Wavelet Transform Based Error Detection in Signal Acquired from Artillery Unit

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Abstract— **In real time environment, noise often embeds with the signal during data acquisition process. Error detection will be difficult task when signals are corrupted with noise. Therefore, noise removal is the first step towards the detection of error in signal acquired from artillery unit. In this work, wavelet based signal enhancement technique is proposed to remove the noise from acquired signal. Doubechies wavelet with order 1 is used to decompose the signal up to four levels. Empirically chosen thresholds are applied in each detail coefficient and the denoised signal is reconstructed using the approximation coefficient and thresholded detail coefficients. To detect the error, Doubechies wavelet with order 6 is applied to decompose the enhanced signal up to four-level. Each detail coefficient represents the distortion if original signal is erroneous. The proposed method is tested by means of signal to noise ratio, average power and spectrogram analysis. Experimental results show that the performance of the proposed method is consistently well at different SNR both off line testing and online testing, and also able to detect the error properly.**

Keywords: **Data acquisition, Power spectral density, Short time Fourier transforms, Wavelet analysis.**

I. INTRODUCTION

Almost all signals required for the artillery unit to be operated are regular signals. They are all square wave voltage signals and each one having a specific period or frequency with specific amplitude. So any unwanted voltage signal comparable to the voltage level of original signal will be considered as error. As a result there will be a significant change in the regular frequency in the original signal.

To detect the above types of error, several traditional signal processing methods can be followed. In this scenario at first, the common signal processing method, FFT (Fast Fourier Transform) comes into picture. But in real time environment several high frequency noise components are present, although not so significant. In this paper the interested type of signal is a square wave signal, which has infinite range of frequency in the frequency domain. Although the contribution of higher order frequency is less, still they can’t be ignored completely. Considering into above cases it will be a difficult task to implement fast Fourier transform as an error detection technique. After all the signal is not a stationary signal. So it is essential to find other signal processing tools for error detection. For non stationary signals, conventional Time-Frequency methods like, Wavelet transform (WT) method ant Short time Fourier Transform (STFT) method will be suitable choice. But for square wave signal the transient will arise very frequently due to the error in the signal, noise and the signal itself. Hence STFT method will not be a suitable choice here.

In this case, WT will be a better choice. WT provides multiple resolutions in frequency and time and hence becomes much efficient to analyze the transient behavior of signal. So the application of STFT and the Power Spectral Density (PSD) method to the transformed signal will be a better approach for online error detection.

The organization of the paper is described as follows: Section II explained about theoretical background. Section III describes about the proposed method applied to the signal. Sections IV demonstrate the experimental setup. Section V shows the results and discussion which is followed Section VI that concludes about the error detection of acquired signal using proposed method.

II. THERIOTICAL BACKGROUND

As described in the Section I, Wavelet Analysis will be a better method for signal enhancement as well as error detection of acquired signal.

A. DESCRETE WAVELET TRANSFORM (DWT)

The wavelet transform is a recently developed mathematical tool that provides a non- uniform division of Data or signal, into different frequency components, and then studies each component with a resolution matched to its scale [10]. So Wavelet analysis is an approach which decomposes a time domain signal into components in different time windows and different frequency bands and presents the resulting information in the form of a surface in the time-frequency plane.

Wavelet transform decomposes a signal into a set of basis function. These basis functions are called wavelets.

Wavelets are obtained from a single prototype m(t) called mother wavelet, by dilation and shifting[12].

So if a mother wavelet function is defined such that,

$$\Psi(t) \in L^2(R) \tag{1}$$

Then the mother wavelet can form a basis set denoted by:

$$\psi_{s,u}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right) \tag{2}$$

Where u is the translating parameter and s is the scaling parameter. S is always greater than zero because, negative scaling is undefined. Now the continuous wavelet transform can be defined in terms of mother wavelet as given below.

$$Wf(s,u) = \int_{-\infty}^{\infty} f(t)\psi_{s,u}^{*}(t)dt \tag{3}$$

$$= \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{s}}\psi^{*}(\frac{t-u}{s})dt \tag{4}$$

In the same way the inverse wavelet transform can be defined as:

$$f(t) = \frac{1}{C_{\psi}}\int_{0}^{\infty}\int_{-\infty}^{\infty} Wf(s,u)\frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)du\frac{ds}{s^2} \tag{5}$$

Where C_{ψ} is defined as:

$$C_{\psi} = \int_{0}^{\infty}\frac{|\psi(\omega)|^2}{\omega}dw < \infty \tag{6}$$

Here $\psi(\omega)$ is the Fourier transform of mother wavelet $\psi(t)$. The Fourier transform of a signal S (t) will be defined as:

$$S(f) = \int_{-\infty}^{\infty} S(t)e^{-j2\pi ft}dt \tag{7}$$

So the Fourier transform is based on harmonic wave, where as the Wavelet transform is based on the mother wavelet. However the Fourier transform can only be defined for stationary signal, where the frequency will not vary with time.

The coverage of frequency band for a three level decomposition process is shown in figure1. The frequency response of the filters of higher order mother wavelets are more ideal. Hence the overlapping of frequency bands of higher order Wavelet is less as compared to lower order. To obtain wavelet decomposition process a dyadic analysis filter bank is to be constructed, that decomposes a broadband signal into a collection of successively more band limited components.

A 2-level filter bank structure is shown in figure.2. At each level, the low-frequency output of the previous level is decomposed into adjacent high- and low-frequency sub bands by a high pass (HP) and low pass (LP) filter pair. Each of the two output sub bands is half the bandwidth of the input to that level. The band limited output of each filter is maximally decimated by a factor of 2 to preserve the bit rate of the original signal.

B. SHORT TIME FOURIER TRANSFORM

Fourier transform cannot provide any information regarding temporal localization of frequency components. Hence to overcome from this problem STFT tries to solve it by introducing a sliding window, and hence in each slide, it emphasizes the signal at that time and suppresses the signal at other time. The window is designed to extract a small portion of the signal, which will be converted to frequency domain by taking the Fourier transform.

The STFT of a signal f(t) can be found out as:

$$Sf(u,\xi) = \int_{-\infty}^{\infty} f(t)w(t-u)e^{-j\xi t}dt \tag{8}$$

Where, w(t-u) is the sliding window.
The energy density spectrum at time will be:

$$P(t,\xi) = |Sf(u,\xi)|^2 = \left|\int_{-\infty}^{\infty} f(t)w(t-u)e^{-j\xi t}dt\right|^2 \tag{9}$$

Hence the energy density of STFT represents the spectrogram of function, which is generally represented in color plots. *C.*

AVERAGE POWER

The square wave signal discussed here is continuous in time but produces discrete power spectrum. The waveform to be analyzed is a case of power signal that has infinite energy, but finite average power. To average power can be calculated by integrating the power spectral density curve (PSD). The PSD signifies the power per frequency in DB/HZ. So ultimately the area under PSD curve is the measure of the average power.

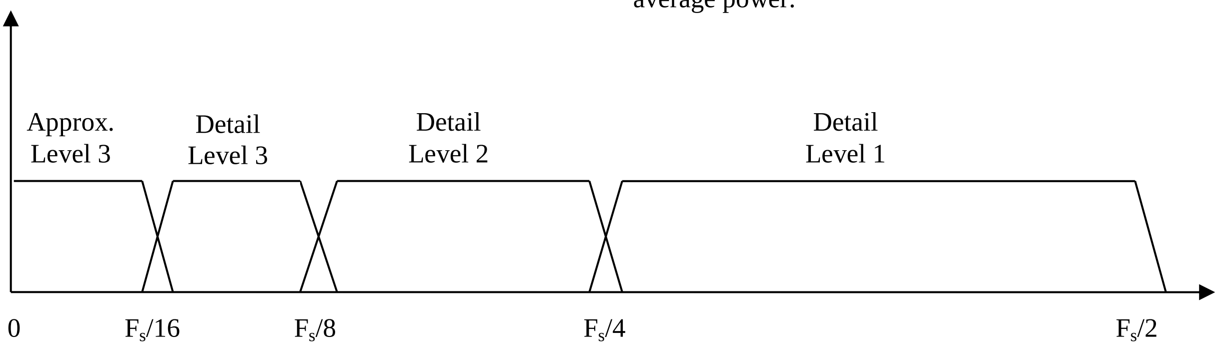

Fig.1: Frequency range coverage of detail and approximate level approximation

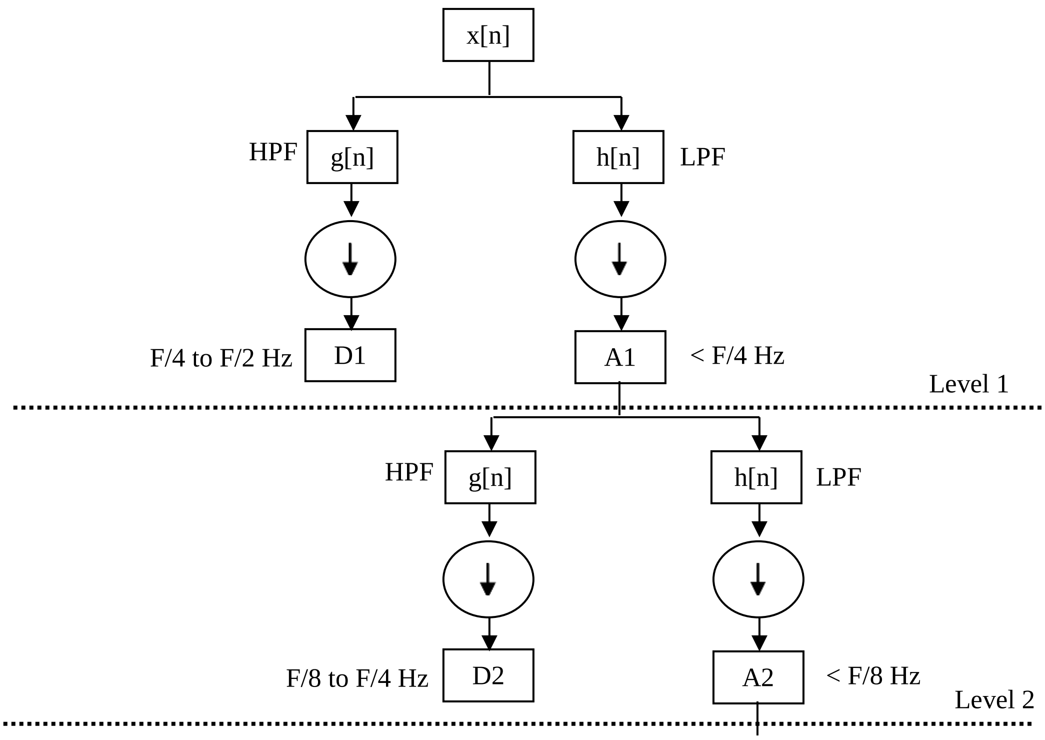

Fig.2 Wavelet analysis filter bank of DWT decomposition

III. PROPOSED METHOD

The signal that was acquired got embedded with the noise during data acquisition process. The sources of error were due to the mechanical vibration of the equipments during firing. As a result some transient noise with spikes got embedded with the acquired signal. These noises were removed before the error detection process.

A. DENOISING OF THE ACQUIRED SIGNAL

As described in the section I, wavelet based decomposition method was applied to remove the noise present in the signal. The signals which were acquired which includes both correct and erroneous signal were decomposed into four levels using db1 as the mother wavelet. Although the frequency response of low pass and high pass filters of lower order wavelet (db1) is least ideal, still it is chosen as mother wavelet for this experiment. The reason is that, in this experiment square wave signals were used as test signals which contains infinite range of frequency in the frequency domain. So we don't require any clear separation of frequency bands of signal to remove the noise. In addition to that db1 shows better results in terms of reproduction of corners and edges. Hence as described in the section II db1 will be a better choice for de noising of square wave signals.

Each level of the decomposed signal was threshold using a limiter. The depth of threshold limit at each level depends upon the amount of noise present at that level. Generally larger threshold limit is applied at higher order frequency band where the signal strength is less and noise strength is high. After threshold at each level, the signal is reconstructed back using wavelet reconstruct method.

B. ERROR DETECTION OF DE NOISED SIGNAL

The de noised signal which includes both error signal and correct signal were further wavelet decomposed for error analysis. This time db4 is used s mother wavelet and six decomposition level. The higher order detail levels were analyzed and compared for both error and correct signal. For a quick response about the presence of error, spectrograms of highest decomposition level of both signals were taken where the presence of error was found to be more pronounced. Further analysis was done by estimating the average power of each level of both of the signals and by making a comparison between corresponding levels and hence calculating the fault factor. The proposed method for de noising and error detection process is shown as block diagram in the Fig.3.

IV. EXPERIMENTAL SETUP

A multichannel data acquisition system was designed to [1-3] acquires the data in real time. In this experiment we required a data acquisition card [4-5] housed with a wooden frame for safety purpose, a set of co axial cable terminated with banana clips in both end to prevent interference among channels and a personal computer loaded with application software. In this experiment, a USB based data acquisition card was used. LABVIEW was used as application software

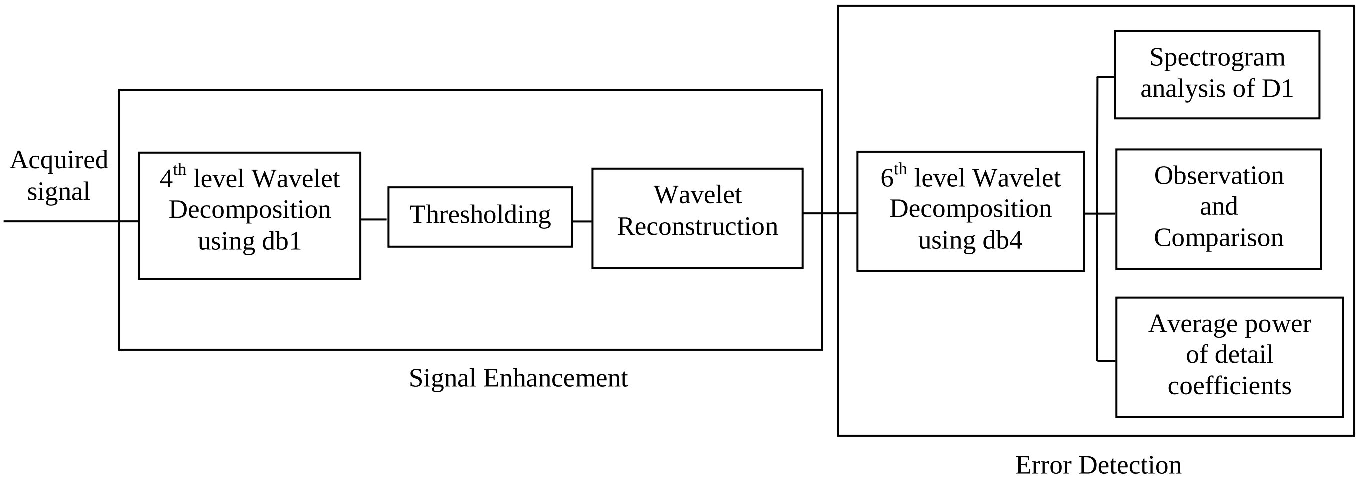

Fig.3: Block diagram of proposed method

for a continuous data acquisition process [6-8]. DAQ Assistant was used as primary module which configures multiple voltage channels [8]. The experimental setup is shown in the figure 4.

Some essential parameters are to be considered during the data acquisition process. The important parameters would be sampling rate, number of samples, and voltage level. The range of parameters used for this experiment are:

Frequency range of acquired signal: 2-5 Hz.

Number of samples: 15 K samples/sec

Sampling rate: 1 kHz

Selection of voltage range depends upon individual channel signal amplitude with an overall range of 100 mV – 10V.

The signal that was captured was full of noise. The primary sources of noise are due to continuous vibration of mechanical equipments during firing, improper grounding,

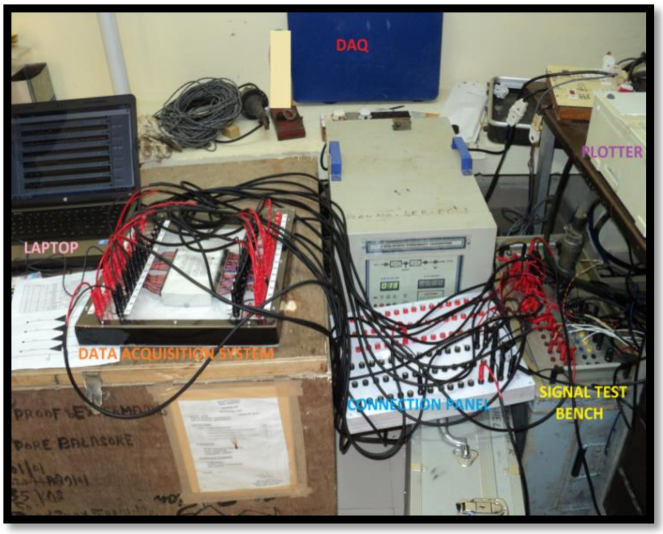

Fig.4: Experimental setup with Data acquisition card

and lose connection which becomes more looser after heavy vibration. A Sample of correct data and erroneous data being corrupted with noise are given in the figure.5.

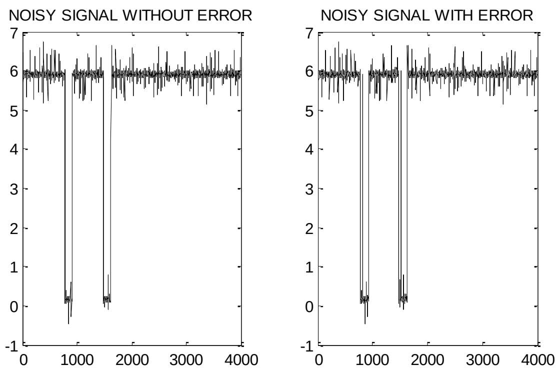

Fig.5: Captured signal with and without error

Various methods were applied to the acquired signal for error detection. But as shown in the figure 5, the presence of excessive noise bearing higher order frequency component dominant the presence of error. As the error is also having the higher order frequency component, it is difficult to detect it in the noisy environment. Hence it becomes essential to enhance the signal before detecting the error.

V. RESULTS AND DISCUSSION

A. SIGNAL ENHANCEMENT

In the real time system we don't have the signal void of noise. Hence we cannot compare the accuracy of noisy or de noised signal with the original signal. So before applying any signal enhancement method to the noisy signal, we need to evaluate the performance of the applied method using a model with a similar type of signal.

In the model, a signal is simulated similar to the signal that we have acquired through data acquisition process. Then the signal is added with white Gaussian noise of 5db 10db and 15db each time. Then this noisy signal is enhanced using wavelet transform method and the performance was evaluated.

TABLE1: PERFORMANCE EVALUATION OF WT METHOD FOR DE NOISING THE SIGNAL

INPUT SNR (db)	O/P SNR USING WT (db)
14.8399	17.3973
9.9778	14.3149
5.4064	10.9017

From the result obtained in Table1, it can be concluded that, the Wavelet transform method will be good approach towards de noising the acquired signal without any loss of information. In this method Wavelet transform was applied and decomposed the signal into five levels. Then the signal was reconstructed back after thresholding each level.

Now the acquired signal was de noised using the above described method, and the result is shown in the figure.6.

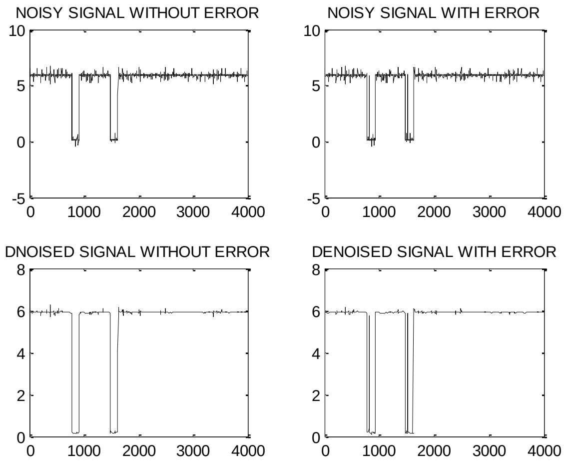

Fig.6: Resultant signal after de noising

B. ERROR DETECTION

For error detection in the de noised signal, Wavelet transform is applied over it to decompose it into different frequency level. In this experiment the frequency of the square wave signal varies from 2-5 Hz. Although the theoretical bandwidth of the square wave signal is infinite, the practical bandwidth will be same as 2-5 Hz. The signal is sampled at 1K Hz. during data acquisition process. The signal is decomposed into five detail level by wavelet transform method. In this experiment, db1 is used as mother wavelet. The coverage of frequency band for each level is given in Table.2.

TABLE.2: FREQUENCY COVERAGE FOR EACH LEVEL

Decomposition Level	Frequency Range (Hz)
Detail level 1	250 – 500
Detail level 2	125 – 250
Detail level 3	62.5 – 125
Detail level 4	31.25 – 62.5

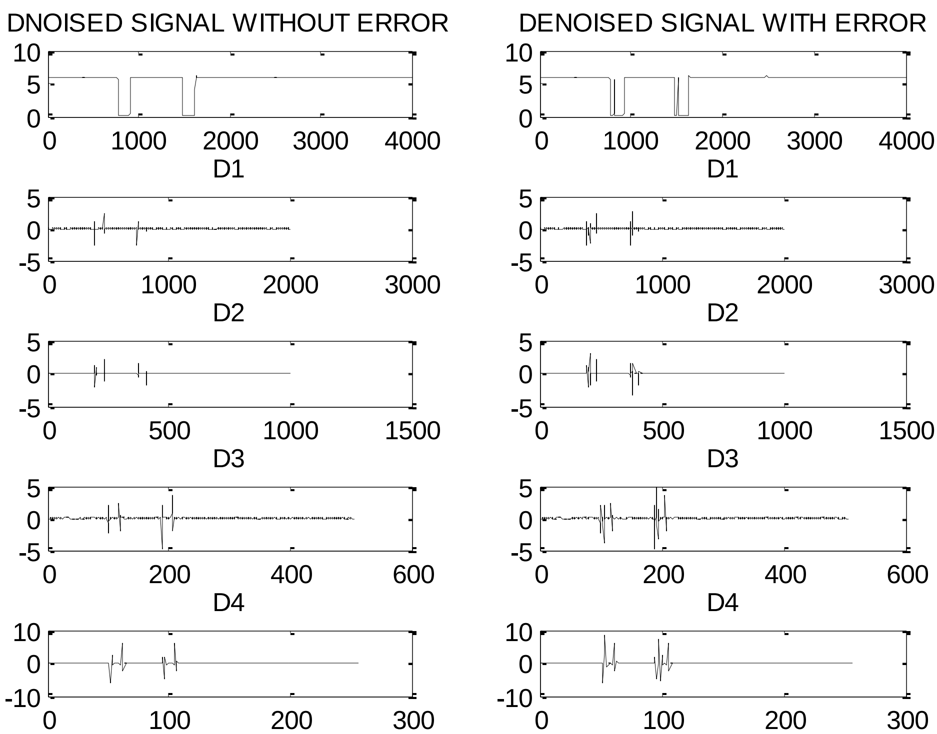

Fig.7: Detail levels of correct and erroneous de noised signal

The result of wavelet transform for both correct signal and erroneous signal are shown in the figure.7 using db4 as mother wavelet. The presences of extra spikes are clearly visible in the detail level D1 through D4 in the erroneous signal which confirms the presence of error. The presence of error will be more pronounced if the spectrogram analysis of detail level will be taken which is shown as figure.8.

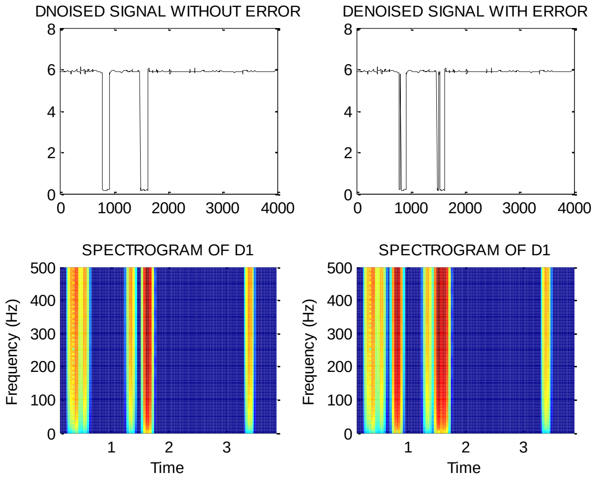

Fig.8: Spectrogram analysis of detail level 1

The spectrogram of detail level1 is taken after decomposing the signal using db1 as the mother wavelet. The difference is now clearly visible. Now the presence of error can be detected more instantly.

This process can be further preceded by taking the average power [9] of the detail level of both the signal and comparing the result, which is given in table.3. the average power is calculated by taking the area under power spectral density curve.

From the table it is clear that due to the presence of error, bearing higher order frequency content, the energy content of detail level D1 through D5 are comparatively higher for erroneous signal. Hence any significant change in the detail level energy content will indicate the onset of error.

TABLE.3: AVERAGE POWER OF DETAIL LEVEL OF EACH SIGNAL

Signal	D1	D2	D3	D4	D5	D6	D6
Without error	.003	.069	.067	1.47	1.96	12.14	12.1
With Error	.016	.109	.178	2.6	2.04	11.24	11.2

VII. CONCLUSION

This paper proposes an error detection process of signals that are acquired from artillery unit. The proposed method consists of two sequential techniques. First, the acquired signals are enhanced using wavelet based technique and followed by detection of error of enhanced signal based on wavelet transform technique. The Daubechies wavelet with order 1 is used here for denoising the acquired signal where as for detection of error in signal, Daubechies wavelet with order 4 is applied. Experiment is conducted on three different noise levels i.e. 5dB, 10dB and 15dB. In each case, the proposed signal enhancement shows efficient performance without losing the information. The proposed error detection method is evaluated using spectrogram analysis and shows the high performance for instant error detection in distorted signal. In addition to that, calculation of average power of each detail level provides a measure of effectiveness of error detection technique. Therefore, in real time environment, the proposed technique could be used as a powerful tool for error detection in acquired signal.

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