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EXPERT SYSTEM FOR SPECTRAL ANALYSIS

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RESUME

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Les techniques d'estimation spectrale font appel essentiellement à deux types de méthodes : les méthodes classiques, via la F.F.T., et les méthodes paramétriques (AR, ARMA, PRONY). Un grand nombre d'études comparatives ont été menées, tant du point de vue théorique qu'expérimental. Une difficulté majeure est le choix de la méthode à utiliser et la maîtrise des différentes techniques associées à chacune d'elles. Aussi, il nous a paru intéressant d'apporter une solution à ce problème par l'utilisation de système expert, aptes à maîtriser une grande quantité de connaissances.

Un système expert utilisant le principe des réseaux logiques des règles de production a été développé. Deux étapes essentielles sont à considérer. Tout d'abord, à partir d'une étude comparative des performances de chacune des méthodes et des caractéristiques connues des signaux, on effectue un premier choix. Une fois la méthode choisie et un premier calcul de la densité spectrale de puissance effectué, le système expert propose les moyens nécessaires pour l'améliorer.

La base de connaissance est complétée par un réseau adjoint des règles de contrôle, qui permet en particulier d'orienter le processus d'amélioration en réorientant les buts du réseau de production.

La mise en oeuvre des modules de calcul et de visualisation se fait par l'intermédiaire d'un progiciel de traitement du signal.

SUMMARY

ABSTRACT

A great number of spectrum analysis methods is proposed in literature : non parametric and parametric methods. Their performances have been comparatively studied in many papers. A major problem in the applications is an appropriate choice of a spectral analysis method and the associated parameters. Attempting to help achieving spectral analysis, this paper presents a new solution that is based on the design of a rule based expert system.

The expert system is based on the use of logical networks of production rules. The spectral analysis process consists of two main steps : choice of a method and result improvement. The first one is based on the analysis of the signal characteristics .The second one is to improve the result.

In addition to the knowledge rules, control rules are also employed in particular in the improvement step, which embody inferences about the order in which the knowledge rules are matched. The program activation and result visualisation are achieved by interfacing the modules implemented in a signal processing software system.

I. INTRODUCTION (22)

For wide sense stationary signal, a large number of spectral analysis methods has been proposed in the last two decades. One has non parametric methods such as the classical periodogram and Blackman-Tukey's methods, parametric methods such as the Burg's, Marple's for AR model, the Cadzow's for ARMA model and the extended Prony's methods (1-8).

The performance of several non parametric methods is comparatively discussed in Carter and Nuttall (12) and in Yuen (11). The features of several parametric methods are also illustrated by Kay and Marple (9.10). Experiences of applications of these methods to particular cases are also present (in 13,14 for example).

Attempting to help achieving the spectrum analysis in practice, this paper presents a solution which is based on the design of a rule- based expert system. Such a solution was motivated by a number of issues which needed to be addressed and studied :

1) Different spectral analysis techniques are often complementary in performance. A method is required for organizing these to function together.

2) The presence of studies of performance or features of different methods and experiences of the applications ; the absence of an explicit scheme for representing this knowledge.

3) The need of a better understanding of a method for practical application ; the lack of an interactive and explicit system in the field of spectrum analysis, for non specialist users in particular.

Following discussion shows how the proposed solution effects each :

1) Integration of spectral analysis methods

For a given signal, different spectral analysis techniques often provide quite different spectra with varying degree of success. Although there exist experiences in particular applications, the diversity of the signal nature, complexity, length and signal-to- noise ratio presents difficulties in finding a general framework which can integrate these efforts. The primary goal of this research was to design a system flexible enough to incorporate these for different signal situations.

2) Knowledge representation

In the rule-based approach, knowledge is split, organized and coded into rules, which are modular entities that can be modified without affecting the structure of the system. The advantage of such an approach is the ability of reasoning about a set of uncertain and incomplete knowledge.

3) Interface

The interface between the expert system and an existing signal processing software system replaces the work of parameter specifications of a program that the users were obliged to evaluate.

II. STRUCTURE OF THE SYSTEM

The structure of the system is shown in Fig. 1

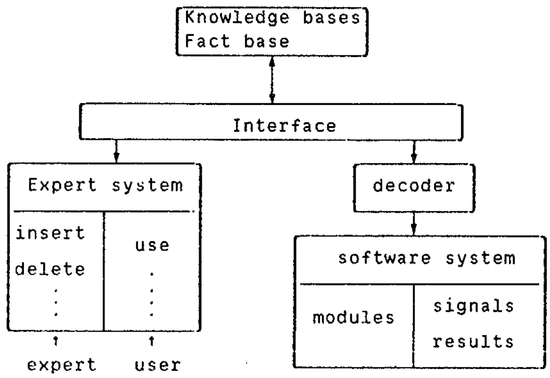


Fig. 1 - Structure of the system

The system is mainly composed of four parts : the knowledge and fact bases, the production rules based expert system, a signal processing software system and an interface. They will be successively described.

III. REFERENCE AND KNOWLEDGE BASES

The production rules based systems have been widely used in Artificial Intelligence either to model human's psychological behaviour (15) or to build knowledge based expert systems (16, 17). We describe here an interactive system which can incorporate either phenomenological rules and causal relations or classification relations. Its detailed structure and some of its applications are described in (18, 19, 20).

III.1 - The knowledge base creation and acquisition

A knowledge base can always be viewed as a set of production rules. We are not concerned here with the problems of weighting rules by a certainty factor as in Mycin but different categories of rules for object level knowledge or meta level knowledge used for control or strategy purpose can be introduced in the system. The system SUPER enables the human expert to develop incrementally any of knowledge base. Its main properties are :

a) The system is interactive.

b) The rules can be inserted in natural language.

c) The human expert can check at any time the knowledge bases.

d) The system is able to warn the human expert of the conflicting rules.

e) The system proposes to reduce redundancy as much as possible.

III.1.1 The structure of the production rules system

A production rule is viewed as a set of premises (P) on the left hand and an action (A) on the right hand. It can be formulated by a conditional expression such as : if(P_1 and $P_2 ... P_n$) then A, meaning that if all the premises P_i are true then the action A is executed.

An action usually modifies the fact base and therefore the result of an action can update the value of some premises of other rules. In this case, the set of rules can be organized as an and/or network.

III.1.2 The insertion of a new production rule

The first step of the analysis, when inserting a new rule, is to compare the new rule to each of existing rules. The set of premises of a rule R is called SETR, and the corresponding action is called A. The different cases and the corresponding algorithm of the system are shown in Fig. 2.

III.2 - Modification of an existing rule network

The primary goal of the system was to give a tool to create or modify a knowledge base at any time by inserting or deleting production rules. The system should give a resulting rule network which should be optimized in terms of redundancy no matter how and where the rules are inserted or modified. The network is thus progressively modified by inserting new rules and deleting existing ones.

For the insertion of a rule R the first step is to compare the rule to be inserted with each of the existing rules R_i and to add if necessary the concerned rules. It is important to note that the algorithm starts by examining all the cases of type e) presented in figure 2.

The second step is to compare the new form of R to each of the R_i. If some of the cases presented above are detected then the rule is inserted as it is. Otherwise reduction and link of the concerned rules are made according to figure 2. The process is iterated for any rules that has been changed until the network remains unchanged.

The problem of deleting a rule R is much simpler since it can be done by deleting R, deleting the links to the successors of R, and deleting the links between R and its predecessors.

III.3 - The rule interpretor

The knowledge bases can be experimented immediately after a rule has been inserted or modified. The user can choose either a data driven inference mechanism (forward chaining) or a goal oriented strategy (backward chaining). At this level, it is possible to consider and use a second rule network which is purely logical (Ex. : If a parametric method has been used then there is no sidelobes in the spectrum).

This type of rules can be viewed as a special kind of metarules, because they can be used at each node of the rule network to prune the subset of applicable rules. These rules can be inserted by using the same interactive system. The corresponding meta-network can be optimized and used with a forward chaining strategy.

a)

R_1						R_2				
P_1	P_2	P_3		A_1		P_1	P_2	P_3		A_1

$SETR_1 = SETR_2$ and $A_1 = A_2$

=> Warning, No insertion

b)

P_1	P_2	P_3		A_1		P_1	P_2	P_3		A_2

$SETR_1 = SETR_2$ and $A_1 \neq A_2$

=> Warning, One of the two rules must be omitted or completed

c)

P_1	P_2		A_1		P_1	P_2	P_3		A_1

$SETR_1 \subset SETR_2$ and $A_1 = A_2$

=> Warning Confirmation of R_2 is required and R_1 is not kept or Cancel

d)

P_1	P_2		A_1		P_1	P_2	P_3		A_2

$SETR_1 \subset SETR_2$ and $A_1 \neq A_2$

=> R_1 is kept and $SETR_2$ is modified : $SETR_2 = (SETR_2 - SETR_1) \cup A_1$

e)

P_1	P_2	P_3		A_1		P_4	P_5	A_1		A_2

$A_1 \in SETR_2$

=> If $SETR_1 \cap SETR_2 = 0$ then no change
Else, keep R_1 and $SETR_2 = SETR_2 - SETR_1$

Fig. 2 - Cases of transformation of rules during an insertion

IV. SPECTRAL ANALYSIS METHODS AND TRAINING OF "HUMAN EXPERT"

Spectral estimation ends always by the use of a spectral analysis method. In our system, four methods have been chosen :

- non parametric : the classical periodogram (1) and Blackman-Tukey (21) methods
- parametric : the Marple's new AR (6) and the extended Prony's (9) methods

A brief overview of their key properties (strengths and limitations) is available in the tutorial of Kay and Marple (9).

Our studies were with emphasis on spectral evolutions for a wide range of simulated and real signals :

1) Evolution of spectra (resolution, sidelobes, variance, bias...) estimated by the non parametric methods with respect to the number of samples, the signal to noise ratio, the number of segments, the type of linear window for the periodogram and the type of quadratic window to the Blackman-Tukey's method...

2) Evolution of spectra (resolution, form, accuracy of peaks...) estimated by parametric methods with respect to the number of samples, the signal-to-noise ratio and the model order...

3) Differences of spectral features (resolution, sidelobes, accuracy of peaks,...) between non parametric methods and parametric methods.

V. KNOWLEDGE BASE DESIGN

V.1 - Analysis of human expert's behaviour

Given a signal, two cases can be distinguished for a human expert :

a) The signal is a priori unknown

He makes a visual observation of the signal, examines probably the signal nature, wide sense stationarity, mean and other qualitative informations in time domain. The signal preprocessing, if it is necessary, can be the extraction of a stationary segment and the extraction of signal mean. Then, he decides, according to his knowledge of available spectral analysis methods, to choose one among them. The first choice of a method and the associated parameters are often conservative so that the spectral resolution and informations in detail may be maintained.

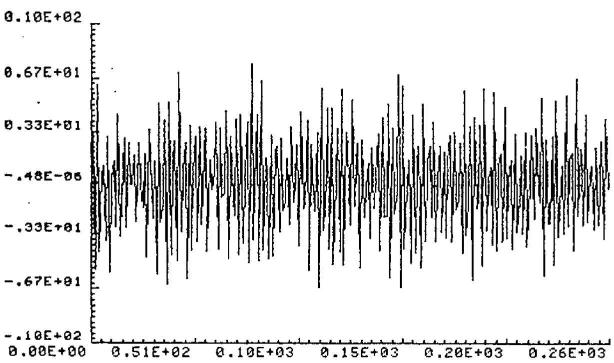
For an expert, the spectral analysis process is also the process of understanding of the content of a signal. After examining the first spectrum, he can be interested in the accuracy of peaks, the sidelobes, the resolution, the variance (bias) ... or in a band of spectrum, and then he decides, if necessary, to improve the result in some directions. The improvement is concrete and relative, but not always absolute.

b) Signals of the same type have already been analyzed

In this case, it requires simply that he recalls the spectral analysis method and the associated parameters used before, and if necessary to enter on the improvement step.

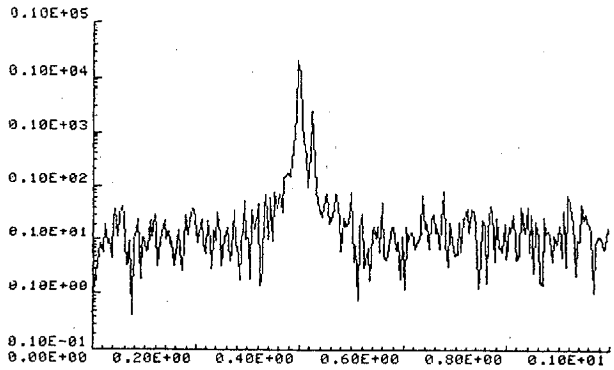
It should be noted that the human expert's behaviour in the improvement step can be very sophisticated.

This two steps process is illustrated by the following example (7).



a) Cadzow's signal, 512 samples used

Informations in time domain
  signal nature : random, quasi periodic
  stationarity : stationary
  mean : 0
  variation : rapid
  number of samples : 512
  signal to noise ratio : medium by observation
  signal-to-noise ratio : 6 db by estimation



b) Simple periodogram

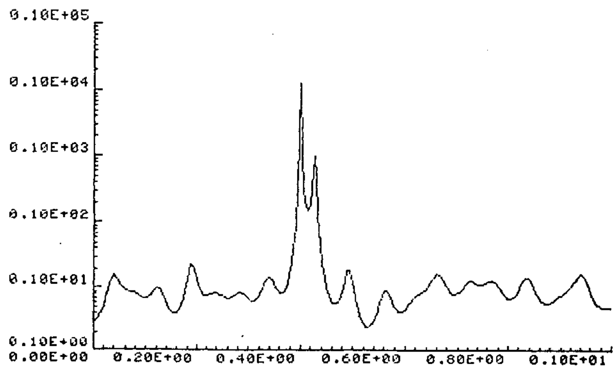
spectral estimation by the periodogram
  number of segments : 1
  number of samples : 512
  type of window : rectangular

Informations in frequency domain
  position of maximum value : center
  number of high peaks : 2
  differences peaks to noise in db : 30 db
  : 20 db
  sidelobes : low
  relative position of peaks : very close
  variance : very high

Improvement directions
  decrease of variance
  improvement of resolution

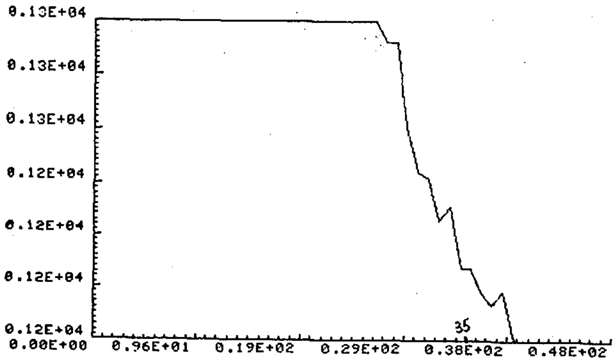
Analysis of previous actions
  periodogram used
  rectangular window used
  number of segments : 1
  signal-to-noise ratio : high

Solutions to be considered
  AR method with order to be determined
  BT method with no rectangular window
  PE method with no rectangular window



c) AR spectral estimate, order 38

Spectral estimation of AR method
  number of samples : 512
  model order : corresponding to local minimum value of FPE around 35



d) Final prediction error trace (zoom)

Fig. 3 - Example of a spectral analysis process

V.2 - Knowledge base design strategies

The system's spectral analysis process is illustrated in the following block diagram.

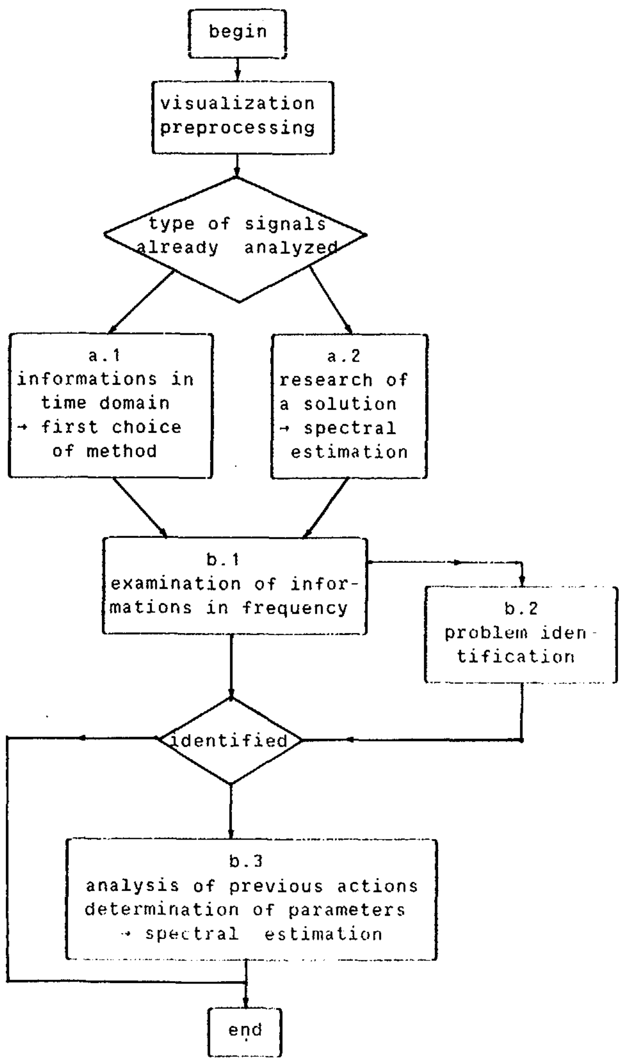


Fig. 4 - Block diagram of spectral analysis process

In this diagram, the spectral analysis process consists of two steps :

a) first step : choice of a method

a.1) Its function is to achieve the first choice of a method. The type of signals can be very different. To ease the problems of analysis and program activation, signals are classified according to their nature (deterministic, transient, quasi-periodic, random) and to their length (32, 64, 128,...,2048 samples). Other informations as the :

- signal variation, signal-to-noise ratio by observation and by estimation
- user's a priori specifications of spectral quality (low variance, low sidelobes, high peak accuracy, high resolution, etc...)
- the trace of the prediction error with respect to model order and the trace of one of existing criteria such as the Akaike's Final Prediction Error with respect to model order (if a parametric method is to be used)

are used for the choice of the method and the associated parameters.

a.2) Its function is to find an existing solution. It searches for the existing optimum solutions of the laboratory organized by the signal types (speech, vibration,...) and the particular informations which are application-dependent.

b) Second step : result improvement

b.1) Its function is to examine the spectrum. The features of the spectrum (number of peaks, sidelobes, variance, etc...) are examined until some key problems are identified. The user's further specifications of spectral quality are also used in necessary cases.

b.2) Its function is a problem identification. The meta rules here are used to determine the improvement directions (resolution,...), find the possible solutions corresponding to these directions during spectrum examination and control the end of the latter. A great number of goals are eliminated in the same time by updating the fact base, those which remain are the best.

b.3) Its function is to determine precisely the parameters of the chosen method so that the result may evolve in the improvement directions (such as increase of model order).

Some of the actions activate the signal processing software programs. This is realized by an interface.

VI. INTERFACE

The interface and the decoder between the expert system and the signal processing software system translate a code associated with an action of a rule to a succession of commands. For example, the action:

"We have to try the periodogram program

PE:512 512 512 0"

involves the commands :

specifications of input file name

specification of output file name

activation of periodogram with
number of samples = 512
segment length = 512
FFT size = 512
type of window = 0 (rectangular)

calculate logarithmic spectrum

visualize the result

end of commands

VII. DISCUSSIONS AND PERSPECTIVES

This paper has proposed an approach to help achieving spectral analysis. This approach is based on the design of a rule based expert system. It is original in the sense that it is an adapted designed system for computer aided spectral analysis. The spectral analysis process consists of two steps : choice of a method and result improvement. These are on the basis of the analysis of the human experts' behaviour. This system has been tested on different types of signals, and is able to select the appropriate one among the four methods and the associated parameters. The first result given by the system was in accordance with human expert's conclusion for seventy percent of cases. The system is able to propose improvement directions even when the informations contained in the spectrum are sophisticated.

Other methods of spectral analysis can be inserted in this system without strong modifications.

The idea of the use of an expert system to spectral analysis can be extended to the case of the time-varying spectral estimation of a non-stationary signal.

REFERENCES

1) P.D. WELCH, "The use of fast Fourier transform for the estimation of power spectra : a method based on time averaging over short, modified periodograms",IEEE Trans. Audio and Electroacoust. vol. au-15, n° 2, pp. 70-73, June 1967

2) R.B. BLACKMAN and J.W. TUKEY, "The measurement of power spectra", New-York, Dover publications, 1958

3) C. BINGHAM, M.D. GODFERY and J.W TUKEY, "Modern techniques of power spectrum estimations", IEEE Trans. Audio and Electroacoust., vol. au-15, n° 2, pp. 56-66, 1967

4) J.P. BURG, "Maximum entropy spectral analysis", PH.D dissertation, Dep. Geophs., Stanford Univ., Stanford, CA, May 1975

5) J.P. BURG, "A new analysis technique for time series data", NATO Advanced Study Institute on Signal Processing with emphasis on Underwater Acoustics, 1968

6) L. MARPLE, "A new autoregressive spectrum analysis algorithm", IEEE Trans. ASSP, vol. ASSP 28, n° 4, Aug. 1980

7) J.A. CADZOW, "High performance spectral estimation A new ARMA method", IEEE Trans. ASSP, vol. ASSP28, n° 4, Oct. 1980

8) R. PRONY, "Essai expérimental et analytique sur les lois de la dilatabilité des fluides élastiques", J. de l'Ecole Polytechnique, n° 1, Floréal et Prairial, An III, 1795

9) S.M. KAY and S.L. MARPLE, JR, "Spectrum analysis A modern perspective", Proc. IEEE, vol. 69, n° 11, Nov. 1981

10) C.V. SCHOONEVELP and M. SONDAG, "Spectrum analysis : on the application of data windowing to Kay and Marple's results", Proc. IEEE, vol. 71 n° 6, June 1983

11) C.K. YUEN, "A comparaison of five methods for computing the power spectrum of a random process using data segmentation", Proc. IEEE, June 1977

12) G.C. CARTER and A.H. NUTTALL, "On the weighted overlapped segment averaging method for power spectral estimation", IEEE Proc., vol. 68, pp. 1352-1354, Oct. 1980

13) L'analyse spectrale : un outil privilégié pour l'analyse du signal", Dossier Mesure-Régulation-Automatisme, Juin-Juillet 1982

14) F. CASTANIE et P. SOULE, "Comparaison expérimentale des méthodes paramétriques d'analyse spectrale appliquées aux signaux de télémesures spatiales", 9e Colloque sur le Traitement du signal et ses applications, Nice, Mai 1983

15) A. NEWELL, "Production system : Models of control structure in visual information processing", William G. Chase (ed), pp. 463-526, Academic Press, 1973

16) R. DAVIS, B.G. BUCHANAN and E.H. SHORTLIFFE, "Production rules as a representation for a knowledge base consultation system", Artificial Intelligence, 8:15-45, 1977

17) E. SHORTLIFFE, "Computer based consultation in clinical therapeutics explanation and rule acquisition capabilities of the MYCIN system", Computers and Biomedical Research, Aug. 1975

18) D. FONTAINE and P. LE BEUX, "An expert system for rubella consultations", Medinfo 83, van Bemmel Ball, Wijertz Editors, pp. 529-532, IFIP-IMIA, North Holland (1983)

19) D. FONTAINE and P. LE BEUX, "Le système SUPER", rapport technique ERA-CNRS, 1983

20) D. FONTAINE and P. LE BEUX, "SUPER : an expert system for medical applications", ISMM, New York, 1983

21) C.M. RADER, "An improved algorithm for high speed autocorrelation with applications to spectral estimation", IEEE Trans. Audio Electroacoust., vol. AU-18, n° 4, pp. 439-442, 1970

22) X. LI, "Système expert en analyse spectrale", rapport UTC, Sept. 84