MULTIRESOLUTION BASED ANALYSIS OF WEAK MAGNETIC FIELD DISTURBANCES

M. Petkovski[a],* M. Kostov[a], V. Ceselkoska[a]

[a]*Department of Electrical Engineering, Faculty of Technical Sciences, St. Kliment Ohridski University, Bitola, Macedonia,*

e-mail: mile.petkovski@tfb.uklo.edu.mk

Received February xx, 2014

Abstract – In this paper an approach of real time measurement and analysis of magnetic field disturbances is described. Multiresolution based analysis appears as useful tool for feature extraction and identification of different signal phenomena. As a sensing element, a magentoresistive sensor is utilized together with virtual instrumentation. Experimental results are presented graphically.

INTRODUCTION

Sensing of magnetic field provides a highly effective way for detection and measurement of linear and/or angular displacements as well as electric current or voltage disturbances. This is because even small movement of actuating components in machinery (metal rods, gears, cams etc.) can create measurable changes in magnetic field. Examples where this property is put to good effect can be found in instrumentation and control equipment, which often requires position sensors capable to detecting displacements in the region of tenths of millimeter, and in electronic ignition systems, which must be able to determine the firing positions of an internal-combustion engine with great accuracy.

Many of these measuring systems were based on Hall-effect sensors, which make use of the property of a current-carrying semiconductor membrane (Hall Element) of generating a voltage perpendicular to the direction of current flow subjected to a magnetic field normal to its surface.

A more recent development for detecting magnetic field variations, however, is the magneto-resistive sensor [1], which in many applications provides a suitable alternative to the Hall-effect sensor. Some magneto-resistive sensors are more sensitive than the Hall-effect sensor and can operate over an extremely wide temperature range. What’s more, its frequency range is much wider: from DC up to several megahertz.

Since it has a longer sensing distance and lower Gauss operation than Hall-effect sensors, it can be used with lower cost magnets. The following are typical applications for the magneto-resistive sensors:

• Cylinder position sensing in pneumatic cylinders

• Elevator sensor

• Lid sensor for laptop computers

• Digital current sensing for: overload circuit protection, traffic light burnout detection, motor overload sensor, power loss detection, and industrial process monitoring

• Position sensor for materials handling equipment (lift trucks)

• Gear-tooth sensor for industrial applications

• Handicapped lift for van / bus

• Low-cost industrial proximity sensors for ferromagnetic targets

• Blood analyzer

• Magnetic encoders

In this paper, we explore some capabilities of magneto-resistive sensors [2] to detect small magnetic field disturbances. Utilization of virtual instruments is a proven technique in signal measurements and their parameter estimation [3]. Further improvements can be achieved applying wavelet based analysis [4] especially in the phase of pre-processing, where signal de-noising [5] is common for many applications. In the case of signal feature extraction and disturbances detection multi-resolution analysis is a proven very advanced technique [6], combining different wavelet bases [7].

The next section provides theoretical background of magneto-resistive effect and wavelet based signal analysis. Section three shows experimental results of magnetic field measurements and signal analysis combined with utilization of virtual instruments. Conclusions are listed in the last section providing possibilities of further application developments in the field of analysing physical phenomena and identification purposes.

THEORETICAL BACKGROUND

Magnetoresistive effect

Magnetoresistivity is the ability of a material to change resistance under the influence of magnetic fields [1]. There are several different magnetoresistive effects, but most of sensors use the Anisotropic Magneto Resistive (AMR) effect, which occurs in ferrous materials, including Permalloy. Permalloy is an alloy of nickel and iron and has been used as a sensing material since the early part of the 20th century in transformer designs. Low sensitivity to mechanical stress coupled with high sensitivity to magnetic fields provides sensors that vary from magnetometers to automotive engine applications.

When an external magnetic field (B) is applied, the film's resistance changes proportional to the square of the sine of the angle θ (Theta in the XZ plane) between the magnetization vector (M) and current flow vector (I). The magnetization vector is the net summation of the film's internal fields and the applied external field. The internal fields arise from the film properties, layout geometry, and fabrication process. The films do exhibit some magnetic hysteresis (switch point variance) which can be minimized by operating in one magnetic quadrant (i.e. only presenting a single pole of the magnet) when possible in the application. The AMR effect responds to the in-plane (XZ plane) external magnetic field components BX and BZ as previously described (proportional to the square of the sine of the angle θ.

Multiresolution analysis

The wavelet transform performs an analysis by representing signals in terms of a basis of functions localized in both space and frequency domain [8]. It decomposes the signal into a set of orthogonal components describing the signal variation across the scale [9]. The orthogonal components are generated by dilations and translations of a prototype function ϕ, called mother wavelet.

In analogy with other function expansions, a function f is presented for each discrete coordinate t as a sum of a wavelet expansion up to certain scale J plus a residual term, that is:

$$f(t)=\sum_{j=1}^{J}\sum_{k=1}^{2^{-j}M} d_{jk}\psi_{jk}(t)+\sum_{k=1}^{2^{-J}M} a_{Jk}\phi_{Jk}(t) \tag{1}$$

where ψ_{jk} and ϕ_{Jk} denote wavelet and scaling function, respectively, the indexes j and k are for dilatation and translation, and a_{Jk} and d_{jk} are approximation and detail coefficients. The approximation coefficients a_{Jk} contain the signal identity while the detail coefficients d_{jk} can be processed for the purposes of denoising [5], compression, edge detection, etc. [6,7].

Wavelet decompositions and multiresolution concepts are closely related to filter bank theory. For this reason, it is helpful to view the scaling and wavelet function as a low pass and high pass filters, H_0 and H_1, respectively. The wavelet transform is applied to low pass results (approximations) as it is illustrated in Fig. 1.

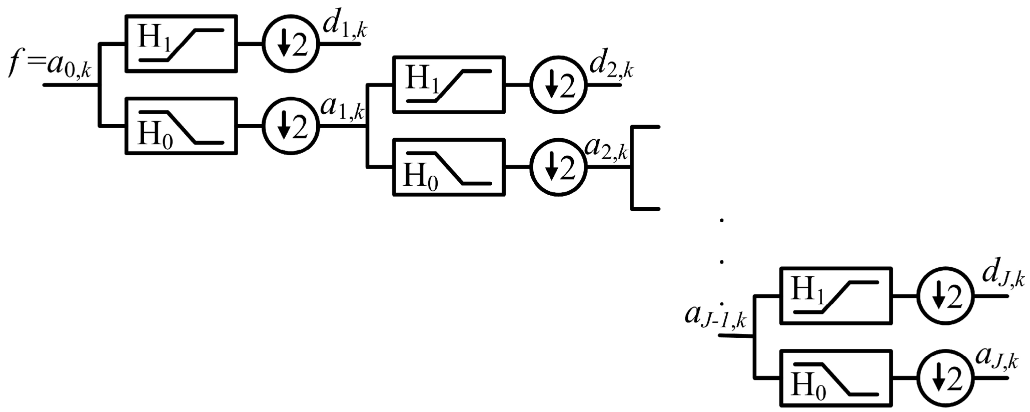

Fig. 1. Discrete wavelet transform tree.

The most popular form of wavelet-based filtering, commonly known as wavelet shrinkage [4], weights the corresponding wavelet coefficient by a number $0 \le h_{jk} \le 1$, can be expressed by:

$$\begin{aligned} &\left\{\mathbf{A}^{(k)}, \mathbf{D}^{(1)}, \mathbf{D}^{(2)}, \cdots \mathbf{D}^{(k)}\right\} = DWT(\mathbf{s}), \\ &\mathbf{s}^* = IDWT\left(f\left(\mathbf{A}^{(k)}, \mathbf{h}^{(1)}.\times \mathbf{D}^{(1)}, \mathbf{h}^{(2)}.\times \mathbf{D}^{(2)}, \cdots, \mathbf{h}^{(k)}.\times \mathbf{D}^{(k)}\right)\right) \end{aligned} \tag{2}$$

where **s** is input signal, **s*** is filtered signal, **A**(k) and **D**(k) are approximation and detail coefficients at level k, respectively, f is a function of the modified detail and approximation coefficients, .× is element-by-element multiplying and

$$\mathbf{h}^{(k)} = \left[h_1^{(k)}, h_2^{(k)}, \cdots h_j^{(k)}\right]^T \tag{3}$$

are weighting coefficients of the corresponding detail coefficients at level k.

In case of the conventional hard threshold filtering the weighting coefficients are

$$h_j^{(k)}(hard) = \begin{cases} 1, & if \left|D_j^{(k)}\right| > \tau^{(k)} \\ 0, & otherwise \end{cases} \tag{4}$$

while for the soft threshold filtering they are

$$h_j^{(k)}(soft) = \begin{cases} 1 - \dfrac{\tau^{(k)} \operatorname{sgn}\left(D_j^{(k)}\right)}{D_j^{(k)}}, & if \left|D_j^{(k)}\right| > \tau^{(k)} \\ 0, & otherwise \end{cases} \tag{5}$$

where τ (k) is user specified threshold for the k-th level details.

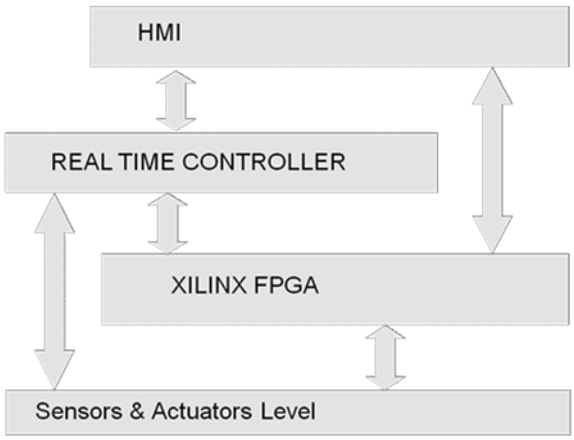

Fig. 2. Blok diagram of applied hardware.

REAL TIME TARGET PLATFORM

Real-Time Module developed by National Instruments allows combining LabVIEW graphical environment and virtual instrument with the power of real time control hardware. Real time measurement application short response time within a determined time period. In the other hand, the non real time measurement does not guarantee precise time localization in the measured signals and events.

Data acquisition systems are based on repeated a measurement, which is performed in a loop. In that case, complete signal measurement has to be finished in a single loop cycle.
This is typically applied in an embedded systems and applications which usually operate without keyboard end/or monitor, and are limited in some resources like physical memory.

Otherwise then Windows based applications which are not deterministic due to pre-emptive characteristic of the operating system, the LabView real time module maintains the highest priority loop to be executed first.

The Timed loop supported by the LabView provides the high priority loops to run on time.

Hardware description

In the measurement performed in this work the National Instrument single board RIO is utilized as a real time controller and personal computer is used as a Human Machine interface to show graphical results. The sigle board RIO is based on Freescale MPC5200 real-time processor and Xilinx Spartan-3 Field Programmable Gate Array (FPGA), analog and digital I/O, and communication ports. The internal block diagram of realized data acquisition system is presented at the Fig. 2.

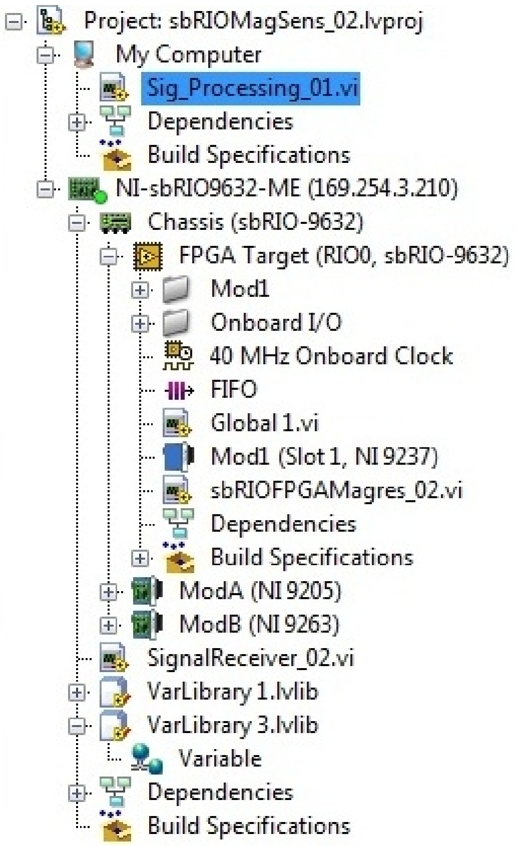

Fig. 3. Real Time Project Structure.

Fig. 4. Magnetoresistive sensor located near electronic watch.

The measurement starts at the bottom level where are located sensors and/or actuators connected via C – series analog or digital input-output modules. Measured data are transferred via FIFO (First In First Out) channel to the real time controller and Human Machine interface.

Software development steps

Programming real time application in the Ni LabView environment supposes starting a FPGA project. This action include FPGA target in the project structure as showed at Fig. 3.

Communication between two or more loops in a target is performed by the shared variables through FIFO (First In Firs Out) channel.

Determinism in the measurement process is performed utilizing FPGA circuit where are the most time critical loops programmed. At the higher level are places real time processing of the signal and human machine interface for processed signal presentation. There is combination of a high priority tasks and lower priority tasks.

Signal processing tasks and feature detection procedure are implemented utilizing graphical programming language and LabView development environment. The program structure is presented at the Fig. 5. Measured data obtained at the bottom level of

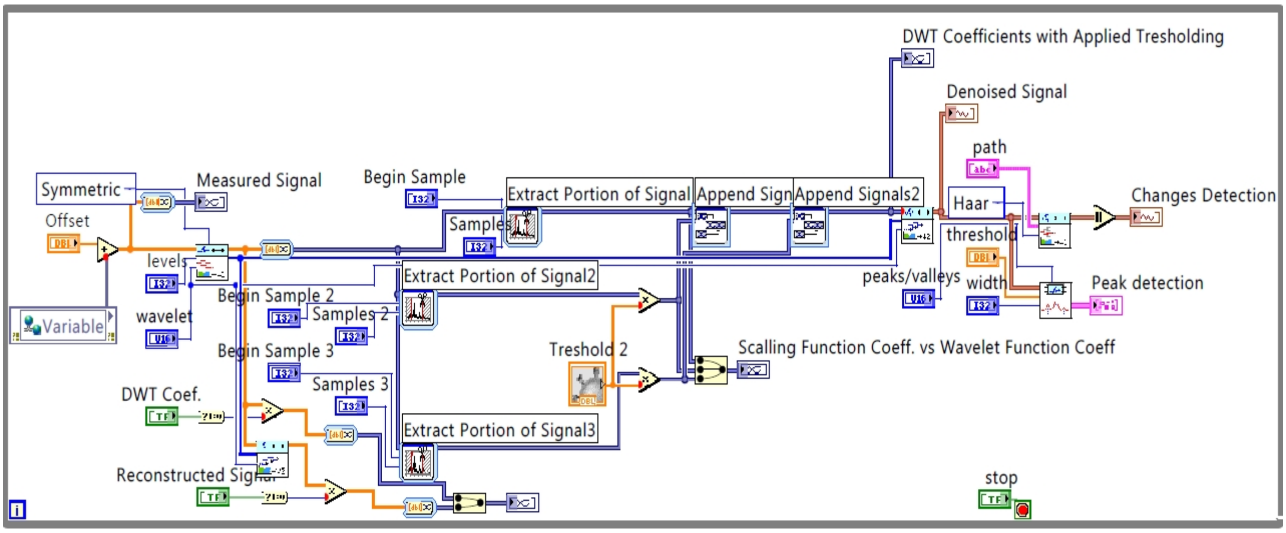

Fig. 5. Signal processing program structure.

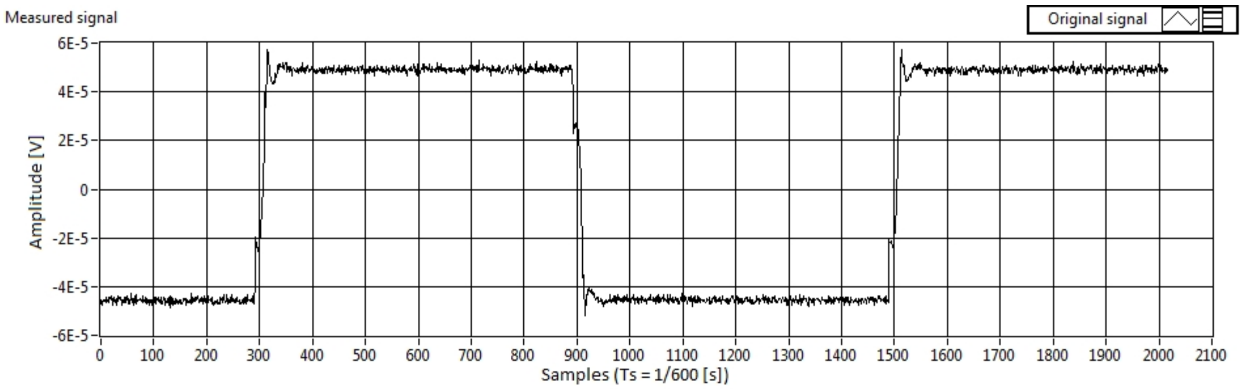

Fig. 6. Measured signal.

measurement hardware structure are sent to the processing loop via shared variable. Processing loop consist of direct discrete wavelet transform, inverse discrete wavelet transform, denoising block and peak and edge detection blocks. Feature enhancement and detection is realized exploiting transforms with different wavelet bases, in this case Haar wavelet and some performed conversion on the coefficients. Resulted signals are delivered to the human machine interface blocks for suitable representation.

EXPERIMENTAL RESULTS

Experiments are performed utilizing the magneto resistive bridge KMZ10B in Ni data acquisition environment. Signal taken by the sensor is obtained measuring magnetic field disturbances caused by electronic watch. Fig. 6 shows the signal obtained by the sensor. Sampling rate applied in this experiment is approximately 600 samples per second and 2048 samples signal length is further processed utilizing discrete wavelet transform.

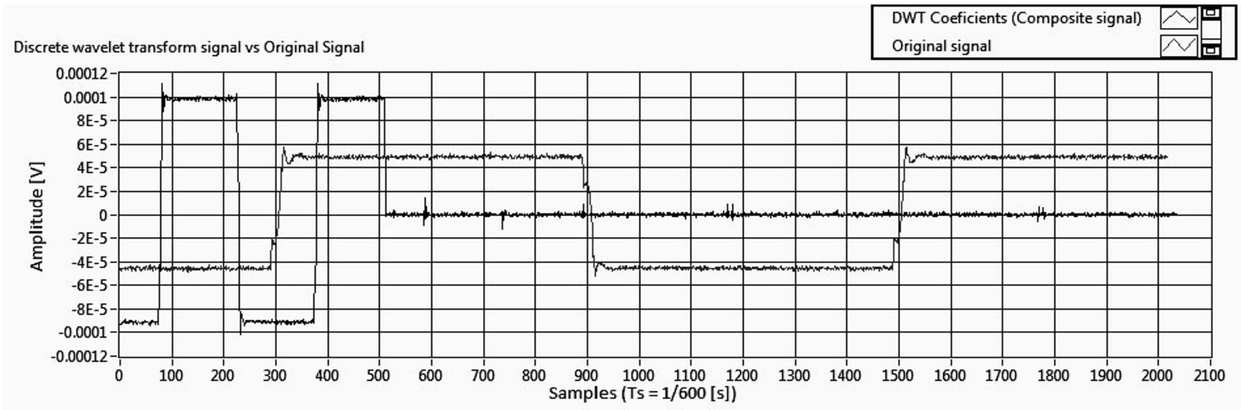

Fig. 7.DWT Coefficients and original signal.

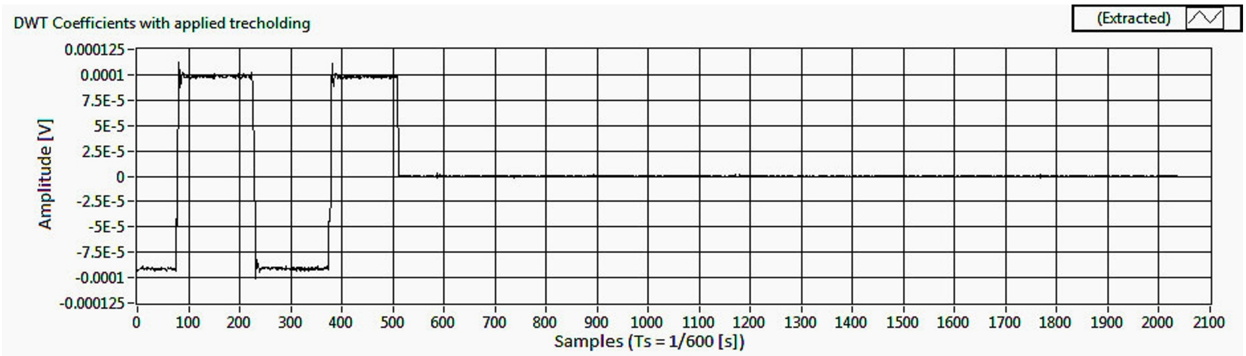

Fig.8.Detail coefficients processing for denoising purposes .

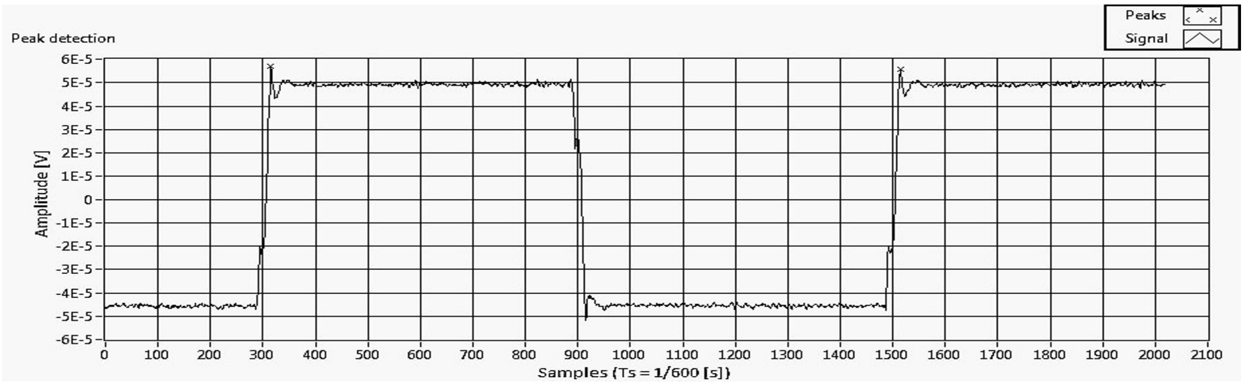

Fig.9.Local peaks detection.

The magnetic field around the magneto-resistive sensor element is too weak and is contaminated with a noise. To extract some features from the measured signal a denoising procedure is applied. Multiresolution based denoising procedure starts with a discrete wavelet transform of the measured signal presented at the Fig. 7. As mentioned in the theoretical introduction wavelet denoising procedure suppose some changes on detail coefficients in the discrete wavelet transform applying threshold value as showed at the Fig. 8.

As mentioned earlier discrete wavelet transform is localized in time and scales which allows extracting some features from the signal. Denoised signal obtained during previous stage of signal processing is further processed detecting the local peak values and edges of the original signal. The results are presented at the Fig. 9 and Fig. 10.

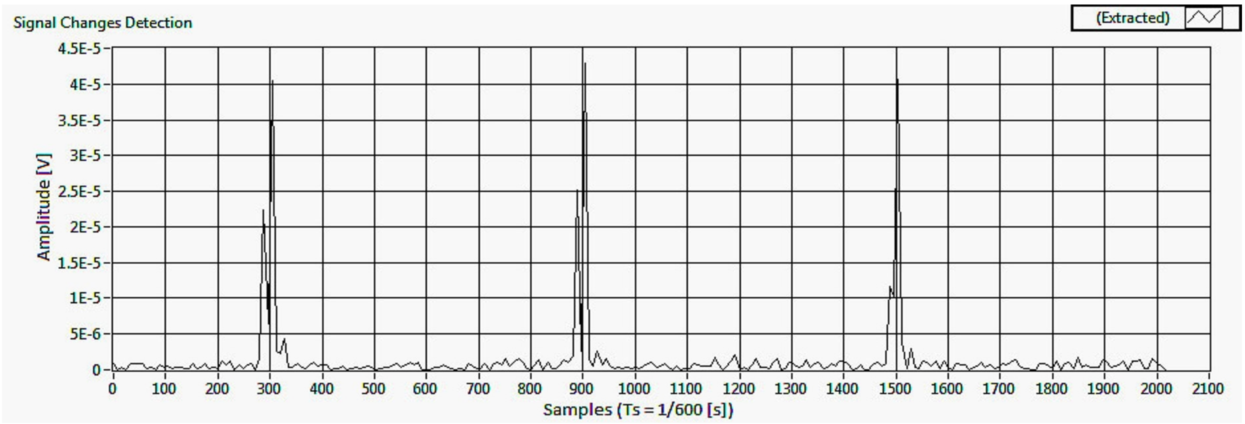

Fig.10.Edge Detection.

CONCLUSION

In this paper, an overview of measuring, analyzing and feature extraction technique in a real time environment is considered. Applying Real Time programming in LabView introduces in the concepts of deterministic design of software for reliable operation and reduction failures due to data loss. Multiresolution analysis is presented as a promising tool for such applications especially in the field of classification and identification.

REFERENCES

[1] A. Jander, C. Smith, R. Schneider, “Magnetoresistive sensors for nondestructive evaluation”, *Proceedings of the SPIE*, Volume 5770, pp. 1-13 (2005) (Invited Paper)

[2] KMZ10B, Magnetic Field Sensor, Philips Semiconductors, Product Specifications, March 1998.

[3] D. A. Istselemov, E. V. Lyubimov, N. A. Belyaev, “A virtual instrument for determining basic parameters of sinusoidal signals in stationary modes”, *Russian Electrical Engineering*, Volume 84, Issue 11, pp 626-629, November 2013.

[4] N.M. Astaf’eva, *Wavelet analysis: basic theory and some applications*. Space Research Institute, Russian Academy of Sciences, Moscow, Russian Federation, vol. 166, no 11, Nov. 1996.

[5] D. L. Donoho, "Wavelet Thresholding and W.V.D.: A 10-minute Tour", *Int. Conf. on Wavelets and Applications*, Toulouse, France, June 1992.

[6] O.V. Lazorenko, S.V. Lazorenko, L.F. Chernogor, “Wavelet Analysis Model Signals With Singularities”, *Radiophysics and Radioastronomy*, 2007, vol. 12, No.3, page 278-294. (Russian Language).

[7] J. Lim, Y. Kim, and J. Paik, Comparative Analysis of Wavelet-Based Scale-Invariant Feature Extraction Using Different Wavelet Bases, *International Journal of Signal Processing, Image Pro-cessing and Pattern Recognition,* Vol. 2, No. 4, December 2009.

[8] M. Vetterli, J. Kovacevic, *Wavelet and Subband Codding*, Originally published in 1995 by Prentice Hall PTR, Englewood Cli□s, New Jersey, Reissued by the authors in 2007.

[9] G. Strang and T. Nguyen, *Wavelets and Filter Banks*. Wellesley-Cambrige Press, 1996.