

Real-Time Wavelet Analysis of a Vibration Signal Based on Arduino-UNO and LabVIEW

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Abstract—This paper deals with on-line (Real-time) multi-resolution signal analysis using wavelet transform by means of graphical programming using LabVIEW. A system for wavelet analysis has been designed based on Arduino-Uno board interfaced to LabVIEW. To achieve the interfacing LIFA has been used. Firstly, the noise from the signal was removed using wavelet transform, and then the de-noised signal analyzed to multi-level frequency bands. A Matlab code to do wavelet analysis was written in a Matlab script node in LabVIEW. To test this system, a vibration signal from robotic arm was captured and analyzed using this system, and the result utilized to establish if there is fault in the robot. The result showed that multi-resolution analysis can be achieved efficiently using this system and can be applied in many applications.

Index Terms—wavelet transform, signal de-noising, Arduino, LabVIEW, fault detection

I. INTRODUCTION

A wavelet is a small localized wave based on a mathematical function. Wavelet analysis is able to represent signals in time and frequency domain at the same time. There are a lot of modern applications have used wavelet analysis as diverse as condition monitoring, signal and image processing. For instance, an intelligent prediction monitoring system based on wavelet decomposition was carried out to estimate the remaining useful lifetime of the cutting tool in high speed machining (HSM) [1]. The vibration, force, and acoustic emission sensors were used in the experimental tests to collect signals from cutting tool. However, wavelet decomposition technique was applied to extract the important information from sensor's signals. Another research study used wavelet multi-resolution analysis (WMRA) coupled with a neural network based approach in order to diagnosis the faults in an industrial robot manipulator [2]. They concluded that the WMRA is excellent for data reduction and capturing the important properties of the signal.

Moreover, the biomedical signals represent the fundamental observations for diagnosing a wide spectrum of diseases. Therefore, wavelet analysis was used efficiently for analyzing body functions. For example, in reference [3] wavelet analysis, based on LabView programming, has been used for noise removing from

ECG signal. And then the important features, which are related to specific diseases, have been extracted. Additionally, two dimension wavelet transform was utilized to increase the resolution of the 3-D medical images [4]. The researchers conclude that wavelet transform can significantly improve the quality of medical images.

Arduino microcontrollers are an open source single-board microcontroller designed to make the electronics projects more accessible. They have been successfully employed in many scientific applications. For example, a low cost acquisition and control system based on Arduino and LabVIEW was designed to control a DC motor [5]. Another interesting application, wireless heart rate monitoring system in sport training has been designed based on Arduino-Nano [6]. However, in addition to open source property of Arduino boards, they have many features, such as low cost, wired and wireless communication can be carried out, and able to run on different platforms [5].

From the reviewed papers, it has been noticed that most of researches when capturing their signals of interest, using Arduino boards or different data acquisition devices, they save these signals in a separate file. And after that, they carry out off-line signal processing on the saved signals to extract usable features from them or to remove their noise [3], [7]. Additionally, as it is known some applications, such as condition monitoring, need continuous feature extraction and decision making system. As a result, in this research a real-time wavelet analysis system of a live signal, captured using Arduino-Uno, has been designed. Also, in this system a wavelet analysis code has written by in incorporating Matlab programming into the LabVIEW graphical programming. To summarize, the main goal of this paper is to use a low cost Arduino board and utilize it as a data acquisition card to carry out real-time wavelet analysis. The proposed system here can be applied for features extraction or in many other applications, such as fault detection.

II. DISCRETE WAVELET TRANSFORMS (DWT)

The idea of discrete wavelet transform is filters of different cut off frequencies are utilized to analyze the signal at different scales. Firstly, the signal passed through a high pass filter to analyze the high frequencies,

and then it is passed through a low pass filter to analyze the low frequencies. However, by using digital techniques like this, a time-scale representation of a digital signal is obtained as shown in the Fig. 1, below.

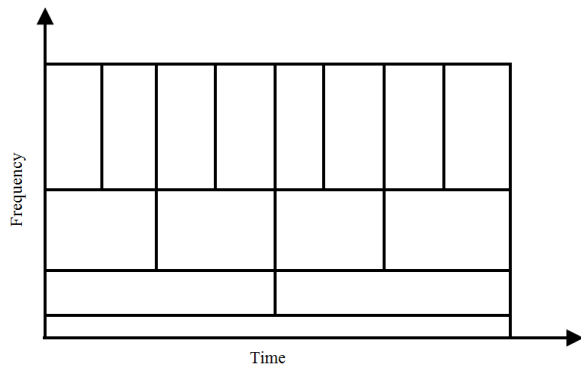


Figure 1. Time-scale representation of a signal.

From the above figure, it can be seen clearly that the wide frequency bandwidth means low frequency resolution. Similarly, long time duration means rough time resolution. Generally speaking, by using DWT a multi-resolution analysis can be performed at different frequency bands with different resolution by decomposing the time domain signal [8], [9]. Two sets of function are employed in DWT called wavelet function and scaling function, which are associated with high pass (HP) filter and low pass (LP) filter, respectively. At the first level, the original signal $x[n]$ is decomposed into an approximation coefficient (A1) and a detail coefficient (D1) by passing it through a high pass filter $g[n]$ and a low pass filter $h[n]$ respectively. This can be expressed mathematically as follows:

$$y_{high}[k] = \sum_n x[n] * g[2k - n] \quad (1)$$

$$y_{low}[k] = \sum_n x[n] * h[2k - n] \quad (2)$$

where $y_{high}[k]$ and $y_{low}[k]$ are the outputs of the high pass and low pass filters, respectively, after down sampling by 2.

The above procedure can be repeated to decompose A1 into another approximation coefficient A2, and another detail coefficient D2. This represents the second level of decomposition as shown in Fig. 2. At every level, the filtering and down sampling will result in half the number of samples (half the time resolution) and half the frequency band (double frequency resolution).

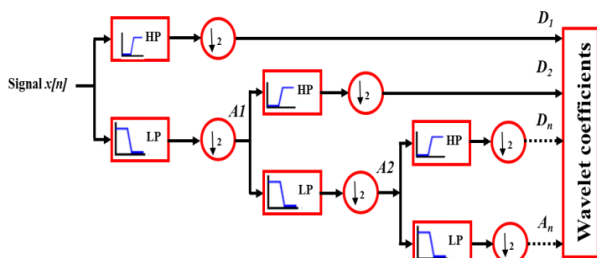


Figure 2. Signal decomposition using discrete wavelet transform

This process continues until a pre-defined certain level. Lastly, by concatenating all coefficients starting from the last level of decomposition, the DWT of the original

signal is then produced, and it will have the same number of coefficients as the original signal.

III. SIGNAL DE-NOISING USING DWT

It is normal when conducting experiments, captured signals will be corrupted with noise. That is either because of environmental influences or because of data acquisition process. Therefore, the de-noising of such signals, which can be described as to remove the noise while retaining and not distorting the quality of processed signal [10], represents the first step in the analyzing process. However, signal de-noising using discrete wavelet transform consist from three steps [11]. The first step is signal decomposition, which transforms the signal to time-scale plane by analyzing it at number of levels (N) by using suitable wavelet family. Wavelet detail coefficients thresholding represent the second step in this process. This step has to be applied to eliminate the small coefficients associated to noise from the wavelet coefficients, which are the result of decomposition step. The elimination of the small coefficient generally employed on the detail coefficients after the decomposition process as it is typically considered that the noise has high frequency coefficients [10].

Commonly, there are two thresholding methods, named, hard and soft thresholding. The hard thresholding process can be achieved by settling the wavelet coefficients whose absolute values below the threshold to zero. However, in soft thresholding the coefficients that have absolute values greater than the threshold are reduced by a quantity equal to the value of the threshold. These can be expressed mathematically in the equations below:

$$D_h (\text{hard threshold}) = \begin{cases} w & \text{if } |w| \geq T \\ 0 & \text{if } |w| < T \end{cases} \quad (3)$$

$$D_s (\text{soft threshold}) = \begin{cases} \text{sgn}(w)(|w| - T) & \text{if } |w| \geq T \\ 0 & \text{if } |w| < T \end{cases} \quad (4)$$

Finally, after the signal is being thresholded, the inverse discrete wavelet transform has to be performed to construct the signal back from shrunken coefficients as explained in Fig. 3.

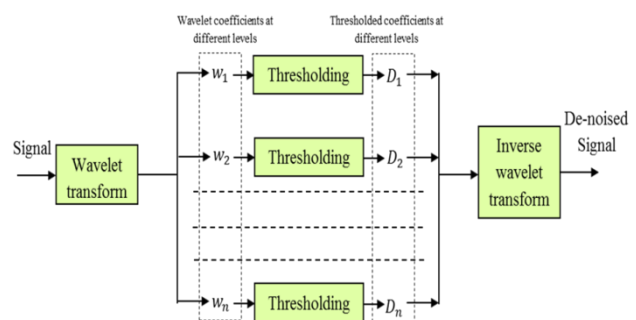


Figure 3. Signal de-noising procedure

IV. INTERFACING ARDUINO-UNO TO LABVIEW

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB

connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. Simply it can be connected to a computer with a USB cable. The Arduino Uno can be powered via the USB connection or with an external power supply or a battery.

Moreover, LabVIEW is a graphical programming language can be used for data acquisition, control and communication. By using LabVIEW, easy interfacing between instrumentation devices and computer can be achieved. The LabVIEW Interface for Arduino (LIFA) toolkit, which comes with its own Arduino code, provides an interface between LabVIEW and an Arduino. However, for Arduino-Uno (or some other boards as Mega 2560 and Dimuelanove w/Atmega 328) to efficiently work with LabVIEW, software called VI Package Manager (VIPM) is needed to be installed. The VIPM permits the users to quickly access to the networked code repositories and get them into the LabVIEW development environment. Therefore, after installing this package the LIFA can be installed. The LabVIEW Interface for Arduino includes open source firmware for Arduino as well as over 100 VIs to access the Arduino functionality from within LabVIEW. However, to get Arduino Uno interfaced to LabView, LIFA code has to be uploaded to the board. For more details and step-by-step setup explanation it is recommended to go to this website <https://decibel.ni.com/content/docs/DOC-15971>.

V. EXPERIMENTAL WORK AND LABVIEW BLOCK DIAGRAM

A. Experimental Work

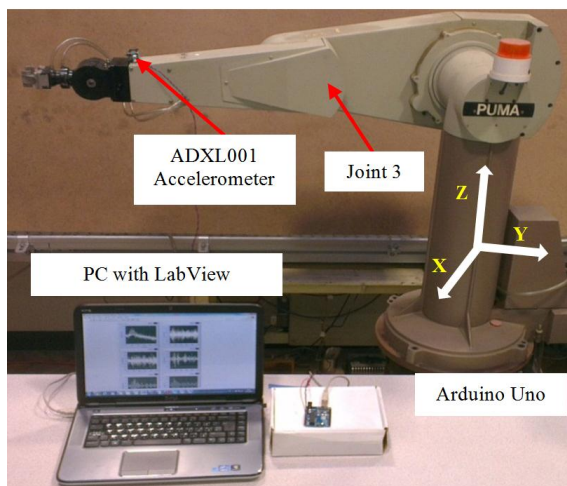


Figure 4. The experimental set up

The experimental work has been performed using PUMA 560, which is a PC controlled serial manipulator with six revolute joints/degree of freedom (DOF) [12]. However, for the purpose of this research, a single axis, analog outputs, 70g, MEMS accelerometers type ADXL001 from Analog Device have been used for signal capturing. The accelerometer was fixed on a robotic arm using specially designed adapter, as shown in Fig. 4. The

arm has been programmed to move in a cyclic motion at low speed, to avoid exciting the high frequencies of the robot. The maximum sampling frequency can be achieved by using LIFA continuous reading mode is up to 5 kHz [13], therefore, it is recommended to consider what needed maximum sampling frequency is before using the prepared code in this paper. Additionally, the accelerometer required to be powered from Arduino-Uno by 5V, and the Arduino Uno has this ability. Also, to read the accelerometer's output signal, its output pin must be connected to one of the board's analog input, and in this experiment it is connected to (A0).

B. LabVIEW Block Diagram

In terms of programming, many functions have been provided by LabVIEW, such as interface with Matlab and C language, made graphical programming in LabVIEW more flexible. Furthermore, Matlab, software developed by American Math Works, has many specialized, efficient, and easy to learn toolboxes, such as wavelet analysis toolbox, which some of its commands were used here. This toolbox offers many options help to accomplish wavelet analysis, as specify the number of decomposition levels and select suitable wavelet family. Also, this toolbox has many functions that can be employed to carry out signal de-noising. Therefore, by using the capabilities of Matlab in data processing and combining them with the advantages of LabVIEW graphical programming, the produced virtual instrument will have more capabilities and flexibility. However, in order to achieve LabVIEW and Matlab interface, LabVIEW offers a Matlab script node to call programme written by Matlab language. In this research a Matlab code to do wavelet analysis was written in a Matlab script node. The LabVIEW block diagram is illustrated in the Fig. 5.

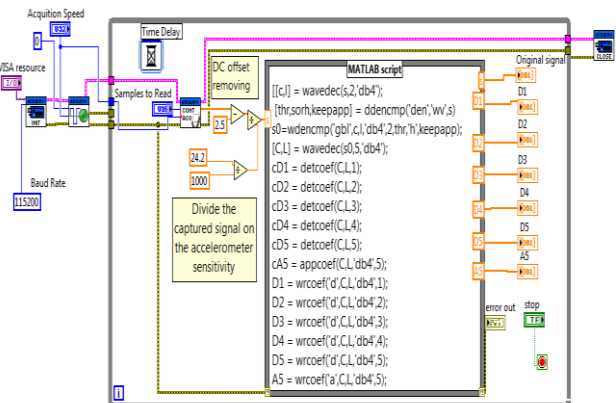


Figure 5. VI block diagram for wavelet analysis

The LabVIEW block diagram begins with while loop first. Then, an Arduino sketch works as an input/output engine, which helps to interface Arduino with LabVIEW, was used. Yet, all the tools required to use Arduino functions with LabVIEW will be available after installing LIFA. By using continuous acquisition VI (from Arduino palette), the Arduino will be continuously read and write analog samples to the serial port at specific sampling

frequency. After the signal being captured, the DC offset, which is 2.5V as specified in the accelerometer's datasheet, has been removed. Numerical control indicators have been utilized to manually set the PC port to be opened, number of samples to read and sampling frequency. To turn the instrument off, a Boolean switch "STOP" was used. Also, to show the error of running a string control was used.

A Matlab code was written in a Matlab node to carry out wavelet analysis. However, many parameters in the code have to be tuned properly for accurate wavelet analysis, such as which wavelet family, number of decomposition levels, and to do that (**wadec**) was used. Also, for signal de-noising the threshold value (**thr**), soft or hard (**sorh**) thresholding, and thresholding the approximation coefficient or leave them (**keepapp**), have to be set; therefore, the (**ddencmp**) command was used. This command provide the default parameters for signal de-noising. After these parameters being adjusted, the signal de-noising can be carried out by this command (**wdencmp**). In this research the Daubechies (**db4**) wavelet has been used, and also the signal was analysed up to five levels. Moreover, for signal de-noising the hard thresholding technique has been applied. However, adjusting the signal de-noising and wavelet analysis parameters depends on the researches requirements and the condition of acquired signal. Because of that, it is advised for researches who want to accomplish noise removing and feature extraction using wavelet to go and read in details the (wavelet toolbox user guide) [11].

VI. RESULTS AND DISCUSSION

The results of multi-resolution signal analysis using previous VI block diagram are shown in Fig. 6. One input and seven output variables have been added to the Matlab node. The input variable is the captured noisy signal (S), and the output variables are the de-noised signal, five constructed signals from the detail coefficients (D1, D2, D3, D4, and D5), and one from approximation coefficients (A5). Firstly, the user has to identify the port that Arduino board has been connected to using VISA control indicator in the front panel. Also, the sampling rate and number of samples have to be chosen correctly. As it is mentioned previously the maximum sampling frequency can be get using LIFA is 5kHz, therefore, this system does not work with applications which need high sampling frequency. The user can also invest the existence of statistic calculations icon in LabVIEW software to extract some important features from the constructed signals, for example, the root mean square, standard deviations, or kurtosis. Moreover, these features can be saved to a measurement files to be used later for signal evaluation and detection.

Furthermore, by looking on Fig. 6, it can be noticed that the noise is successfully removed by using discrete wavelet transform. However, there are very strong relations between wavelet parameters, such as wavelet family, number of decomposition levels and type of thresholding (soft or hard), and level of noise removed. And the same thing is true with multi-level analysis (after

removing the noise) for feature extraction using wavelet transform.

However, in terms of application, the system has been used for purpose of fault detection on the robot. Backlash in the robot's gears has been introduced to simulate a fault in the robot. Moreover, to investigate the effect of backlash on the dynamic behavior of the robot, each joint should be considered separately. In this research, joint 3 (Fig. 3), which is defined as the elbow joint, was chosen to study the backlash detection. The transmission system of joint 3 composed of two stage gearbox. And to introduce backlash in joint 3, there are number of screws should be rotated to adjust the pitch between the gears pairs. After adjusting the backlash, the robot was programmed to oscillate over a range of ± 10 from the vertical position. In the first instant, the robot was tested when backlash level fine-tuned to be as minimum as possible (healthy robot), and then increased to simulate the fault condition on the robot. After capturing and analyzing the vibration signals using wavelet transform, features, such as kurtosis, which is used as an indication about the severity of vibration, have been computed from the constructed signals. These features are saved to a measurement files to be used for robot evaluation and detection.

From analyzing the results of kurtosis of the constructed signals (D1, D2, ..., D5) have been established that the backlash (fault) cannot be recognized easily from all levels of signal analysis. However, very significant difference can be noticed between the kurtosis values of the healthy and faulty robots in the level 5 details (D5) as demonstrated in Fig. 7. This can be related to the amount of backlash, which has been introduced, as it excites some modes of vibration within level 5 frequency ranges as.

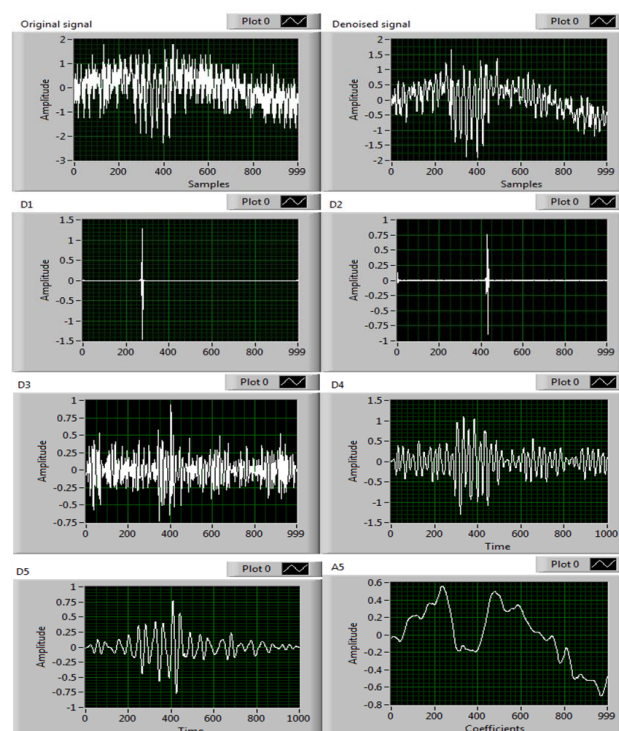


Figure 6. The output of VI block diagram

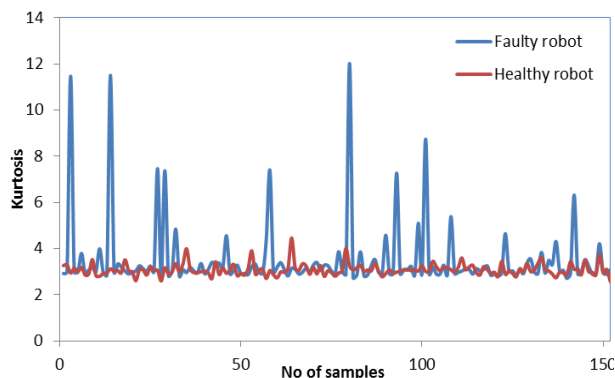


Figure 7. Kurtosis values for healthy and faulty robot calculated from level 5 details (D5)

VII. CONCLUSION

Wavelet analysis represents an efficient time-frequency analysis method. By using wavelet analysis, noise from the signals can be removed, the original signal can be restored, and therefore the signal-to-noise ratio will be improved. Also, by applying wavelet analysis, the signal can be analyzed to its sub-bands frequencies. In this paper real-time wavelet analysis system has been designed. To get a cost effective data acquisition system, Arduino-UNO board was efficiently interfaced to LabVIEW after installing LabVIEW Interface for Arduino toolkit. Hybrid programming, by combining LabVIEW graphical programming with Matlab textual programming, has showed to be an effective method to build intelligent signal monitoring and feature extraction. Also, this system showed acceptable performance when it is applied for industrial robot fault detection. Moreover, this system can be used for many other applications, such as noise removing, biomedical signals analysis or can be modified to be applied for many control applications.

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