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A Novel Approach of Wavelet Packet Transform for Knock Signal Analysis

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Abstract: The computation complexity dominates Continuous Wavelet Transform (CWT) and the low frequency resolution limit the Discrete Wavelet Transform (DWT). The degradation in frequency resolution in Discrete Wavelet Transform (DWT) is due to the fact, that, DWT decomposes only the approximation coefficients at each level. This detail is not enough to analyse the signal like knock in the engine. The acceleration sensor or knock sensor receives the signal from various part of the engine (i.e. the signal from various sensors will super impose) and a specific technique to analyses this signal is in need. The idea of decomposing both approximation coefficients and detail coefficients is achieved by Wavelet Packet Transform. This paper proposes a novel approach of analysing the knock signal by Wavelet Packet Transform. The signals are captured from the engine running at various RPM (Revolution Per Minute) (i.e. 1000, 2000, 3000, 4000 and 5000). The signals are sampled at a rate of 150, 200, 250, 300 and 350 per clock cycle. The samples are aggregated for a period of 10,000 clock cycles and analysed using the Wavelet Packet Transform in Matlab 2014. The results are promising in terms of error rate, when compared with the conventional Fourier and Wavelet Transform.

Key words: Continuous Wavelet Transform (CWT) · Discrete Wavelet Transform (DWT) · Wavelet Packet Transform · Fourier Transform.

INTRODUCTION

The process of manufacturing and production of motor depends on several factors such as low fuel consumption, high efficiency and quality along with safety. This normal factor is affected mechanical, electrical and thermal system of the engine. The spark ignition engine knock [1] is experienced as an outcome of end gas spontaneous ignition in the cylinder. The pressure wave is formed by an increase in pressure, which is the result of releasing energy rapidly. This pressure wave is forwarded to the engine, which ends up in knock and vibration. The engine destruction is overcome by protecting the engine wall and the piston by embedded system. The detection of knock signal has several advantages such as, increase stability of combustion and efficiency of the engine also reduces the pollution. In modern days, the engine is designed with high efficiency also with pollution constraints. In addition, the fuel consumption of the designed engine should be low and have the ability to classify the signal from various sensors.

Initially the fault in the engine is detected by signal processing, analytical method and fault-diagnosis method. The research interest degrades as the above said methods are dealing with the engine at static condition. Later, the research of interest has changed to the fault detection of dynamic engine. The Fourier Transform is used to classify the knock signal [2] in earlier stages and the detected knock signal is verified with threshold value for amplitude and energy. The Fourier Transform analysis of the knock signal shows high efficiency, only when the engine runs at low speed. As the speed of the engine increases, there is degradation in the efficiency of the Fourier Transform. Throughout the combustion cycle, the speed and chamber volume vary resulting in the unsteady knock signal [3]. In [4], the author has investigated the need for time-frequency analysis of knock signal. The engine knock detection using wavelet transform is shown in [5]. The results are promising, compared to the conventional transform, since the wavelet provides the time-frequency analysis. In similar, the wavelet classification of knock signal in engine is proposed in [6].

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The wavelet transform for knock detection and fuzzy scheme for knock intensity detection is evaluated in [7]. In [8], the engine knock is detected by Self Organizing Maps (SOM) along with wavelet. The researchers prefer Discrete Wavelet Transform (DWT), since the computational complexity of Continuous Wavelet Transform is high. In this paper, Wavelet Packet is used to analyse the knock signal, since the frequency resolution of Discrete Wavelet Transform (DWT) is low [9].

MATERIALS AND METHODS

In combustion engine, the knock signal can be detected by two methods. Electronic Control Unit (ECU), the phenomenon of the knock signal algorithm is implemented. As mentioned in the section 1, the pressure wave is the vital cause for knock in the engine. This pressure is accompanied by frequent oscillation and the pressure sensor is used to detect the knock. The knock signal is experienced, outside of the engine block, if the wall of the combustion chamber is affected by a pressure wave. The knock sensor also called as acceleration sensor is used to detect the knock signal outside of the engine block. The performance and quality of the knock signal detected by the pressure sensor is high and at the same time, the cost of sensor is high. The pressure sensor is replaced by the knock sensor as an alternative to detect the knock signal. The limitation of acceleration sensor is that, the signals from various part of the engine also detected and act as noise for knock signal. The proposed system of Wavelet Packet recognition has a high frequency resolution [9], which can classify the knock signal from various super imposed engine signals.

Wavelet Analysis of Knock Signal: Wavelet analysis [10-11] is a modern signal processing techniques, where the application varies from feature extraction, separation of signal noise and filtering of signal. The wavelet transform, provides a time-frequency analysis, where the result has time domain location at various frequencies. The time domain representation of the signal has more information and frequency domain has good filter characteristics. The principle of the wavelet transform is shown in Figure 1. The signal is divided into Detail coefficients (D) and approximate coefficients (A) in the first level of decomposition. To obtain the frequency resolution, the level of decomposition is increased. The self-ignition of unused mixture in the combustion chamber leads to the knocking in the engine.

This occurs before the, intended ignition reaches the chamber. The pressure increases dramatically due to the wave hitting the chamber after the shock. This dramatic increase in the pressure wave leads to familiar noise also called as knock. The knock signal can be detected by other sensors, apart from the methods listed in section 2. The ionization current, which leads to knock in the engine, can be detected by the sensor and also the mixture (air/fuel) present in the combustion chamber can be monitored by optical devices. The knock signal analysis in the time-frequency domain is more accurate, compared to time and frequency domain analysis separately. The propagation speed and geometry of the cylinder dominate the resonant frequency, which is basically found between 3 KHz and 10 KHz.

The detection of knock signal is dominated by the filtering method, since the noise (i.e. signal from various engine parts) should be removed from the signal from pressure sensor or knock sensor. The wavelet analysis can be applied to the non-stationary signal; fortunately, the knock signal is one among them. The analysis reveals the shape of the signal, the shape here is the detailed information of the signal. Let 100 KHz be the sampling frequency of the signal, as mentioned earlier, the knock signal is available between 3KHz and 10 KHz, the frequency is cut down to 50 KHz for wavelet analysis. The decomposition of 50 KHz signal by wavelet transform is shown in Figure 2. The wavelet toolbox from Matlab 2013 is used to analyze the signal from the pressure and knock sensor.

Implementation of the Wavelet Packet to Analyse the Knock Signal: As mentioned earlier, the wavelet transform decompose approximation coefficients of the signal at each level. The decomposition of approximation coefficients leads to the degradation of the frequency resolution [9].

The novel method of decomposing the signal of both approximation and detailed coefficients is applied through Wavelet Packet Transform as shown in Figure 3. The shearlet methodology function declares at different scales and locations and according to different orthogonal transformations controlled by shearing matrices. For 3D (dimension D = 3), a shearlet system is acquired by suitably combining three systems of functions associated with the pyramidal regions in which the Fourier space R ^^3is partitioned, shown in Figure 2. To evaluate and compare the results of proposed Wavelet Packet Transform, the same 100 KHz signal is taken as in Wavelet Transform. The signal is terminated to 50 KHZ, as the knock signal lies between 3-10 KHz. To extend the

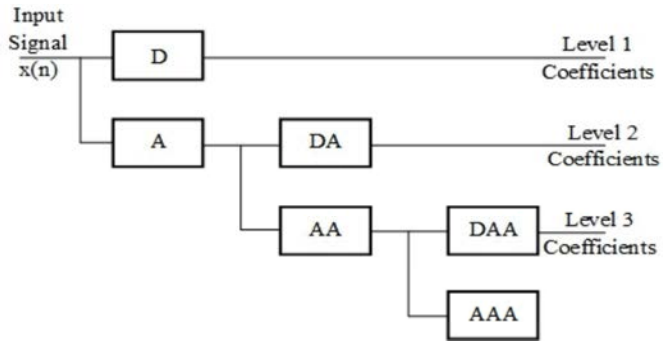

Fig. 1: Wavelet Transform

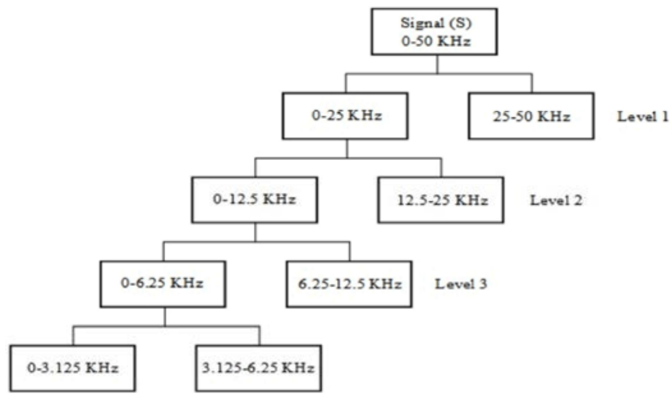

Fig. 2: Decomposition of 50KHz signal by Wavelet Transform

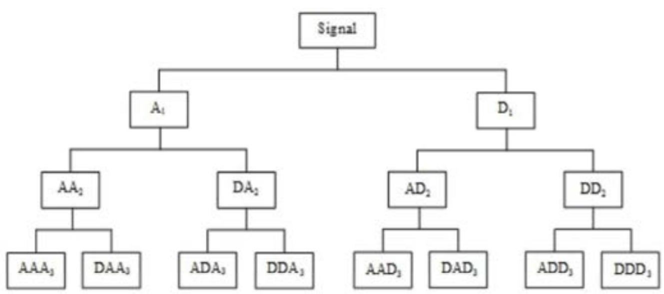

Fig. 3: Wavelet Packet Transform

Fig. 4: Decomposition of 50KHz signal by Wavelet Packet Transform

analysis, the signal data are extracted from the engine running at various RPM (Revolution per Minute) such as 1000, 2000, 3000, 4000 and 5000. In each case (i.e. various RPM), the samples are collected at various rates, such as 150, 200, 250,300 and 350 per clock cycles. The samples are aggregated for a total of 10,000 clock cycles. The decomposition of 50 KHz signal by Wavelet Packet Transform is shown in Figure 4. The decomposed value in each level shows the increase in the frequency resolution of the signal. The detailed evaluation of the signal based on clock cycle, RPM, sampling rate is discussed in the next section.

RESULT

The Wavelet Packet Transformation is applied to the signal from the knock sensor is analysed using Matlab 2014. As the wavelet transform, decompose only the approximation coefficients, leading to the degradation in frequency resolution. The knock sensor is fixed to receive the signal from the engine running at various RPM (Revolution per Minute) such as 1000, 2000, 3000, 4000 and 5000. To complicate the evaluation based on Wavelet Packet Transform, the sampling rate per clock varies from 150, 200, 250, 300 and 350. The samples are collected for the total of 10,000 clock cycles. The error rate in percentage (%) for the signal captured from an engine running at 1000 RPM is shown in Table 1. The error rate is calculated for various samples and compared with the error rate of both Wavelet Transform and the Fourier Transform. The Wavelet Transform outperforms the Fourier Transform in terms of error rate and result degradation is observed when compared with Wavelet Packet Transform.

The error rate of the signal captured from the engine running at 2000 and 3000 RPM is shown in Table 2 and Table 3 respectively. The results in entire cases reveal that, the high error rate is achieved at the sample rate of 250. For examples in Table 3, the error rate achieved by Fourier Transform, Wavelet Transform and Wavelet Packet Transform are 79.14%, 79.94% and 81.85% respectively. These error rates are high when compared to the error rate achieved at a sample rate of 150, 200, 300 and 350. In similar, the error rate of the signal captured from the engine running at 4000 and 5000 RPM is shown in Table 4 and Table 5 respectively. In this case also the results conclude that the stable sample rate for the knock signal detection is 250, where the RPM of the engine is not a consideration.

For illustration, the results in the Table 5, has 78.17%, 79.60% and 81.85% for various transform as mentioned earlier at the sampling rate of 250. In the same case, the error rate for the sample rate of 300 is 77.42%, 78.35% and 80.09% for the Fourier Transform, Wavelet Transform and 8Wavelet Packet Transform respectively. The same case for the sample rate of 350 is 76.70%, 77.15% and 79.10%. This result concludes that, the percentage of error rate is decreased as the sampling rate is increased.The phenomenon is due to that, if the decomposition level increase, the content of the knock in the original signal will decrease. Hence, from the entire results, the proposed approach of the Wavelet Packet Transform outperforms the conventional Fourier and Wavelet analysis.

Table 1: Comparison of Error Rate at 1000 RPM

	1000 Revolution Per Minute				
	Sampling Rate				
Signal From Knock Sensor	150	200	250	300	350
Error Rate of Fourier Transform	74.60%	75.37%	77.95%	77.34%	76.45%
Error Rate of Wavelet Transform	75.86%	76.43%	79.17%	78.05%	77.23%
Error Rate of Wavelet Packet Transform	77.85%	78.50%	81.25%	80.56%	79.42%

Table 2: Comparison of Error Rate at 2000 RPM

	2000 Revolution Per Minute				
	Sampling Rate				
Signal From Knock Sensor	150	200	250	300	350
Error Rate of Fourier Transform	75.15%	76.36%	77.83%	76.95%	76.03%
Error Rate of Wavelet Transform	76.29%	77.37%	78.75%	77.90%	77.48%
Error Rate of Wavelet Packet Transform	78.46%	79.58%	80.97%	79.55%	79.25%

Table 3: Comparison of Error Rate at 3000 RPM

	3000 Revolution Per Minute				
	Sampling Rate				
Signal From Knock Sensor	150	200	250	300	350
Error Rate of Fourier Transform	75.32%	76.17%	79.14%	78.81%	78.03%
Error Rate of Wavelet Transform	76.68%	77.80%	79.94%	78.70%	77.73%
Error Rate of Wavelet Packet Transform	78.30%	79.80%	81.85%	80.30%	79.09%

Table 4: Comparison of Error Rate at 4000 RPM

	4000 Revolution Per Minute				
	Sampling Rate				
Signal From Knock Sensor	150	200	250	300	350
Error Rate of Fourier Transform	74.40%	75.50%	78.89%	77.20%	76.40%
Error Rate of Wavelet Transform	75.75%	76.55%	78.82%	77.80%	76.95%
Error Rate of Wavelet Packet Transform	77.83%	78.99%	81.25%	79.50%	78.80%

Table 5: Comparison of Error Rate at 5000 RPM

	5000 Revolution Per Minute				
	Sampling Rate				
Signal From Knock Sensor	150	200	250	300	350
Error Rate of Fourier Transform	75.05%	76.20%	78.17%	77.42%	76.70%
Error Rate of Wavelet Transform	76.83%	77.13%	79.60%	78.35%	77.15%
Error Rate of Wavelet Packet Transform	78.80%	79.77%	81.85%	80.09%	79.10%

CONCLUSION

A novel approach of Wavelet Packet Transformation is used to analyse the knock signal from the engine. The signal is extracted from the engine running at various RPM (Revolution per Minute) with sampling rate varies from 150-350 per clock cycle. The wavelet packet analysis is done using the Matlab 2014, for the aggregated sample of 10,000 clock cycles. The results are evaluated in terms of error rate (%) and compared with the conventional transforms. The result analysis concludes that, high error rate is achieved at the sample rate of 250 by entire transform. Finally the remarkable improvement is achieved by the Wavelet Packet Transform over conventional Fourier and Wavelet Transform. This paper has contributed to the analysis of the captured knock signal, in the future, the paper can be extended to real time application and also this novel technique can be combined with Fuzzy logic and Self Organizing Maps (SOM) for better results.

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