99305

Application of Spectral Analysis in the Remote Sensing of Marine Geological Deposits and in the Detection of Periodicities in the Sedimentation Processes in Continental Geological Systems.

PART II.

Elfi VAN OVERLOOP, Luc PEIRLINCKX AND Leo P. VAN BIESEN

Vrije Universiteit Brussel
Earth Technology Institute
Pleinlaan 2
B-1050 BRUSSELS
Belgium

Abstract - **An Expert System has been designed for the spectrum estimation of a very broad area of signals or processes. It is well known that for very short data records, obtained from the sampling of stochastic processes, the use of classical spectrum estimators, such as the methods originated from the Discrete Fourier Transform, yield weak performances. Nowadays, more powerful modern spectrum estimators are available [1], which are based on a parametric modelling approach. For instance, the AR, MA and ARMA models enable to estimate the Power Spectral Density of stochastic processes. A framework for knowledge based spectral analysis is established at the VUB [2]. This study has lead to the design and implementation of an expert system, named ExSpect: an Expert System for Spectrum Estimation. A project, in which the use of ExSpect has shown to be a very useful tool, deals with the investigation of periodicities hidden in some geological parameters, obtained from the processing of continental geological samples.**

INTRODUCTION

In climatology and astronomy, the search for systematic periodicities has become very important and is, therefore, well studied nowadays. However, it can be shown that some other geological phenomena also possess a periodicity. For instance, at the "Earth Technology Institute" the study of sediments in a drilling core using stabile isotopes and the investigation of the presence of some minerals (e.g. $CaCO_3$) or fossils has lead to the conclusion that climatic variations or more drastic global changes also reflect in a periodic behavior of e.g. the sedimentation process. ExSpect is used here to guide the palynologists, geochronologists - or more general the geologists -, who do not have a fundamental basis of modern spectral analysis, in finding the hidden periodicities. These users employ the system as novices and are guided by the inference engine of the knowledge based driven machine to discover periodicities, if present, and to obtain qualitative explanations about the presented results [2]. In this section, the problem of the detection of such periodicities will be treated.

EXAMPLE

For a specific core of 186 m from the subsidence basin of Thessaloniki in Greece, the content of $CaCO_3$ is analyzed for an average depth change of 88 cm. The obtained results are shown in table 1.

13.52	16.4	16	12.2	15.8	4.2	14.5
14.46	21.51	16.3	16.3	15.94	10.04	35.69
11.69	13.49	14.31	12.97	9.66	9.18	10.69
11.99	40.35	22.33	12.53	6.32	5.69	5.31
9.87	13.14	13.77	5.5	5.37	5.48	10.01
42.03	5.44	44.84	9.92	6.25	3	9.14
49.81	7.38	20.97	0.79	2.05	6.61	5.6
8.61	10.39	9.64	5.9	7.8	4.54	20.73
12.47	4.62	20.1	8.7	12.56	11.75	7.31
5.1	10.08	9.17	7.69	10.82	11.71	8.01
11.55	10.06	7.1	5.84	11.32	10.32	10.98
8.13	9.54	7.46	7.75	6.89	11.16	11.95
4.66	8.41	15.29	19.48	15.52	39.18	9.41
5.16	30.5	20.72	6.11	4.64	4.64	10.96
9.39	11.26	15.11	7.44	9.59	2.79	7.31
9.98	13.58	64.8	24.12	0.81	7.27	6.16
3.39	1.83	2.76	2.93	3.49	2.26	0.76
0.97	24.97	74.17	13.4	65.92	34.05	65.48
15.8	40.81	7.85	0.3	1.88	0.41	5.25
1.73	0.93	2.48	12.13	14.09	13.17	1.48
16.58	12.2	32.39	39.98	41.25	34.22	51.45
7.84	18.63	52.08	22.05	31.53	6.61	5.28
2.21	8.27	1.1	5.73	4.04	0.82	7.22
8.84	0.61	5.92	9.31	6.49	6.1	7.05
4.57	4.91	7.73	7.6	8.66	4.91	7.67
4.91	2.62	1.95	3.95	2.68	5.32	1
0.67	1.93	1.06	1.23	1.89	1.81	0.29
0.81	0.78	5.16	3.42	1.99	0.84	1.05
1.54	0.6	0.75	0.73	0	0.59	1.61
0	1.55	0.78	0.72	0.96	1.57	1.21
0.53	0.66	0.86	0	0	0.13	0.29
0.39	3.06	1.07				

Table 1: 210 measurements of the content of $CaCO_3$ in a core sample. The spacing between two samples corresponds to an average depth change of 88 cm. The measurements of $CaCO_3$ are expressed in %.

When these samples are plotted depth changes versus % content of $CaCO_3$, the following plot is obtained.

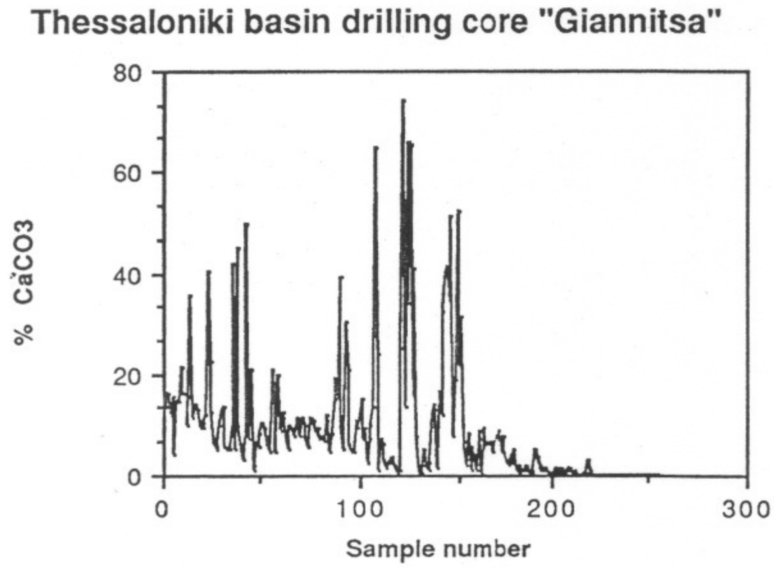


Figure 1: Sample number versus % $CaCO_3$

This record is presented to ExSpect. From the figure 1, one can see that, due to the present peaks, a rather periodic behavior is hidden in the data record. First, the classical Periodogram estimator is chosen to compute The Power Spectral Density, or the P.S.D.. The result is shown in figure 2.

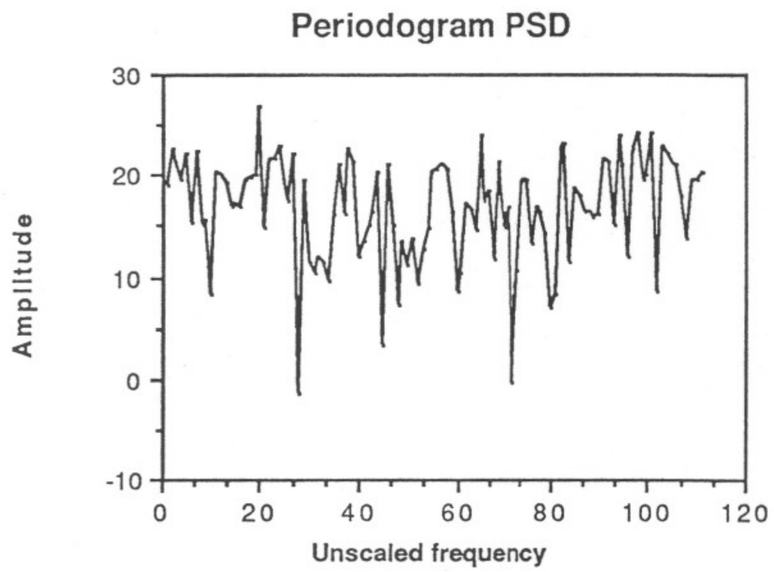


Figure 2: The Periodogram applied to the data from Table 1.

A first visual inspection of the PSD leads to the indication that a periodic behavior, indeed, is present. However, one can also learn from this plot that some successive peaks, although a difference in amplitude can be noticed, are spaced nearly equidistantly in the frequency domain. This can be explained as follows. If a periodicity, expressed in the proper dimension, which so far has not been done in this presentation, is found at 100 ky, but also a much higher

frequency, yielding a lower periodicity of e.g. 9.9 ky, is found, then one should be very careful in explaining the presence of these periodicities, since such results express the same probability of having a cyclic appearance. This is due to the fact that the higher harmonic of e.g. 9.9 ky is related to the first investigated periodicity of 100 ky (9.9 ky ≈ 10ky, which multiplied by 10 yields 100 ky).
To enable a more elaborated processing and interpretation of this first result, two steps are foreseen. First, ExSpect will look for the most appropriate estimator, which in this case has shown to be an AR-estimator of order 31 [1], [2]. This result is shown in figure 3.

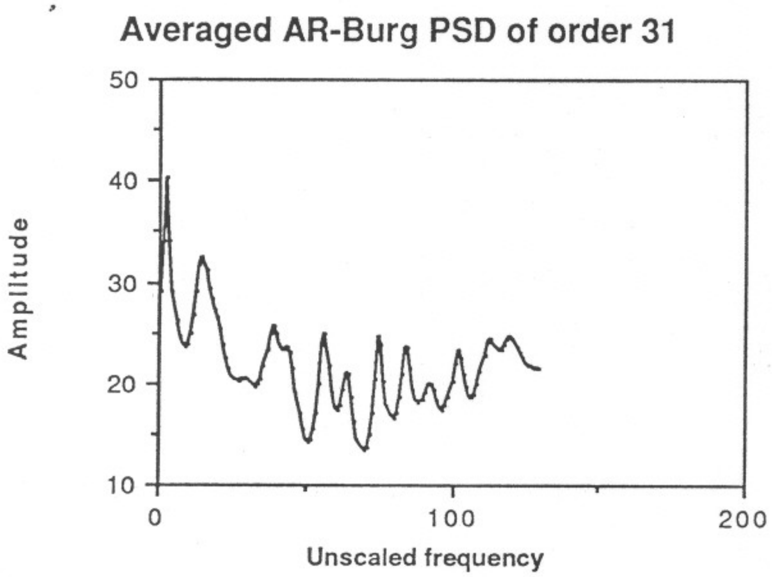
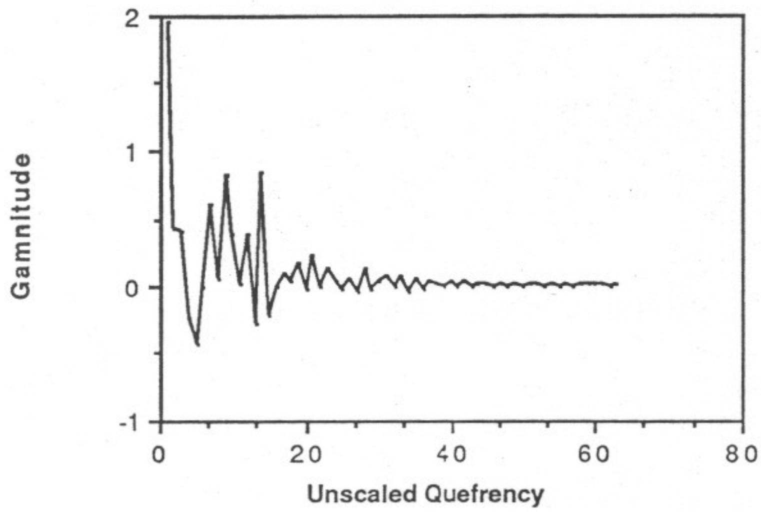


Figure 3: The Burg 31 order AR-estimator detects the hidden periodicities from the data of Table 1.

Using this approach, the most relevant peaks only are found after processing. The criterion used to decide when a peak is to be treated as an important one is the power content, with respect to the background noise; i.e. the well known Signal to Noise Ratio, or SNR.
Secondly, to identify the peaks, which are harmonically related to each other, a dedicated signal processing algorithm, known as the 'Cepstrum' is used [3], [4], [5]. This algorithm is used in speech detection techniques and in the processing of Time Domain Reflectometry applications to perform the *homomorphic deconvolution* [3], [6]. It consists in taking the logarithm of the PSD and having it followed by a second Discrete Fourier Transform, so that the time domain record of figure 1 is transformed into a domain, which has also the dimensions of time. This domain, since it is obtained after processing the frequency domain, is generally called the *quefrency* domain. Having this name building process in mind, the spectrum becomes then the *cepstrum*, the amplitude *gamnitude*, the phase *saphe*, the period *repiod* and so forth.
The advantage of heaving the cepstrum applied is that the harmonically related frequency peaks yield into single *quefrency* lines, and hence into a unique *repiod* and thus periodicity.
The application of the cepstrum technique to the processed P.S.D. of the data in table 1, is shown in figure 4.

Cepstrum applied to the data of Table 1



This plot shows clearly that 4 peaks, with high gamnitude, are present having a relatively low quefrency, and thus a high repoid.

The very next step in this spectral analysis is to identify then the quantitative values of the observed periodicities. This job is without any doubt the most difficult one and requires a multi-disciplinary approach. To yield periodicities expressed in the proper dimensions (e.g. kyear), one must have access either to a dating technique in combination and relation to the raw data to be processed or process immediately data resulting from a dating record.

This most difficult job is still under investigation at the "Earth Technology Institute". The purpose of this paper, therefore, is to show that the application of signal processing techniques in combination with a knowledge based driven inference engine can be a new promising tool in unraveling some of the nowadays still present mysteries in geology.

REFERENCES

[1] Steven M. Kay, "Modern Spectral Estimation", Prentice-Hall, 1988.

[2] James Kulubi, Leo Van Biesen, "A framework for knowledge based spectrum analysis", *IEEE Instrum. and Meas. Conf.*, IMTC90 Conf. Record, IEEE Cat. N° 90CH2735-9, pp. 160-172. February 1990., San Jose, CA, USA.

[3] S. M. Riad, N.S. Nahman, "Application of the Homomorphic Deconvolution for the Separation of TDR Signals Occurring in Overlapping Time Windows.", *IEEE Trans. on Instrum. and. Meas.*, vol IM-25, N° 4, December 1976.

[4] B.P. Bogert, M.J. Healy, J.W. Tukey, "The Quefrency Alanysis of the Time Series for Echoes: Cepstrum, Pseudo-autocovariance, Cross Cepstrum and Saphe Cracking.", *Time Series Analysis*, Rosenbladt M., Ed. Wiley, New York, 1963, Chap. 15, pp 209-243.

[5] D. Childers, D.P. Skinner, R.C. Kemerait, "The Cepstrum: A Guide to Processing.", *Proc. of the IEEE*, vol 65, N° 10, October 1977.

[6] L. P. Van Biesen. J. Renneboog, A. R. F. Barel, "High Accuracy Location of Faults on Electrical Lines Using Digital Signal Processing.", *IEEE Trans. on Instrum. and Meas.*, vol 39, N° 1, February 1990, pp 175-179.