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High Resolution Methods of Analysis of Acoustic Signals in Medicine

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The paper describes an analysis of the possible parametric methods used to estimate the spectrum of short acoustic signals of low oscillations. These kinds of signals often appear in acoustic waves emitted by the temporomandibular joint as it moves [1-2,5]. There is reason to suppose that the frequency which is characteristic of these oscillations could be an essential parameter confirming the pathology of the joint under examination. The measurement of low oscillations is difficult and not accurate, especially when non-parametric methods are used. The paper presents the results of analysis of a simulated short oscillating pulse using the DFT non-parametric method and the parametric method of linear prediction, using Burg algorithm. Finally, results of patient analysis are given, using the FFT and parametric methods.

1. Introduction

Searching non-invasive diagnosing of the temporomandibular joint, it was found that as the mandible moves, the joint emits acoustic signals. It was also found that these signals contain information on some of the pathological states of the joint under examination [1,5]. This observation was confirmed during a study carried out at the Clinic of Facial and Maxillofacial Surgery of the Gdańsk Medical Academy in which the system developed by the authors was put to use, [3].

The present research focuses on the identification of the parameters of the signals emitted, characteristic for specific pathologies of the temporomandibular joint. At first, characteristic fragments of the signals were selected (the sounds they make resemble clicks), followed by a group of parameters having the strongest ties to certain joint pathologies. These parameters mainly include energy, moment of appearance, time duration and characteristic spectrum parameters: its effective bandwidth and medium frequency, [1-2,5].

The paper discusses processing methods which lead to a higher accuracy of determining two essential parameters of acoustic emission signals, namely the moment of appearing of the characteristic "click" and the frequency of its oscillations. The problem, however, is that all the short "click" contains are single oscillations. Given these circumstances, using the DFT method (Discrete Fourier Transform) and DWT method (Discrete Wavelet Transform) does not result in the desired accuracy of the frequency measurement, [3]. The solution here seems to be the use of parametric spectral estimation methods, e.g. Yule-Walker, Burg, Forward-Backward or others, [4].

The paper presents the results of analysis obtained using DFT and LP (Linear Prediction) methods using Burg algorithm.

2. Simulation of the Acoustic Emission Signal

At the beginning stage of analysis, the real signal emitted by the temporomandibular joint was substituted by Morlet's wavelet described with the formula:

$$\Psi(\alpha) = e^{\frac{-\alpha^2}{100}} \cos(\alpha) . \qquad (1)$$

The wavelet features short-term and strongly attenuated oscillations, which in some way sometimes resembles clicks in the signals emitted by the temporomandibular joint. This is illustrated in Fig. 1.

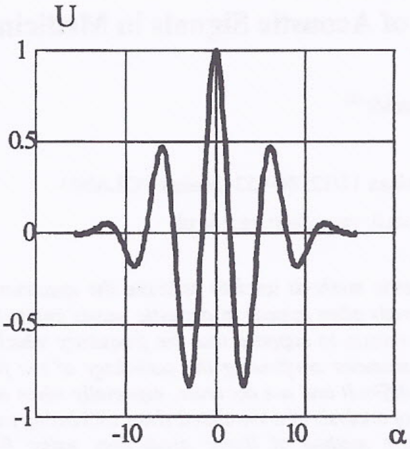

Fig.1a Morlet's wavelet.

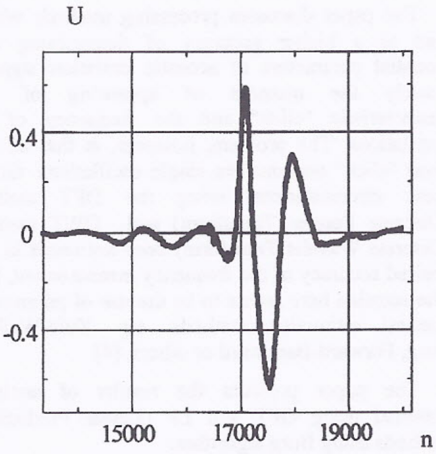

Fig.1b Click in the signal emitted by the temporomandibular joint.

The scale of the ordinate in Fig.1a is set in a normalised angular measure (angle α). The idea of signal simulation is to assign to angle α a successive number of sample n following this relation:

$$\alpha = 2\pi \frac{f_s}{f_p} n \qquad (2)$$

where:

- f_s frequency of oscillation
- f_p frequency of signal sampling,
- n successive sample number.

An analytical description of the wavelet allows the introduction of changes of its frequency and time duration. It also allows an easy observation of the effects caused by the changes, when methods DFT and LP are used. The procedure enables an evaluation of how useful both methods are for the system in question. To compare the resolution obtained using Fourier transformation and linear prediction method an analysis was made of the presented signal whose form was the same as that of the wavelet used. The analysis was made for three such signals with frequencies f_1=60Hz, f_2=70Hz and f_3=80Hz. Each of the signals was symmetrically limited to the number of samples used in the system, i.e. to 1024 samples. The signal analysed with DFT was sampled at frequency of about 22050 Hz, while the frequency of the signal undergoing parametric analysis was artificially reduced 50 times and amounted to 441Hz. This means that the same wavelet in the first case was made from 1024 samples and in the other case of 20 samples.

The enforced reduction of sampling frequency was indispensable for the LP analysis. The reason was a limitation of the algorithm available in the MATLAB programme used for the computations. The algorithm only ensures the prediction of 128 frequencies, linearly distributed on a scale from 0 to Nyquist frequency. At the same time, the artificial frequency reduction narrowed the analysis area down to the lower band which is of interest to us, i.e. to about 220Hz. This helped to obtain a high resolution of the frequency measurement – amounting to some 1.7Hz.

The addition of white noise to both wavelets was an extra operation. Noise dispersion was 1000 times less the maximal wavelet value. This noise was essential to ensure a correct analysis using the parametric method and made analysis conditions resemble the actual conditions more.

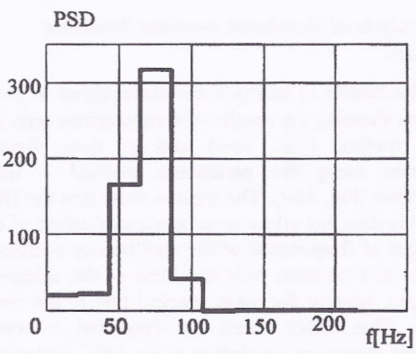

Fig. 3a Wavelet spectrum with frequency of 60Hz and length of 1024 samples computed using DFT.

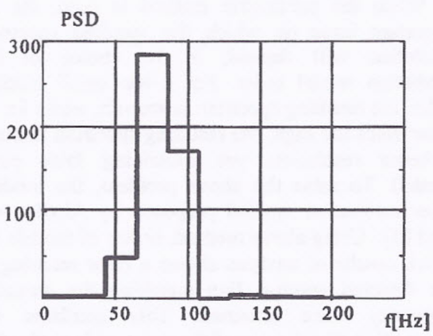

Fig. 3b Wavelet spectrum with frequency of 70Hz and length of 1024 samples computed using DFT.

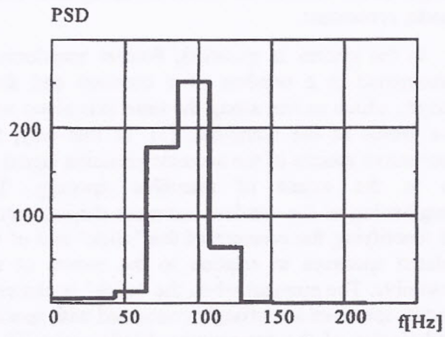

Fig. 3c Wavelet spectrum with frequency of 80Hz and length of 1024 samples computed using DFT.

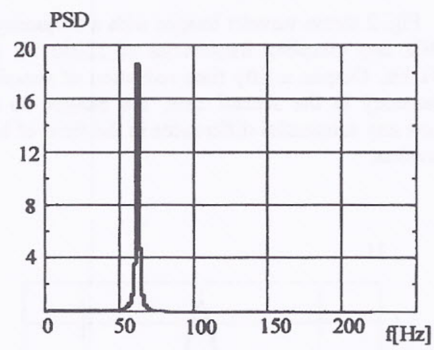

Fig. 3d Wavelet spectrum with frequency of 60Hz and length of 1024 samples determined using LP (Burg algorithm - model's order=3).

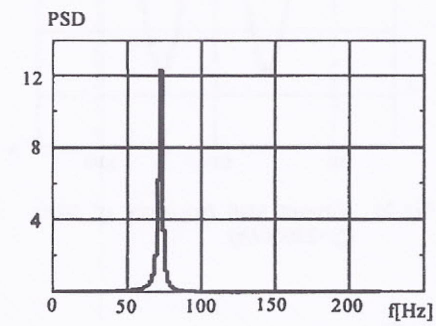

Fig. 3e Wavelet spectrum with frequency of 70Hz and length of 1024 samples computed using LP (Burg algorithm - model's order=3).

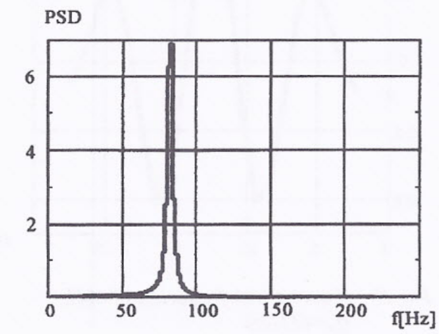

Fig. 3f Wavelet spectrum with frequency of 80Hz and length of 1024 samples determined using LP(Burg algorithm - model's order=3).

Fig. 2 shows wavelet images with a frequency of 60Hz and sampling frequencies of 22050 Hz and 441 Hz. Despite a fifty time reduction of sampling frequency in the second case, the images do not show any substantial differences in the form of both wavelets.

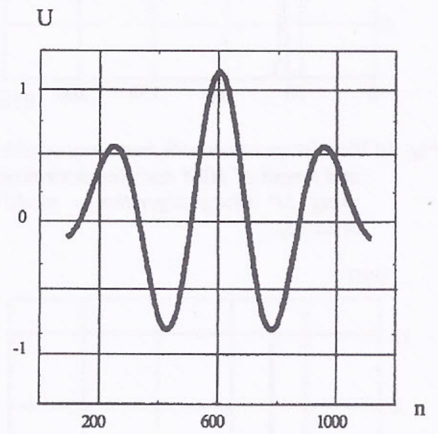

Fig.2a Wavelet with frequency of 60Hz (f_p=22050Hz).

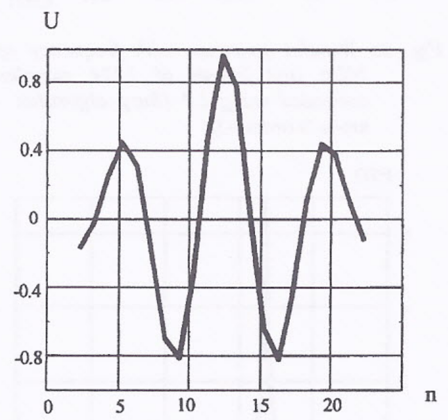

Fig.2b Wavelet with frequency of 60Hz (f_p=441Hz).

3. Analysis of Simulated Acoustic Emission Signals

The results of analysis are exemplified in three figures showing the results of computations with the DFT method (Fig. 3a-c) and in three figures obtained using the parametric method – Burg algorithm (Fig. 3d-f). The figures show that the DFT analysis does not allow an accurate evaluation of the changes of frequencies of the oscillations contained in Morlet's wavelet; only the form of the spectrum changes, leaving the main spectral line in the same place. This effect meets the predicted outcome, because frequency resolution in the DFT analysis is the effect of the duration assumed in the system (window width). This limitation is not present in spectral estimation using linear prediction, which is clearly visible in Fig. 3d-f.

When the parametric method is used, the all important issue on which the required spectrum resolution will depend, is the choice of the prediction model order. For a too small model's order, the resulting spectrum is smooth, while for an order that's too high, the resulting spectrum features a better resolution, yet containing false poles (peaks). To solve the above problem, the model's order estimation method proposed by Akaike was used [6]. Using above method, orders of models for which results of analysis shows à clear retuning of the detected spectral line matching the assumed frequency ware obtained. This confirms the supposition that the use of the parametric method in the system allows a much more accurate oscillation frequency within the "clicks" that are present in the signal emitted by the temporomandibular joint. This is the right conclusion, provided in both cases the length of the window in which the analysis is being made, is constant.

In the system in question, Fourier transform is determined in a window of a constant and short length, which moves along the time axis along with the moves of the mandible, [3]. In this way, the successive spectra of the acoustic emission signal tie in to the extent of mandible opening. The lengthening of the window increases the inaccuracy of identifying the moment of the "click" and of the related spectrum in relation to the moves of the mandible. The moment when the "click" is observed and its spectrum are strongly connected with specific pathologies of the temporomandibular joint, [3,5]. Increasing the length of the window to improve the accuracy of measurements of oscillations contained within the "click" is thus contradictory to the general objectives of the system.

4. Analysis of Actual Acoustic Emission Signals

The LP method was used for the analysis of actual acoustic signals generated by patients with varying degrees of the temporomandibular joint disease. Examples of signals are given in Fig. 4. They came from around the left temporomandibular joint in a healthy and ill patient.

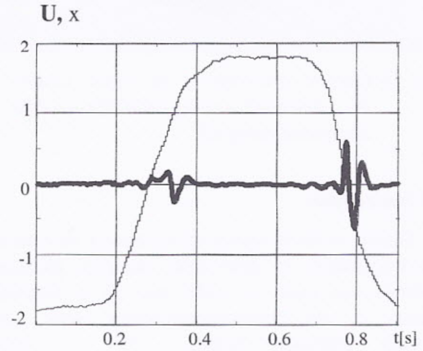

Fig. 4a Healthy patient.

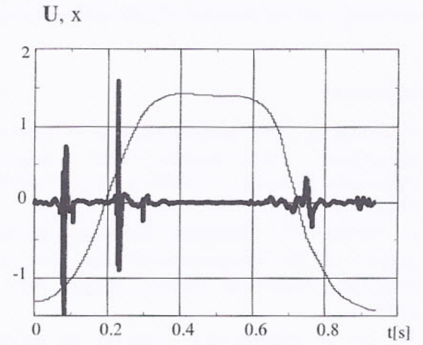

Fig.4b Ill patient.

In the figures, the thick line represents the acoustic signal emitted by the joint under examination, while the thin line portraits the movement of the mandible from its closure through maximal opening up to its repeated closure. As you can see, in the healthy patient the relatively strong "click" appears only in the phase of closing the mandible. In an ill patient, the ordinary "click" during the closing phase is accompanied by additional strong clicks when the mandible is being opened.

The signals registered were then analysed in the mobile time window used in the system. Fig. 5 shows the periodogram computed using DFT and a spectrum determined using LP for signals emitted by the healthy temporomandibular joint.

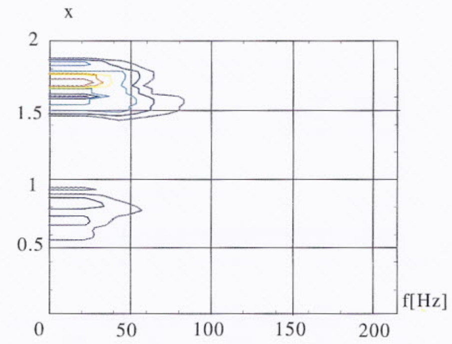

Fig. 5a Healthy patient – DFT method.

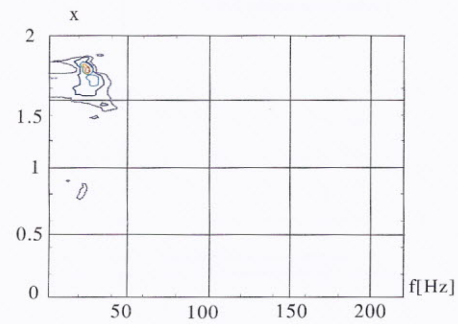

Fig. 5b Healthy patient – LP method.

In the figures, the vertical axis marked as x, shows the size of mandible displacement in two phases of its movement. The first stage, from 0 to 1, illustrates the opening phase of the mandible, whereas 1 to 2 presents the closing phase of the mandible.

You can see clearly, that the frequencies of oscillations that are present in the signal can be easily distinguished and accurately determined from the spectrum computed using the LP method. These possibilities are not provided in the spectrum computed using the DFT method. This is so because the contours containing spectrum poles are fuzzy and reach zero frequency.

The advantages of the LP method become even clearer in the analysis of signals emitted by diseased temporomandibular joints. This is illustrated in Fig. 6 which shows periodogram obtained using both methods in a two-dimensional (contour) presentation and in Fig. 7 where the same spectra are shown in a three-dimensional image.

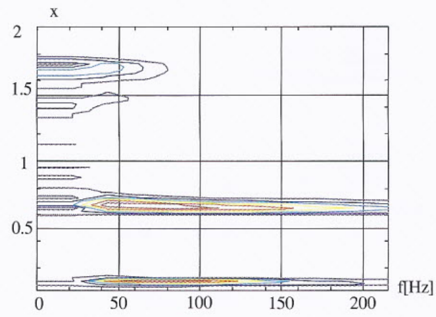

Fig. 6a Current spectrum of the signal emitted by a diseased temporomandibular joint, computed using DFT.

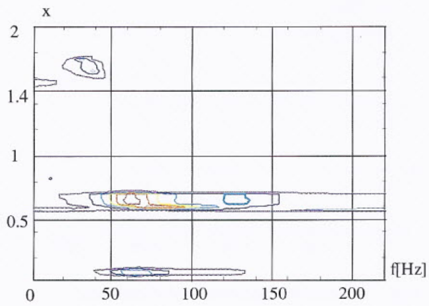

Fig. 6b Current spectrum of the signal emitted by a diseased temporomandibular joint, computed using LP.

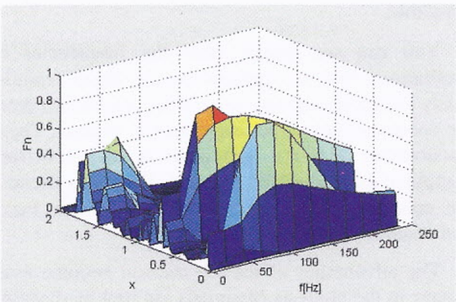

Fig. 7a Current spectrum of the signal emitted by a diseased temporomandibular joint, computed using DFT .

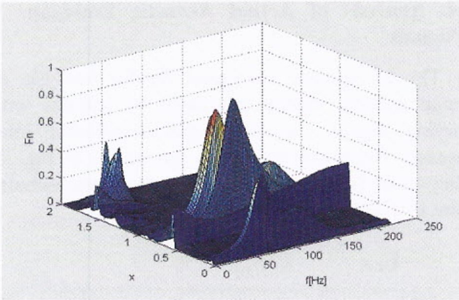

Fig. 7b Current spectrum of the signal emitted by a diseased temporomandibular joint, computed using LP.

5. Conclusions

Thanks to their ability of accurately determining low frequencies in short time intervals, parametric methods can make a useful tool in a diagnosing system of the temporomandibular joint, using acoustic emission signals. For a complete confirmation of this conclusion further clinical studies are required on large groups of patients representing varying degrees of joint pathologies.

6. References

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