WAVELETS AND SHORT TIME FOURIER TRANSFORMS ON ULTRASONIC DOPPLER SIGNALS FOR PREGNANCY DETERMINATION IN SHEEP

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ABSTRACT

The reproductive status of animals is of utmost importance to the modern farmer. Decisions concerning the management of the flock are influenced by the knowledge of the percentage of animals that are pregnant at any specific time. The aim of the project was to gain knowledge for the development of an instrument that is affordable and with which a farmer can do pregnancy determination himself/herself, thereby enabling him/her to make the correct management decisions. Experimental data were obtained from pregnant Dorper ewes with the aid of a portable Doppler instrument. Using real data as input, simulations of Wavelet and Short Time Fourier Transforms (STF) were done in MathCAD. In the simulations known levels of noise were added to the Doppler signals. Satisfactory results were obtained from the simulations of Wavelet Transforms. In the simulation of the Wavelet Transforms, signals with a SNR of -6.5 dB were successfully identified. It can thus be concluded that Wavelet Transforms can be used successfully for the detection of the fetal heartbeat in noisy ultrasonic Doppler signals.

1. INTRODUCTION

Many methods have already been described to diagnose pregnancy in sheep and goats . However, most techniques are unfortunately not adaptable to field conditions. Reliable techniques for early detection of pregnancy in sheep aid in culling or rebreeding and provide a valuable tool for controlled breeding programs [3]. In this study a Ultrasonic Doppler signal obtained from pregnant ewes were analysed by using digital signal processing (DSP) techniques. One of the many uses of Doppler in the medical field is the measurement of the speed, turbulence and flow-rate of blood. Other applications include the recognition of fetal heartbeat [1] [10]. Doppler ultrasound signals can be obtained by means of two methods, namely continuous wave Doppler and pulsed wave Doppler [9] [6]. Most visual fetal monitors use continuous wave ultrasound [8]. Currently, pregnancy determination in sheep has to be done by a veterinarian with a visual ultrasonic scanning device. The most common non-invasive method of measuring fetal heart rate utilises pulsed Doppler ultrasound monitors [7]. The aim of the project was to gain knowledge for the development of a low cost instrument, with which a farmer would be able to do the pregnancy determination himself/herself, thereby enabling him/her to make informed management decisions. In this paper Short Time Fourier and Wavelet Transforms are considered for the possible detection of a fetal heartbeat in noisy ultrasonic Doppler signals.

2. WAVELET, FOURIER AND SHORT TIME FOURIER TRANSFORMS

Any complex signal can be seen as the sum of a number of sine waves, which forms the basis of Fourier analysis [19]. In Doppler systems, spectral estimations were traditionally achieved with the Fast Fourier Transform (FFT) [9] [13] [15]. Although the Fourier analysis functions satisfactorily if the frequency components that are present in the signal are constant over the total period of the signal, no information is available on exactly when specific frequency components appear. The Fourier analysis can determine which frequency components appear in the total signal, but not when the different components appear [7]. The Fourier analysis is thus not ideally effective for non-stationary signals with a time dependent frequency spectrum [10]. Since the FFT method inherently cannot offer a good spectral resolution at highly turbulent blood flows, it sometimes leads to wrong interpretation of cardiac Doppler signals [11] [12].

The discrete Fourier transform of a discrete time periodic signal is defined as [10]:

$$X_k = \sum_{n=0}^{N-1} x(n) e^{(-jkn(2/N))} \tag{1}$$

Where:

X_k = the discrete Fourier coefficients

N = the frame size

$x(n)$ = the input signal in time domain

n = sample

Figure 1 is a representation of a cosine signal that is described in Equation 2.

$$x(t) = \cos(2\pi 10t) + \cos(2\pi 25t) + \cos(2\pi 50t) + \cos(2\pi 100t) \tag{2}$$

Although the signals in Figure 1 and Figure 2 contain the same frequency components, the frequency components appear at different time periods.

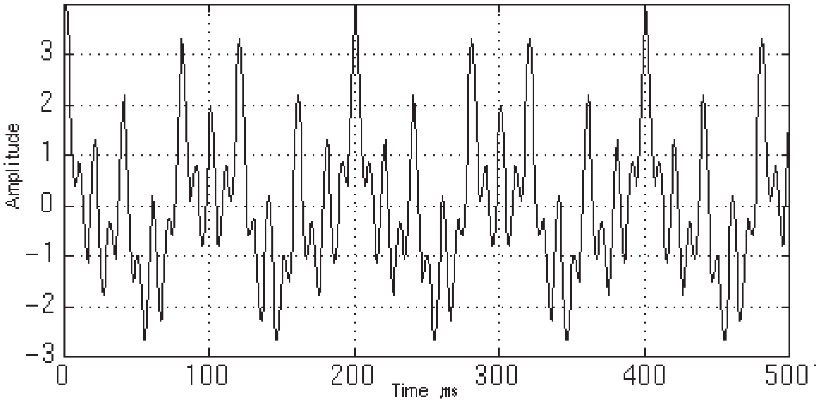


Figure 1: Cosine signal containing 10, 25, 50 and 100 Hz frequency components [16]

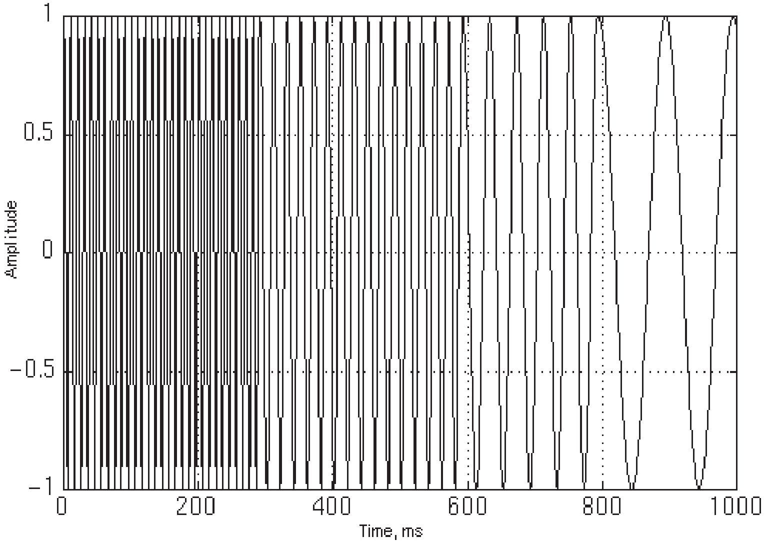


Figure 2: Signal containing 10, 25, 50 and 100 Hz frequency components [16]

The Short Time Fourier Transform (STFT) is a variation of the Fourier transformation (FT). With STFT the signal is broken up into specific constant periods [17]. The FT can then be applied individually on each of these parts of the signal.

The problem with STFT is that if the signal is broken up over long periods, a good frequency resolution can be obtained, but a poor periodic resolution can be reflected. If the signal, however, is broken up into short periods and the FT applied on individual components, a better periodic resolution with a poor frequency resolution will be obtained [8].

A powerful method for the analysis of (non-stationary) signals, namely wavelet transformation (WT), can also be used for the frequency analysis of the Doppler signal. In a WT, linear combinations of the wavelet functions are used to represent the signal [18]. In contrast with the lengthy duration of sine waves in the Fourier analysis, wavelets have limited periods and only appear in a few cycles. As in the Fourier analysis the wavelet analysis also has a fast algorithm to break the signal up into simple components.

$$CWT_{\chi}^{\psi} = \frac{1}{\sqrt{|s|}} \int \chi(t) \psi\left(\frac{t-\tau}{s}\right) dt \qquad (3)$$

Where:

$\psi(t)$ = the mother wavelet

τ = the translation parameter

s = the scale

The term translation is related to the location of the window as the window is shifted through the signal.

The translation axis gives an indication of time while the scale axis is an indication of the frequency. The low values on the scale axis in Figure 3 are an indication of high frequency components and the high values on the scale axis indicate the low frequency components. This is becase the scale parameter "S" in Equation 3 is the inverse of the frequency.

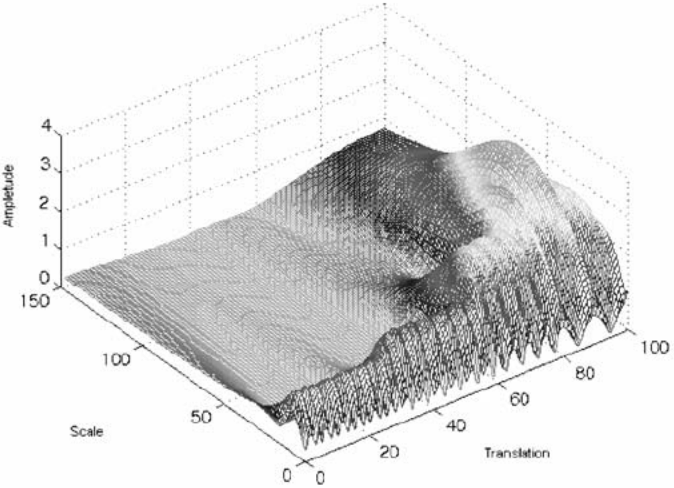


Figure 3: Wavelet transformation of time domain signal in Figure 2 [16]

Characteristics of WT are:

- Wavelets are localised in time and form building blocks for a variety of signals. These signals sometimes consist of characteristics which change with time.
- Wavelets compact the energy functions of the signal into relative small quantities. This characteristic is useful when using image compression.

WT can be applied in a variety of different fields, e.g.:

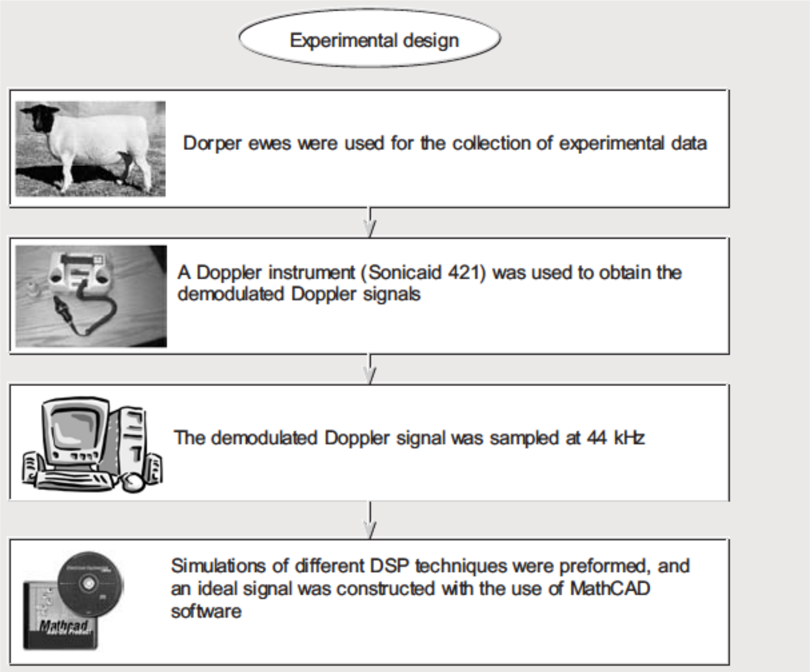
- Medical image processing;
- Pattern recognition;
- Numerical analysis and
- Flow dynamics studies [14].

Some people foresee wavelet compression as the future for both internet graphics and high resolution television graphics; this is because of its ability to compress signals more clearly than other methods [19].

3. EXPERIMENTAL DESIGN

3.1 Introduction

In order to obtain valid data for the analysis of the Doppler signal, the experimental design as shown in Figure 4 has been followed.



Dorper ewes were used for the collection of experimental data

A Doppler instrument (Sonicaid 421) was used to obtain the demodulated Doppler signals

The demodulated Doppler signal was sampled at 44 kHz

Simulations of different DSP techniques were preformed, and an ideal signal was constructed with the use of MathCAD software

Figure 4: Experimental design

3.2 Doppler instrument

A Sonicaid 421 (OXFORD Medical Limited) [6] was used to collect the data. The Doppler instrument is designed to determine the heartbeat of a human fetus during pregnancy. One of the outputs of the instrument is a demodulated Doppler signal. The audio output level of the instrument is of such a level that a computer sound card can sample it.

3.3 Dorper ewes

A number of pregnant Dorper ewes were identified and within one month after the data were obtained, they lambed. The ewes that were used in the sampling were quite tame and were at ease during the examination. The standing position was found to be the best position for the ewes during sampling. The ultrasonic transducer was placed next to the back left leg on a less hairy place of the flank.

Problems were experienced with the coupling where the ultrasonic sensor had to be placed against the skin of the sheep. This is due to the hair that appears on the flanks of the pregnant ewes. In order to get a better acoustic coupling, a suitable gel was used. The gel serves as an acoustic impedance adaptor between the skin of the sheep and the transducer. The transducer was pressed securely against the flank and then turned towards the region of the presumed fetus.

3.4 Sound card

The output of the ultrasonic Doppler instrument was linked to a sound card for sampling. Goldwave software was used for the sampling of the signal.

4. RESULTS AND CONCLUSION

The evaluation consisted of the following:

- Identifying and constructing an ideal signal from sampled signals;
- Using the ideal signal, evaluate simulations of STFT and WT systems as described;
- Evaluating the simulations of the STFT and WT systems at different noise levels;
- Evaluating the simulations of the STFT and WT systems with different sets of measured input data.

4.1 Construction of the ideal signal

In order to evaluate the system an ideal signal was generated. Figure 5 is part of the measured signal which was selected on grounds of correlation with a typical heartbeat signal. Figure 6 indicates a typical heartbeat signal. The P-part of the signal is formed because of the atrial depolarisation, the Q-H-S part is present as result of the ventricular depolarisation and the T-part is formed because of the ventricular repolarisation. From the above-mentioned it can be concluded that the signal in Figure 5 is the fetal heartbeat. This conclusion is further supported by the fact that the frequency of the pulse, correlates with the expected frequency against which the fetal heartbeat appears, namely 2 to 3 Hz. This frequency is considerably higher than the heartbeat of the mother which appears at approximately 1 Hz.

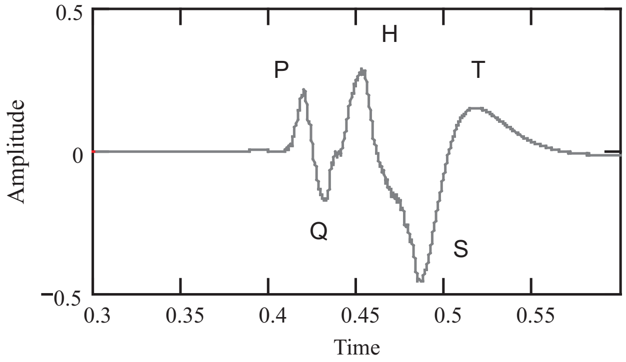


Figure 5 Part of a measured signal that was chosen to form the ideal signal

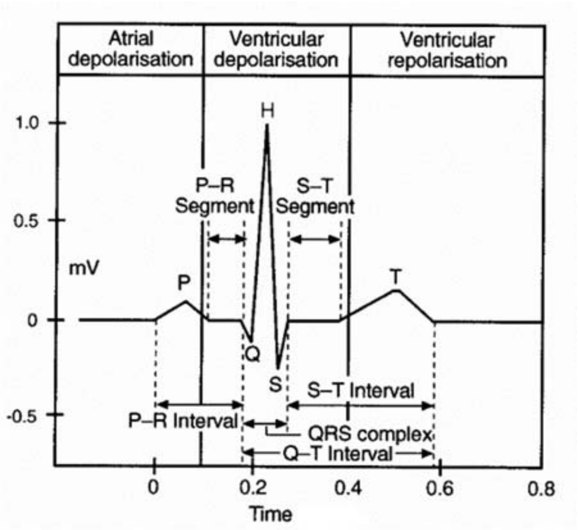


Figure 6 Theoretical form of a typical heartbeat signal [2]

As an example the results of the STFT on the mesured signal in Figure 7 are presented in Figure 8. The signal in Figure 7 was broken up into blocks of 50 samples and the FT applied to each block. Figure 8 is an indication of the frequency spectrum of each of the blocks. Each block gives an indication of a specific period of the total signal and the frequency changes with regard to the time can thus be observed.

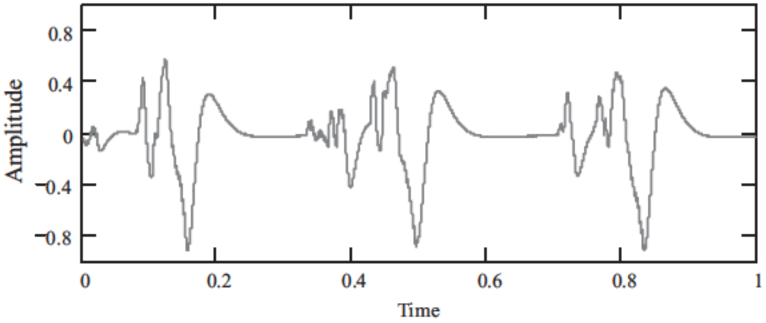


Figure 7: Time domain signal that was used for the STFT in Figure 8

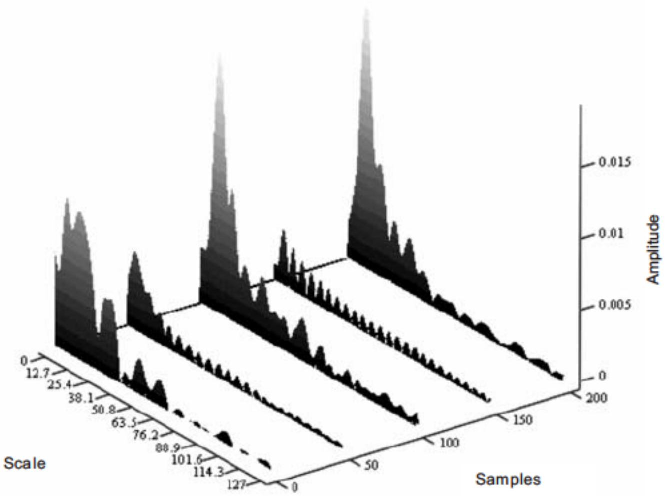


Figure 8: Three-dimensional representation of the signal in Figure 7 analysed with the use of STFT

The fetal heartbeat signal in Figure 5 was also used as input to the simulation of Wavelet transforms. In Figure 9 the appearance of the frequency components, associated with the fetal heartbeat, can clearly be observed at specific time intervals.

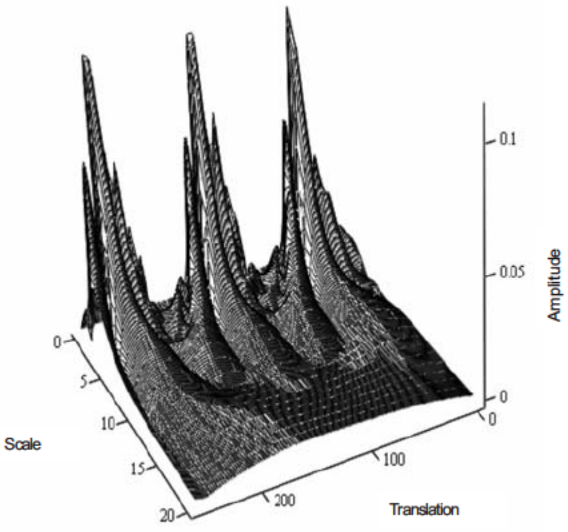


Figure 9: WT applied on measured Doppler signal in Figure 7

In order to investigate the influence of noise on the STFT and continios WT, simulations with different levels of noise were applied on the Doppler signal as obtained from the fetal heartbeat (figure 7). In the simulations it was found that with the use of CWT and a signal-to-noise ratio (SNR) of -6 dB, it was possible to recognise the heartbeat. The STFT simulation gave no clear indication of the presence of the heartbeat at the SNR of -6 dB. The results of the simulations of STFT and CWT at different SNR are represented in Figure 10.

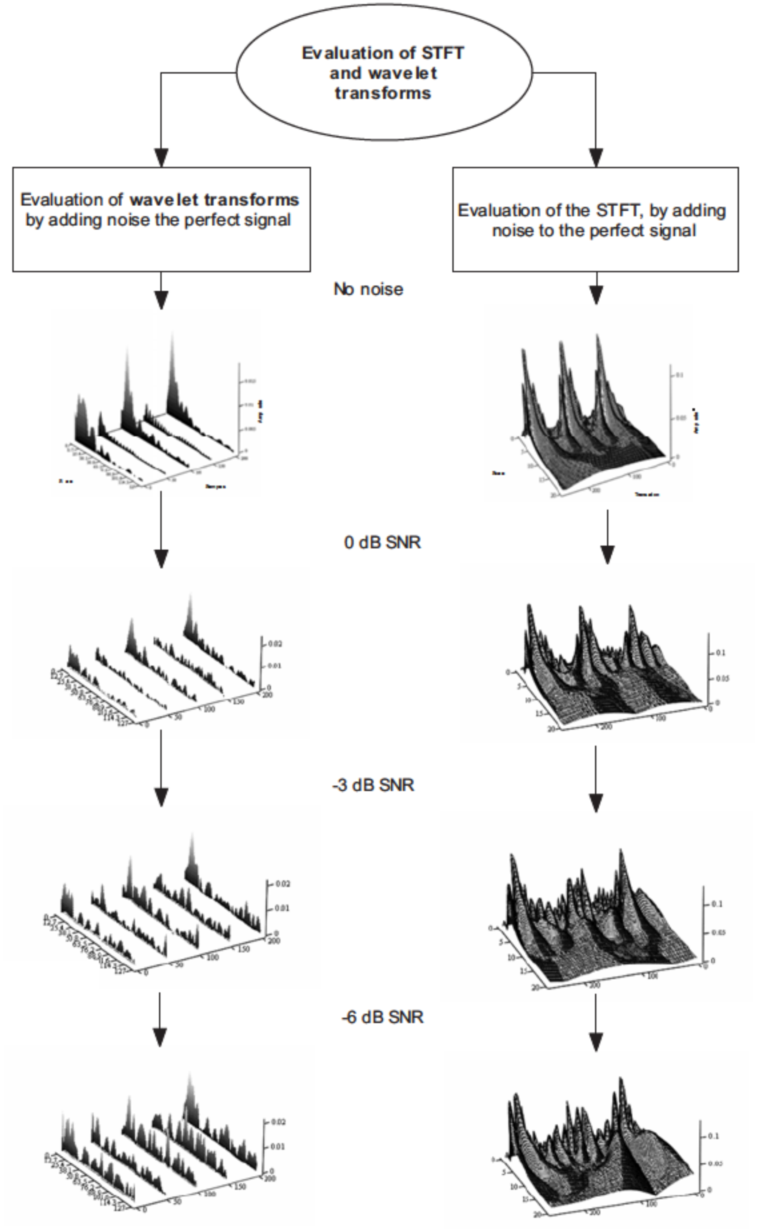


Figure 10: The influence of different levels of noise on Short Time Fourier and Wavelet Transforms

5. REFERENCES

[1] Doherthy, A., James, I.R. and Newman J.P. Estimation of the Doppler ultrasound maximal umbilical waveform envelope estimation method, Ultrasound in med. & Biol. Vol. 28, pp.1251-1259. 2002.

[2] Jennings, D. Flint, A. Turton, B. C.H. Nokes, L.D.M. Introduction to medical electronics applications. Edward Arnold, London, 1995.

[3] Karelsson, B., Berson, M., Helgason, T., Geirsson, R.T. and Pourcelot, L. Effects of fatal and maternal breathing on the ultrasonic Doppler signal due to fetal heart movement, European Journal of Ultrasound. Vol. 11, pp.47-52. 2000.

[4] Livingstone, C. Obstetric Ultrasound. Harcourt Publishers, London, 1999.

[5] Ménigault, E., Berson, M., Vieyres, P., Lepoivre, B., Pourcelot, D. and Pourcelot, L. Feto-maternal circulation: mathematical model and comparison with Doppler measurements, European Journal of Ultrasound. Vol. 7, pp.129-143. 1998.

[6] Operators manual Sonicaid 421 OXFORD Medical Limited 1998.

[7] Chiu, C.C. and Yen S.J. 2001. Assessment of cerebral auto regulation using time-domain cross-correlation analysis, Computers in Biology and Medicine. Vol. 31, pp.471-480.

[8] Gonzàlez, J.S., Vàzquez, K.R. and Nocetti, D.F.G. 2000. Model-base spectral estimation of Doppler signal using parallel genetic algorithms, Artificial Intelligence in Medicine, Vol. 19, pp.75-89.

[9] Guidi, G., Corti, L. and Tortoli, P. 2000. Application of autoregressive methods to mitigate spectral analysis, Ultrasound in Med & Biol, Vol.26, pp.585-592.

[10] Güler, I., Hardalac, F. and Kaymaz, M. 2002. Comparison of FFT and adaptive ARMA methods in transcranial Doppler signals recorded from the cerebral vessels, Computers in Biology and Medicine. Vol. 32, pp.445-453.

[11] Güler, I., Hardalac, F. and Barisci, N. 2002. Application of FFT analysed cardiac Doppler signals of fuzzy algorithm, Computer in Biology and Medicine. Vol. 32, pp.435-444.

[12] Güler, I., Hardalac, F. and Müldür, S. 2001. Determination of aorta failure with the application of FFT, AR and wavelets methods to Doppler technique, Computers in Biology and Medicine. Vol. 31, pp.229-238.

[13] Keeton, P.I.J. and Schlindwein, F.S. 1998. Spectral broadening of clinical Doppler Signals using FFT and autoregressive modeling, European Journal of Ultrasound. Vol.7, pp.209-218.

[14] Kulkarni, A.A., Joshi, J.B., Kumar, V.R. and Kulkarni, B.D. 2001. Wavelets transform of velocity-time data for the analysis of turbulent structures in a bubble column, Chemical Engineering Science. Vol. 56, pp.5305-5315.

[15] Ludu, A., O'Connell, R.F. and Draayer, J.P. 2003. Nonlinear equation and wavelets, Mathematics an Computers in Simulation. Vol. 62, pp.91-99.

[16] Polikar, R. Rowan University, The wavelet tutorial, 2001, http://engineering.rowan.edu.

[17] Turkoglu, I., Arslan, A. and Ilkay, E. 2002. An expert system of diagnosis of the heart valve diseases, Expert Systems with Applications. Vol. 23, pp.229-236.

[18] Verlinde, D., Beckers, F., Ramaekers, D. and Aubert, A.E. 2001. Wavelet decomposition analysis of heart rate variability in aerobic athletes, Autonomic Neuroscience: Basic and Clinical. Vol. 90, pp.138-141.

[19] Wavelets extension pack, MathCAD.