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**Automatic lithofacies segmentation using the Wavelet Transform Modulus
Maxima lines(WTMM) combined with the Detrended Fluctuation
Analysis(DFA)**

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ABSTRACT

In this paper, we design and develop a new software tool that helps automatic lithofacies segmentation from geological data. Lithofacies is a crucial problem in reservoir characterization, and our study intends to prove that soft computing techniques like Wavelet transform modulus maxima lines (WTMM) and Detrended fluctuation analysis (DFA) approaches allow a geological lithology segmentation from differed well logging. On one hand, WTMM prove to be useful for delimitation of each layer. We based on his sensitivity on the presence of more then one layer, On the other hand, DFA is used to enhance the estimation if the roughness coefficient of each lithology. We use them jointly to segment the lithofacies of wells located in the Algerian Sahara. Obtained results are encouraging to publish this method, because the principal benefit is economic.

INTRODUCTION

Fast progress in the data-processing field of the latter years pushed the geophysicists to automate interpretation of well-logs, for that several techniques are proposed. We quote for example (Neural networks, Fuzzy logic and chains of Markov.).These techniques are used either for the characterization of reservoirs or for the evaluation of their parameters. A lot of geophysical works (Bean C. J. ,1996, Hermman ,F.J ,1997), showed the fbm character of signal of well-logs , what brings to characterize each homogeneous layer by a coefficient of roughness .The WTMM is a powerful tool for segmentation, it was used in mammography for the segmentation of cancer and in image processing(Kestener ,P. ,2003) .We treated well-logs data by this technique to delimitate lithofacies and to construct a geological model .

OPTIMIZATION OF THE PROCESSING PARAMETERS

Theoretically the spectrum of exponents of a fbm signal is a segment of a straight line. It has the following equation(A.Arneodo et al , 1995) :

$$\tau(q) = qH - 1 \dots\dots\dots(1)$$

H : is the Hurst exponent. This stage consists in optimizing the parameters of processing by WTMM in order to check this condition. Parameters to be optimized are:

- 1)The maximum value of the scale factor q_{max} which the calculation of the function of partition is carried out on the interval $[-q_{max} , +q_{max}]$.
- 2)Parameters of the analyzing wavelet which is the complex Morlet wavelet. It has the expression (2)

$$\psi(Z) = \exp(-Z^2 / 2) * \exp(i * \Omega * Z) * (1 - \exp(-\Omega^2 / 4) * \exp(-Z^2 / 2))\dots\dots\dots(2)$$

Several experiments on fbm realizations showed that optimal value of Ω for a better estimation of the coefficients of Hurst is equal to 4.8.

TREATMENT OF AN FMB SIGNAL WITH 1024 SAMPLES

We calculate the spectrum of exponents by WTMM of an fbm signal with 1024 samples and a Hurst coefficient H=0.60 for the following values of q_{max} : 2.0, 1.5 ,1.0 and 0.50 , table 1 summarize all obtained results.

q_{max}	H injected	H calculated
2.0	0.60	0.685 ± 0.010
1.5	0.60	0.664 ± 0.005
1.0	0.60	0.685 ± 0.006
0.5	0.60	0.606 ± 0.002

Table-1 Coefficients of Hurst estimated for each value of q_{max}

The spectrum of exponents calculated for $q_{max}=0.50$ show well that this value is optimal is for its linearity which is indicating homogeneities of studied texture and is like an estimator of the coefficient of roughness.

REMARK : Several experiments made on fbm realizations of 512 and 256 samples show well that the value $q_{max}=0.50$ is optimal.

SHORTS TIME-SERIES ANALYSIS

Our objective is to seek very fine textures for that we have to concentrate our studies on signals with low numbers of samples, for that we analyzed sets of signals with 128, 64 and 32 samples. First we built several fbm realizations with 128 samples which different by their coefficients of roughness, it is varied from 0 to 1. A detailed study showed that optimal values of q was accorded with coefficients of Hurst. Table 2. summarize all results

H	q_{max}
$0 < H \leq 0.20$	0.125
$0.20 < H < 0.40$	0.25
$H \geq 0.40$	0.50

Table-2 Optimal parameters according to roughness

To enhance the estimation, we calculated the Hurst exponent by the DFA, obtained results showed that this estimator gives goods results compared to the WTMM.

Same work was made for signals with 64 and 32 samples, we are obtained the following results:

1. WTMM analysis showed that the two types of signals able the same optimal parameters as those obtained for the signals with 128 samples
2. Estimator DFA gives goods results compared to the WTMM.

PHYSICAL RESPONSES OF SEVERAL TEXTURES ANALYSIS

The theory developed by Arneodo show:

That is to say the S(t) signal which constitute of a whole of fbm signals of Hurst exponents $H_1, H_2, H_3, \dots, H_n$. The spectrum of exponents $\tau(q)$ calculated by WTMM formalism is depends only on the maximal and minimal Hurst coefficients. The spectrum of exponents consists of two segments of straight lines of equations(3).

$$\tau(q) = \begin{cases} qH_{max} - 1 & \dots \dots \dots \text{if } (q < 0) \\ qH_{min} - 1 & \dots \dots \dots \text{if } (q > 0) \end{cases} \dots \dots \dots (3)$$

APPLICATION ON SYNTHETIC DATA

In order to check our programs we have to generate a model made up of 04 fbm signals. With the following Hurst exponents: 0.40, 0.60, 0.70 and 0.80, each signal has 64 samples. We applied a WTMM analysis to this signal. The obtained results demonstrate that this method is sensitive only to two textures, the first is that which has a maximum coefficient of roughness, and the other which is characterized by a minimal coefficient.

AUTOMATIC SEGMENTATION ALGORITHM

Our algorithm of segmentation is based on the sensitivity of the WTMM tool, of the presence moreover of one homogeneous texture. This phenomenon is expressed by two segments of straight lines in the spectrum of exponents. The estimate, of roughness coefficients of each texture is calibrated by DFA. The entry of the program of segmentation consists of two variables:

(a) Threshold of decision of homogeneities of textures. It is equal to the difference between the slopes of the two segments of straight lines calculated for $q < 0$ and $q > 0$. We indicate by ΔH this variable.

(b) Minimal size which texture is considered homogeneous, we indicate by W this length. The flow chart of the algorithm of segmentation is represented in figure(1).

REMARK : We indicate by Δz the step of sampling.

APPLICATION ON SYNTHETIC DATA

We applied this algorithm of segmentation to a whole of fbm realizations , which different by their Hurst exponents in order to model geological diversity. The well-log signal consists of 06 fbm signals, each signal has 64 samples. They have the following coefficients of Hurst: 0.1, 0.4, 0.9, 0.2, 0.8 and 0.5. The step of sampling is equal to 0.125(m). All details of segmentation are summarized in table 3.

Layer	H injected	depth injected (m)	Depth calculated	H calculated (WTMM)	H calculated (DFA)
1	0.10	8	7.125	0.15	0.07
2	0.40	8	8.75	0.25	0.39
3	0.90	8	8.50	0.74	0.92
4	0.20	8	7.50	0.26	0.18
5	0.80	8	8.00	1.12	0.82
6	0.50	8	8.00	0.35	0.56

Table-3 Obtained segmentation of a synthetic model with six roughness.

RESULTS INTEPRATATION

The algorithm of segmentation proposed detect with an excellent precision the limits of each layer, for the estimation of the coefficient of roughness , DFA estimator gives better results compared to the WTMM.

STRATIGRAPHIC COLUMN

We analyzed the data of two wells HR196 and HRE-407 located in Hassi Rmel (Algeria), for the well HR196 we treated Gamma ray and sonic well-log data. On the other hand for the well HRE-407 we treated only the recording of the sonic well-log . The step of sampling is equal to 0.125. The first operation consists in removing the deterministic part which is considered linear according to the depth. We used the segmentation given by sedimentologists as a priori information and we analyzed each interval of the stratigraphic column.

WAVELET BASED ANALYSIS

We applied a wavelet based analysis to the signal of the velocity of the P wave recorded in the well HRE-407, which consists in calculating the wavelet transform, then using a linear regression within the least square mean we calculate the Holder exponent at each maximum point. The histogram of the various exponents shows that the coefficients ranging between 0.1 and 0.4 are most dominant, which are meant by the existence of more dominant lithologies characterized by these coefficients of roughness.

WTMM ANALYSIS

In order to prove the power of the WTMM on the real data we analyzed the gamma-ray well-log of the well HR196. The calculation is carried out at each interval of the stratigraphic column.. All spectrum of exponents are consists of two segments of straight lines, what shows that each interval contain more then a homogeneous and isotropic layer.

AUTOMATIC SEGMENTAION ALGORITHM APPLIED AT REAL DATA

We analyzed the signals of velocity of two wells HR196 and HRE-407 by this technique. Figure (2). represents the obtained segmentation, in the half-plane depth - coefficient of roughness , the thickness of the column represents the thickness of the layer cut out and its height represents the value of the coefficient of Hurst estimated evening by WTMM(black) or by DFA(red). The signal in green is the well-log normalized signal.

Segmentation results was comparable with the shape of the signal, we proposed lithofacies discontinuities which belong to the skeleton. Both estimator DFA and WTMM generally gives different results. One prefers those of the DFA because the experiments on the fbm realizations shows that the DFA was most robust .DFA Estimator gives negative coefficients of roughness this is with the recording noises.

CONCLUSION

We planned an automatic algorithm of segmentation, based on the sensitivity of the WTMM, the spectrum of exponents is an indicator of homogeneities of textures. We construct the lithofacies of two wells HRE-407 and HR196 . We do not have the experimental results to compare our model , but when we compared our geological discontinuities with those obtained by the self organizing map (SOM) , we remarked that the mines are more precise . The estimate of the coefficient of roughness of the same medium gives different results from a well-log to another. Thus the coefficient of roughness is a physical characteristic of the geological mediums which also depends on the used well-log.

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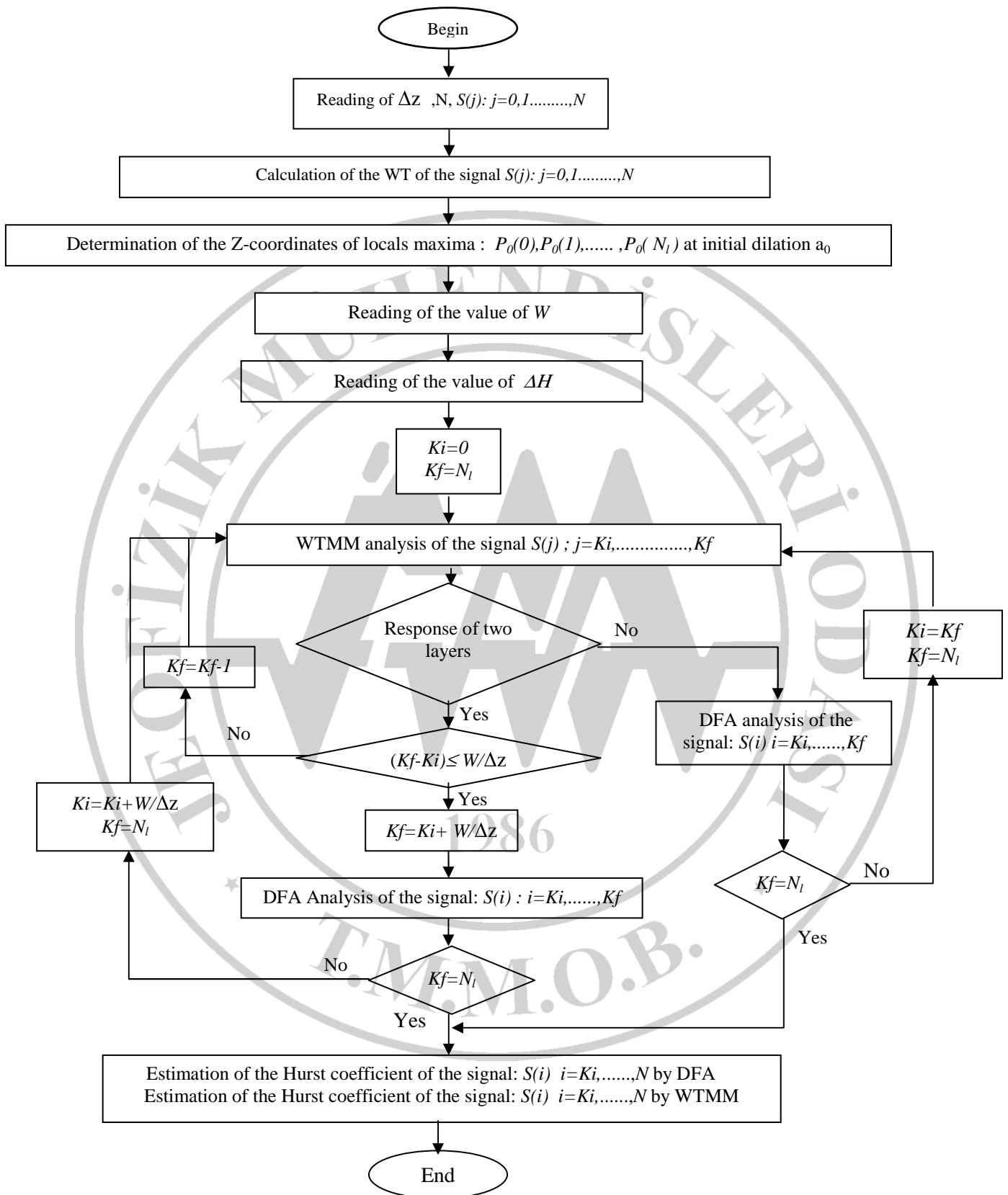


Figure-1. Flow chart of automatic segmentation algorithm

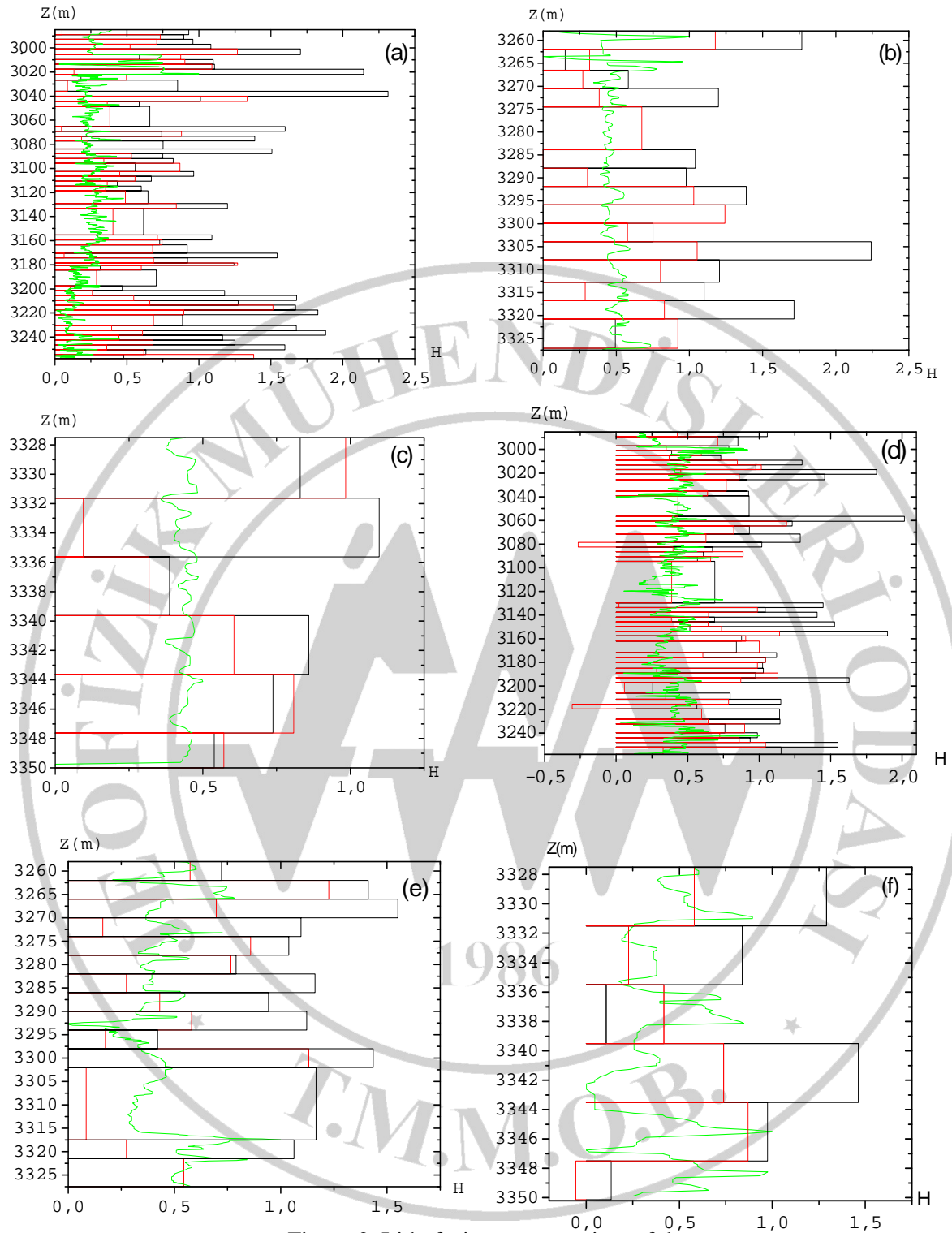


Figure-2. Lithofacies segmentation of the :

Well HR196
Interval : (a) C1,(b) C2 ,(c) C3

Well HRE-407
Interval : (d) C1 ,(e) C2 ,(f) C3

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