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Automotive Fault Detection by Analysing Sound Signal using CWT

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ABSTRACT: Analysis of sound signal is widely used to detect early faults in automotive machineries, especially engines and gearboxes. There are many techniques that have been developed to detect progressing faults in engines and gearboxes. Most of them use time domain as the base of their analysis. Among these techniques, time domain averaging has established itself as a strong sound signal processing technique that can extract periodic waveforms from noisy signals. The time domain average of the sound of a engine represents the sound produced by the engines and gearboxes, and thus indicates the variation of sound produced by engine and gearbox. But even though time domain average of the signal may contain all the information about the smoothly operating engine, it is often hard to detect clear symptoms of any defect in the engine from only the time domain average, especially if the defect is at an early stage.

KEYWORDS: Time- Frequency averaging, Fourier transform, Wavelets, Continuous wavelet transforms, Haar wavelet

I.INTRODUCTION

The sound signal of a engine and gearbox carries the signature of the fault in the engine and gearbox, the detection of early faults like engine knock, leakage in intake manifold of the engine and faults in gearbox like cracks, chipped tooth is possible by analyzing the sound signal using different signal processing techniques. Time domain average can extract the periodic waveforms of a noisy sound signal, whereas continuous wavelet transformation is able to characterize the local features of the signal in different scales. Here using a new technique, Time-Frequency domain Average, which combines the time domain average and continuous wavelet transformation together to extract the periodic waveforms at different scales from noisy sound signals. The technique efficiently cleans up noise and detects both local and distributed faults simultaneously.

Recently a lot of work has been done on the analysis of sound signals in the time-frequency domain, with a view to combine the advantages of both time and frequency domain representation of signal. Undoubtedly, wavelet analysis has proved itself as the best time-frequency domain technique that keeps a good balance between the time and frequency resolution. The most important feature of Wavelet transform is its ability to characterize the local features of the signal at different scales. This is highly advantageous in examining sound signal from a automobile with faults, where either large scale or small scale change in the sound may occur, corresponding to distributed damage or local damage respectively.

This paper proposes a new technique that combines time-domain average with wavelet to produce a time-frequency domain representation of a signal. Time-frequency domain average captures the sound generated by a engine at different frequencies or scales over one complete revolution. It keeps the different scale representation of the wavelet analysis intact and at the same time extracts the periodic components from the noisy signal. Therefore it is best suited to detect faults at any scale from a periodic noisy signal. Time-frequency domain average was applied on real data from a test rig introducing both small and large faults. The results indicate that the time-frequency domain averages of the data sets efficiently identified both large and small scale faults in the engine, even when multiple faults are present simultaneously.

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II.SYSTEM MODEL AND DESIGN METHODOLOGY

In this paper, the fault diagnosis system based on continuous wavelet transform technique has been explained. Wavelet analysis, which allows the sound emission signals of frequency content with time to be visualized, can extract key features using time-frequency representation of sound emission signals from a engine and gearbox. The experimental results show that the proposed fault diagnosis system with time-frequency averaging can be effectively used in engine diagnosis and gearbox of various faults through measurement of engine and gearbox sound emission signal.

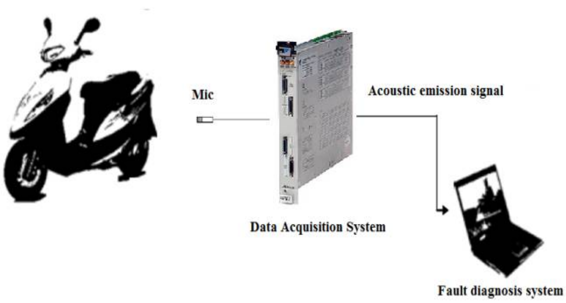

Fig. 1 Fault detection system

The paper implements a fault detection system:

1. The data acquisition system
2. The feature extraction system

The sound signal is acquired from automobile machineries by data acquisition system using a microphone. The sound signal is recorded from the engine under without fault condition and different fault conditions in fixed engine revolutions and a run-up engine operation condition, this phase is data acquisition phase.

In fault diagnosis system the actual computation is done, sound emission signals from each fault condition are analyzed using Continuous wavelet transform technique. The results of both with fault and without fault signals are displayed on GUI build using Microsoft visual studio windows forms.

III. CONTINUOUS WAVELET TRANSFORM

The CWT technique and time-frequency analysis are used to extract the feature of the dynamic characteristics and fault signal from a automotive machineries. The diagnostic trouble code of a machineries can be obtained by using spectrum trend feature method. There are two phases in the present fault diagnosis system: the data acquisition phase and the feature extraction phase. In the feature extraction, the diagnostic technique employs the wavelet transform to decompose the time-waveform signals into two respective parts in the time space and frequency domain and to obtain the feature of analysis signals.

Wavelet analysis has been used to not only successfully detect faults in rotating machinery, but when used with a number of successful classification techniques also diagnose the type of defect present. WT techniques have also been used to successfully de-noise signals prior to fault detection. The de-noising via wavelet thresholding using the discrete wavelet transform has been attempted, but the most research has attempted using a more non-traditional approach of de-noising the bearing fault signal using the continuous wavelet transform. Another approach has been to use the continuous wavelet transform as an optimal filter bank and select the scale that most represents the fault signal.

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The underlying principle of the phenomena just described is due to Heisenberg's uncertainty principle, in signal processing terms, states that it is impossible to know the exact frequency and the exact time of occurrence of this frequency in a signal. In other words, a signal can simply not be represented as a point in the time-frequency space. The uncertainty principle shows that it is very important how one cuts the signal.

The wavelet analysis is probably the most recent solution to overcome the shortcomings of the fourier transform. In wavelet analysis the use of a fully scalable modulated window solves the signal-cutting problem. The window is shifted along the signal and for every position the spectrum is calculated. Then this process is repeated many times with a slightly shorter (or longer) window for every new cycle. In the end the result will be a collection of time-frequency representations of the signal, all with different resolutions. In the case of wavelets its normally not speak about time-frequency representations but about time-scale representations, scale being in a way the opposite of frequency, because the term frequency is reserved for the fourier transform. In the following sections it is presented the wavelet transform and developed a scheme that will allow to implement the wavelet transform in an efficient way on a digital computer.

A continuous wavelet transform (CWT) is used to divide a continuous-time function into wavelets. Unlike Fourier transform, the continuous wavelet transform possesses the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization.

In mathematics, the continuous wavelet transform of a continuous, square-integrable function f(*t*) at a scale s> 0 and translational value u is expressed by the following integral

$$W(s,u) = \langle f, \psi_{s,u} \rangle = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{s}} \psi^* (\frac{t-u}{s}) dt$$

As given in the equationthe transformed signal is a function of two variables, uand s, the translation and scale parameters, respectively. ψ (t) is the transforming function, and it is called the mother wavelet . The term mother wavelet gets its name due to two important properties of the wavelet analysis as explained.

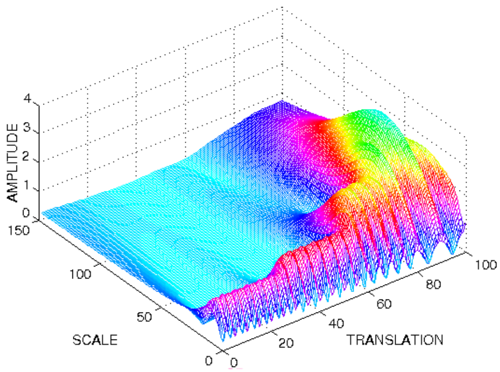

Fig. 2 Continuous wavelet transforms

The term wavelet means a small wave. The smallness refers to the condition that this (window) function is of finite length (compactly supported). The wave refers to the condition that this function is oscillatory. The term mother implies that the functions with different region of support that are used in the transformation process are derived from

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one main function, or the mother wavelet. In other words, the mother wavelet is a prototype for generating the other window functions.

The Haar wavelet is also the simplest possible wavelet. The technical disadvantage of the Haar wavelet is that it is not continuous, and therefore not differentiable. This property can, however, be an advantage for the analysis of signals with sudden transitions, such as monitoring of tool failure in machines.

The Haar wavelet's mother wavelet function $\psi(t)$ is shown in the figure 3 and can be described as given in the equation.

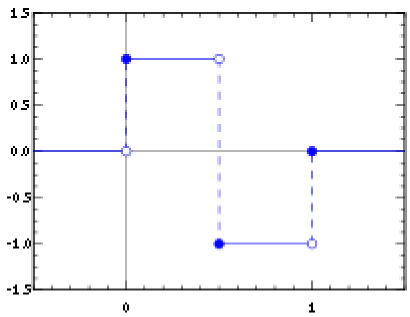

Fig. 3 Haar Wavelet

$$\psi(t) = \begin{cases} 1 & 0 \leq t < 1/2, \\ -1 & 1/2 \leq t < 1, \\ 0 & \text{otherwise.} \end{cases}$$

IV. FAULT DETECTION SYSTEM

A mechanical fault detection system for a automotive machinery platform using continuous wavelet transform involve two stages:
1.The data acquisition: In this stage the sound emission signal of automotive machineries platform is measured by a microphone (PCB 130D20) which is connected a data acquisition system. The sound signal acquired from automotive machineries is as shown in the figure 4. The sampling rate of data acquisition system varies from minimum of 2 Sa/s to the maximum of 102.4 k Sa/s, but in this application sampling frequency is set as 10kHz

2.The feature extraction: x(t) be the signal to be analyzed, the mother wavelet is chosen to serve as a prototype for all windows in the process. All the windows that are used are the dilated (or compressed) and shifted versions of the mother wavelet. There are a number of functions that are used for this purpose. Once the mother wavelet is chosen the computation starts with s=1and the continuous wavelet transform is computed for all values of s, smaller and larger than 1. Depending on the signal, a complete transform is usually not necessary. For all practical purposes, the signals are band limited, and therefore, computation of the transform for a limited interval of scales is usually adequate. Some finite interval of values for sare used.

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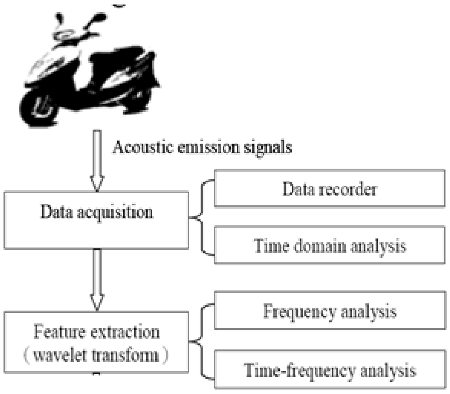

Fig 4. Fault detection system

For convenience, the procedure will be started from scale s=1 and will continue for the increasing values of s, that is the analysis will start from high frequencies and proceed towards low frequencies. This first value of s will correspond to the most compressed wavelet. As the value of s is increased, the wavelet will dilate.

The wavelet is placed at the beginning of the signal at the point which corresponds to time=0. The wavelet function at scale 1 is multiplied by the signal and then integrated over all times. The result of the integration is then multiplied by the constant number 1/sqrt{s}. This multiplication is for energy normalization purposes so that the transformed signal will have the same energy at every scale. The final result is the value of the transformation, that is the value of the continuous wavelet transform at time zero and scale s=1. In other words, it is the value that corresponds to the point tau =0 , n=1 in the time-scale plane.

The wavelet at scale s=1 is then shifted towards the right by tau amount to the location t=tau , and the above equation is computed to get the transform value at t=tau , s=1 in the time-frequency plane. This procedure is repeated until the wavelet reaches the end of the signal. One row of points on the time-scale plane for the scale s=1 is now completed.

Then, sis increased by a small value. This is a continuous transform, and therefore, both tau and s must be incremented continuously. However, if this transform needs to be computed by a computer, then both parameters are increased by a sufficiently small step size. This corresponds to sampling the time-scale plane.

The above procedure is repeated for every value of s. Every computation for a given value of nfills the corresponding single row of the time-scale plane. When the process is completed for all desired values of s the CWT of the signal has been calculated.

In the figure 5, the signal and the wavelet function are shown for four different values of tau. The scale value is 1, corresponding to the lowest scale, or highest frequency. It should be as narrow as the highest frequency component that exists in the signal. Four distinct locations of the wavelet function are shown in the figure at to=2, to=40, to=90, and to=140. At every location, it is multiplied by the signal. Obviously, the product is nonzero only where the signal falls in the region of support of the wavelet, and it is zero elsewhere. By shifting the wavelet in time, the signal is localized in time, and by changing the value of **s**, the signal is localized in scale (frequency). The figure 5 illustrate the entire process step by step.

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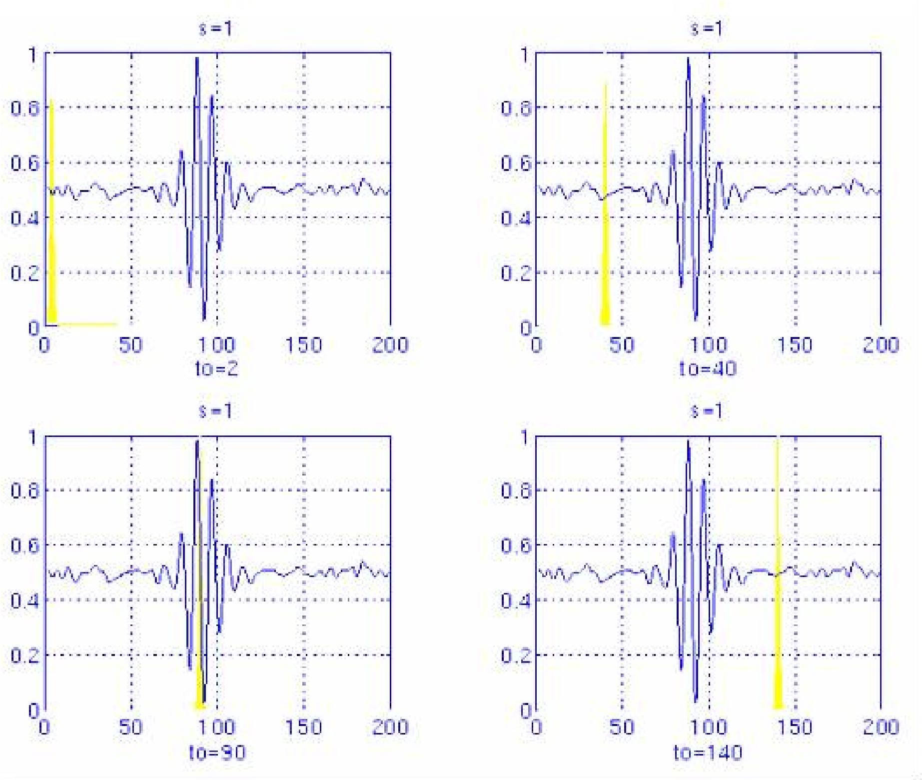

Fig 5. CWT for window size s= 1 at different time

V. RESULT AND DISCUSSION

The cracks and broken tooth in a gearbox is common in industries and automobile machineries. These kinds of faults can be recognized by analyzing the sound signal of the gearbox. Here some of the samples like single chipped tooth and two chipped tooth are implemented. The figure 5.11 shows the sound signal, the waveform length is selected so as to record continuous signal, giving a waveform of 40 msec duration one full gear revolution at 1500 rpm evolution speed of the large gear.The CWT of the signal shown in the below oscilloscope in the UI which is having uniform amplitudes at all cycles.

GUI in the figure 5.12 is displaying the chipped tooth signal of a gearbox and its CWT. In the figure the peaks at regular intervals are visualized. These peaks indicate the missing of tooth where low frequency exists at the space of missing tooth. The amplitudes will be uniform where tooth of the gearbox are normal and peak will exists where there is crack in the tooth or tooth is chipped. This peak can be noticed at every cycle, four peaks are there in complete four cycles of displayed signal so number of tooth missed in the gearbox can be generalized as one.

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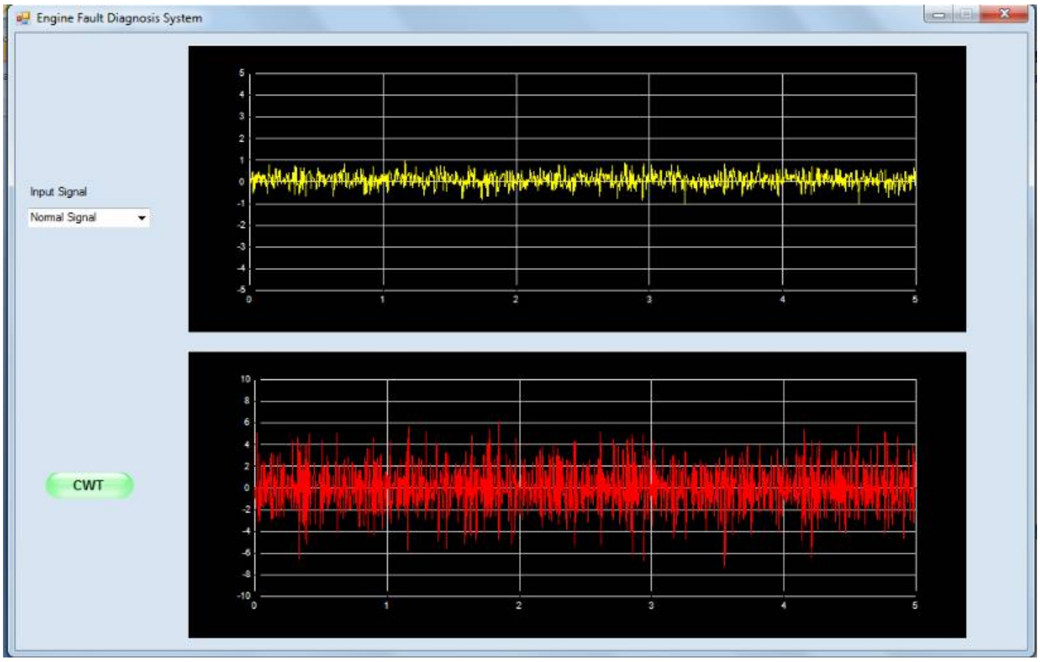

Fig 6. GUI of CWT on normal signal

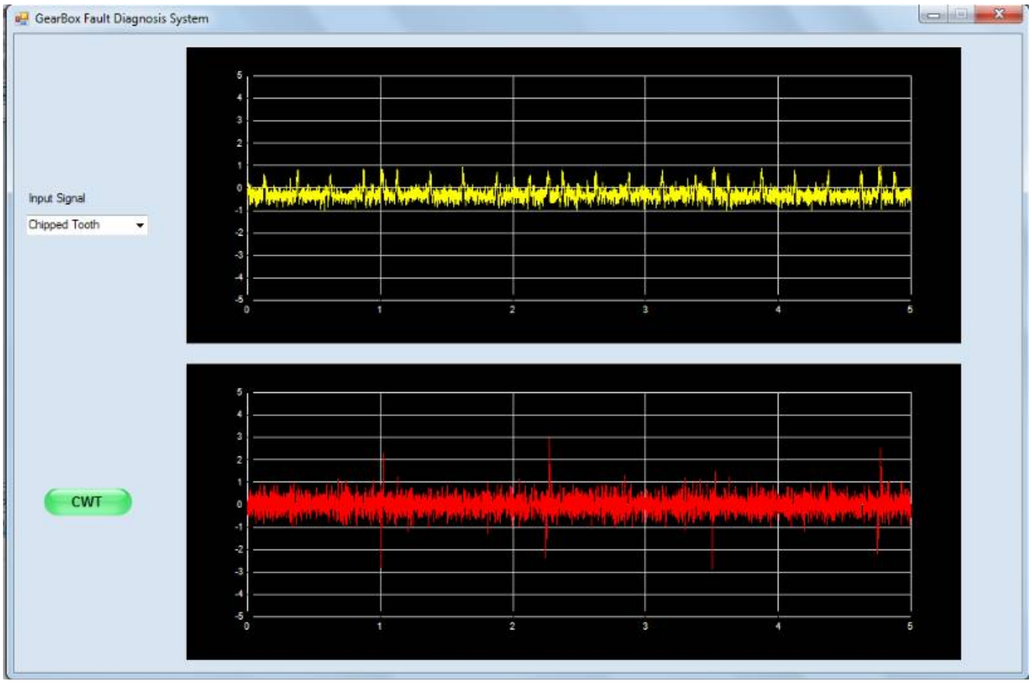

Fig 7. GUI of CWT on Chipped tooth gear box signal

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VI.CONCLUSION

The new technique has been proposed that combines wavelet and time domain averaging to analyze a time series and performs averaging in the time-frequency domain. The strength of the technique lies in the way it preserves the frequency domain information while performing the average, and captures the deterministic part of the periodic signal.

In this paper, the automotive fault diagnosis system based on continuous wavelet transform technique for the purpose of the fault detection has been developed. Wavelet analysis, which allows the sound emission signals of frequency content with time to be visualized, can extract key features using time-frequency representation of sound emission signals from a engine and gearbox. The experimental results show that the proposed fault diagnosis system can be effectively used in automotive machineries diagnosis of various faults through measurement of sound emission signal. This method provides an alternative technique that does not require complex data extraction.

In medical field the CWT technique can be used to find out the abnormalities in the sound of heart beat. So just by visualizing the abnormalities in the heartbeat can be detected. The use CWT is well suited for its good frequency resolutions in low frequencies. This technique allows us to find out some physiological results which add future evidence to the delayed or abnormal ANS developments in anemic infants.

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