k\alpha} \right\} W^{-k(N+\alpha)} \tag{9}$$

where $X_\alpha[k]$ means IFFT of spectrum calculated from the record of values from a sample with "α" index. The rest of the algorithm remains the same.

5 Experiment

Algorithm was tested on real diagnostic signal registered from bearings operating under different condition. For this process a pattern based on the model of the turbine was used (Fig. 1). Signals from bearings and other disturbances are observed the background.

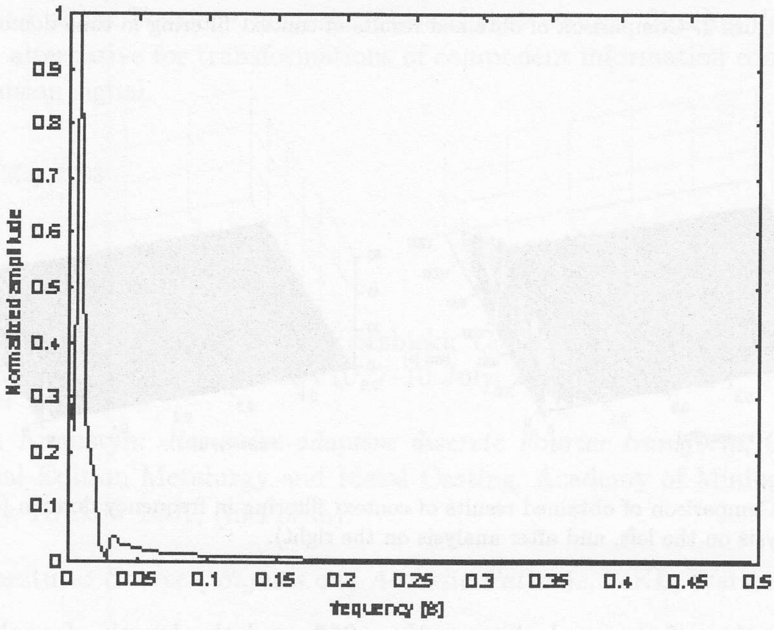

Figure 1. Artificially generated context form from the model.

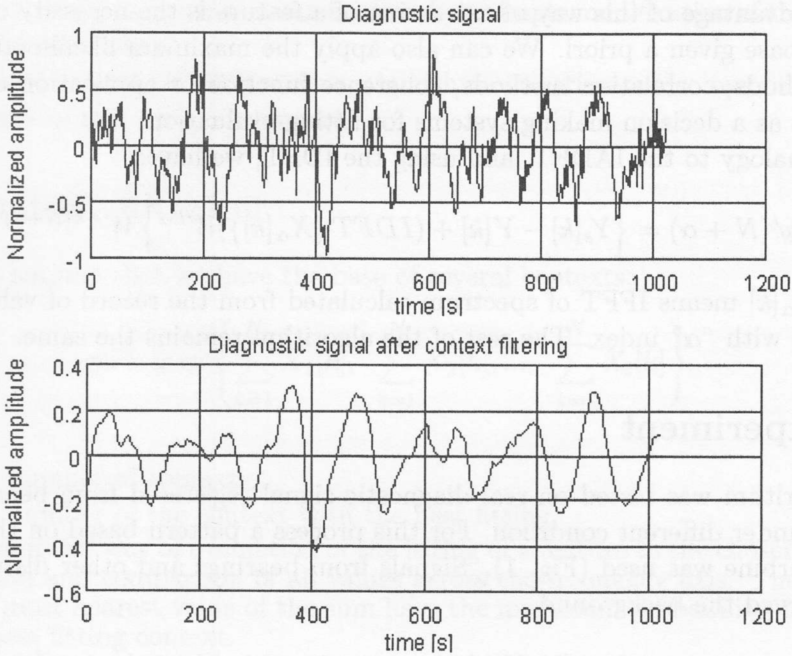

Figure 2. Comparison of obtained results of context filtering in time domain.

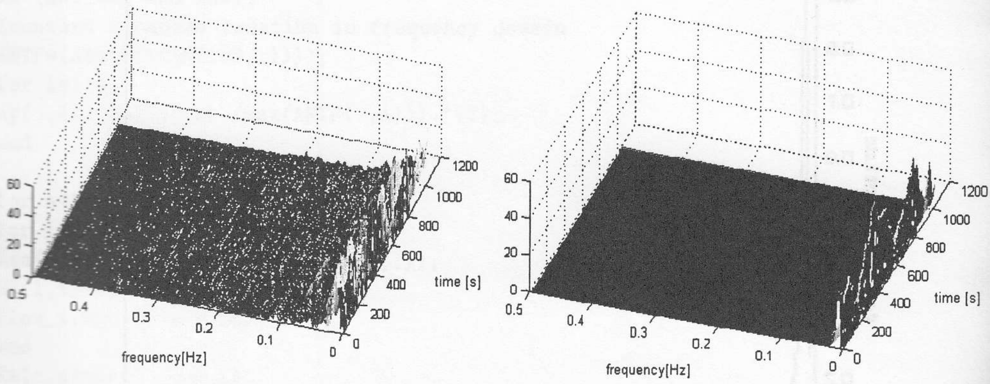

Figure 3. Comparison of obtained results of context filtering in frequency domain (before analysis on the left, and after analysis on the right).

Resolution of the analysis was $N = 256$, and the length of analyzed data record –1000 values, sampling frequency is expressed as a rate of sampling frequency. Results from the experiment are presented in Fig. 2 and Fig. 3. Figures present a comparision of signals before and after decomposition process, considering useful information.

6 Summary

Described example shows that signal decomposition considering noise and useful signal (information) took place. Distortions result from the fact that rectangular analyzing window was used which has the worst properties as well as from the transitient nature of spectrum change. This experiment proves context filtering efficiency in presence of disturbances and permits to infer about possibilities of extraction of component information (mutually independent) even with partly overlaped spectra. In certain situations parameter description of contexts base is possible as a manner of activity of decision stage of such system. Filtration is however only a tool possible to be implemented with classification system of contexts bases containing listed base of features. Initial enlightening of system on given feature research can also be significant for all diagnostic systems especially if it refers to aperiodic phenomenon with nonstationary appearance. Property of feature extraction makes possible its further analysis.

There is no doubt but that tool is not yet in its final form. It is sufficient in the case of problems of off-line transformation of information, however further investigations should go in the direction of improvement and optimization of algorithm, other research on convertible transformations which would be able to be used instead of the Fourier transform. Nevertheless context filtering determines attractive alternative for transformations of component information contained in one-dimension signal.

Received 5 May 2003

References

[1] G. Ł. Augustyn, W. Batko, J. Wierzbicki: *Context Filtering*, 10^{th} Int. Cong. on Sound and Vibration, ICSV10, 7–10 July, 2003, Stockholm .

[2] G. Ł. Augustyn: *Recursive-adaptive discrete Fourier transform*, Quarterly Special Edition Metalurgy and Metal Casting, Academy of Mining & Metalurgy, Kraków 2001, (in Polish).

[3] C. Basztura: *Sources, Signals and Acoustic Patterns*, WKŁ, Warszawa 1988.

[4] C. Basztura: *Computer systems for technical acoustic diagnostics*, Diagnostics of Industrial Processes, Łagów, 8-11 Sept., 19-37, 1997, (in Polish).

[5] S. Haykin: *Adaptive Filter Theory*, Prentice–Hall, Englewood Cliffs, New Jersey 1996.

[6] N. Kalouptsidis: *Signal Processing Systems. Theory and Design*, John Wiley and Sons, Inc., New York 1997.

[7] R. G. Lyons: *Introduction to Digital Signal Processing*, WKŁ, Warszawa 1999, (in Polish).

[8] T. Soderstrom, P. Stoica: *Identification of Systems*, PWN, Warszawa 1997 (in Polish).

[9] S. V. Vaseghi: *Advanced Signal Processing and Digital Noise Reduction*, John Wiley and Sons, New York 1996.

[10] C. S. Williams: *Designing Digital Filters*, Prentice–Hall, Englewood Cliffs, New Jersey 1986.

[11] R. A. Williams: *Communication Systems Analysis and Design: a Systems Approach*, Prentice Hall, New York 1987.

[12] A. Zalewski, R. Cegieła: *MATLAB – Numerical Calculations and Their Applications*, Wyd. NAKOM, Poznań 1998, (in Polish).

[13] T. Zieliński: *From Theory to Digital Signal Processing*, Wyd. EAiE, AGH, Kraków 2002 (in Polish).