Detecting Vibrations produced by faults in a wheel of a pedal cycle through Continuous Wavelet Transform and calculations

Ravikumar. K[a], and Diana Vinster Nadeen. A[b]

[a] Assistant Professor in Engineering Mathematics, Engineering and Technology at Annamalai University,
[b] Research Scholar, Department of Mathematics, Annamalai University

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Abstract: The paper is about the fault detection based on wheels in a pedal cycle which is detected using vibrations. These vibration signals are analysed by wavelet analysis. The faults arise in wheels are puncture, chain break, brake rub, hub squeak, cracked rim, cracked tyre, tread worn off, loose joints and bearing fault. We shall study how these vibrations caused by the faults look like in wavelet analysis. We use Continuous Wavelet Transform (CWT) to analyse the vibration.

Keywords: Fault Detection, Vibration Signals and Continuous Wavelet Transform (CWT)

1. Introduction

The pedal cycle is one of the most creative human-powered transportation. By Mechanism we come to know that up to 99% of human energy is transmitted to the wheels through the pedal from the rider. Faults in wheel parts result in vibration which in turn leads to unbalanced functioning of the pedal cycle. These vibrations vary with the faults. In this paper varied vibrations are analysed with the help of Continuous Wavelet Transform (CWT). The faults that are to be discussed here are i) Fault that arise due to puncture, tread worn off, brake rubbing, loose joints, hub squeaks, cracked rim and tyre lead to wobbling of the wheel, ii) bearing fault and chain break affect the smooth functioning of the wheel. We make use of CWT method to analyse the non-stationary vibration signals [1].

2. Continuous Wavelet Transform

The CWT will simplify the signals into a series of base functions of translated and dilated model of original wavelet function, as continuous wavelet transform is a time frequency signal. The mathematical depiction of CWT is given below:

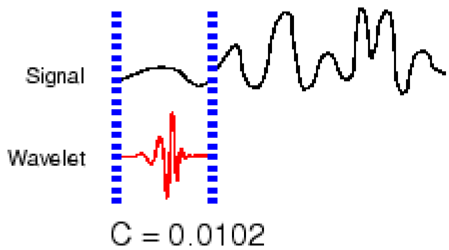
$$\psi_{(x,s)}(t) = \frac{1}{\sqrt{x}}\psi\left(\frac{t-s}{x}\right) \qquad (1)$$

$$W_f(x,s) = \int_{-\infty}^{\infty} f(t)\psi^*_{(x,s)}(t)dt \qquad (2)$$

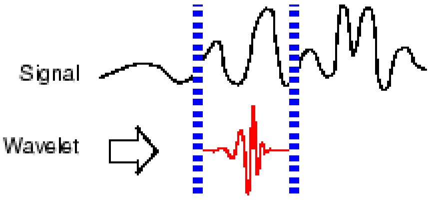
Where f(t), original signal; s, dilation parameter; u, translation parameter; $\psi^*(t)$, conjugate function of the original wavelet.

Steps to compute CWT:

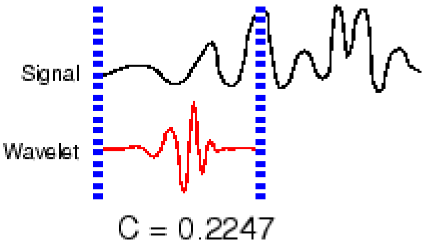
- Here we are choosing a wavelet and equating it to a portion in the beginning of the signal.



- Then by the calculation of CWT Coefficients, we will measure the similarities of that portion of the signal with the wavelet.
- By translating u shift the wavelet to the right and precede with steps 1 and 2.



- Next step is to determine all the translations through CWT coefficients.
- Then comes Scaling the wavelets and repeating steps 1 to 3 above.



- Repeating step 4 for all scales.

3. Experiment

The experimentation consists of normal pedal cycle with a speed of about 16-24 km/h. Also the experimental setup consists of ADXL 335 accelerometer to arrest the vibration data. In order to collect the data from accelerometer, it is integrated with ARDUINO UNO board with microcontroller and it is fit to MATLAB where the vibration data can be featured. The simplified diagram of the experimental setup is shown in Figure 1.

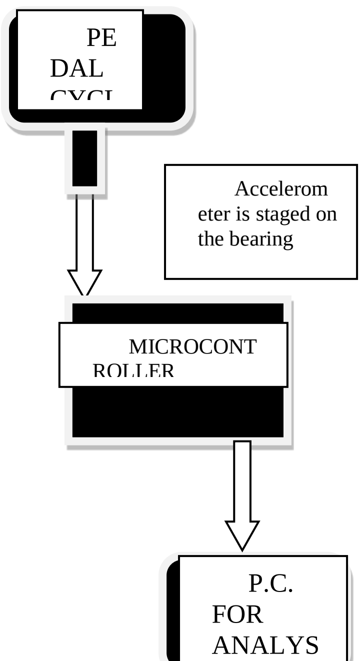


Figure 1

ACCELEROMETER

An Accelerometer measures proper acceleration, which does not depend on the choice of the coordinate system. They have varied applications. Figure 2 shows ADXL 335 accelerometer which is used in the experiment.

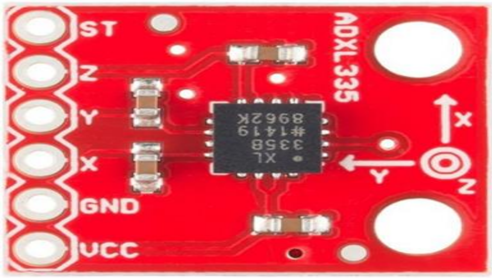


Figure 2

ARDUINO BOARD

This company manufactures and designs kits to develop digital devices and assembled equipments that help to sense, identify and control the literal world as an open source. An Arduino board is built with Atmel 8-bit AVR micro controller with complementary components. Figure 3 shows ARDUINO UNO board used in the experiment.

Figure 3

BEARINGS

The Bearings used here are 9 balls of ¼ inch diameter/side for rear wheel and 10 balls of 3/16 inch diameter/side for front wheel. Figure 4 shows bearings used in the experiment.

Figure 4

APPLICATION OF CWT
FOR FEATURE EXTRACTION

There are three types of signal processing techniques available for analysing the wave forms. They are time domain, frequency domain and time-frequency domain.

In Wavelet analysis the techniques are the most effective as it has time-frequency domain, which is characterised by "Area of low frequency resolves well in the frequency domain but have poor resolution. Area of high frequency has good time resolution but poor frequency resolution". Thus CWT is applied to bearings and CWT plots are acquired and that can be done online. Shown in Figure 5 (healthy bearing), 6 and 7.

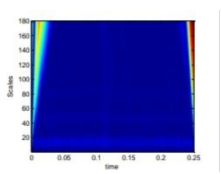


Figure 5

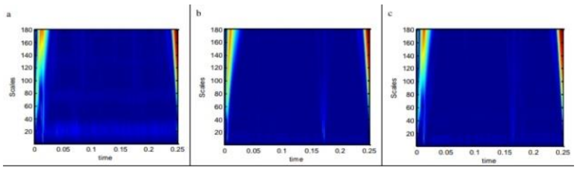


Figure 6: Inner race defect

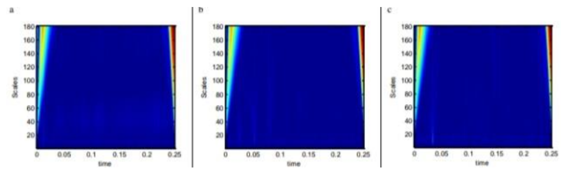


Figure 7: outer race defect

4. Results and Discussion

Description of CWT plots of healthy and faulty bearing

The CWT coefficients are calculated by a matrix with different scale and translation values. If that portion of the signal and the version of the wavelet are very similar then the coefficient value will be high [2-4]. The colours in the plot indicate the relative values of the CWT coefficients. The light coloured area means higher values of the CWT coefficients and thus, signal resembles the wavelets. Whereas, dark coloured area means lower values of the CWT coefficients and it indicates that the respective time and scale versions of the wavelet are not coherent to the signal.

Generation of faults signature

The processed method for derivation of signature of various faults is represented through block diagram in Figure 8. Initially fault signal is converted to CWT coefficient matrix and subtracted from original CWT coefficient wave form. The resulting Difference Coefficient Matrix (DCM) contains the characteristics of faults data. The row elements of DCM are summed up and the resulting matrix is known as Unique Feature Matrix (UFM), which will be used to create a unique pattern or signature [5-8].

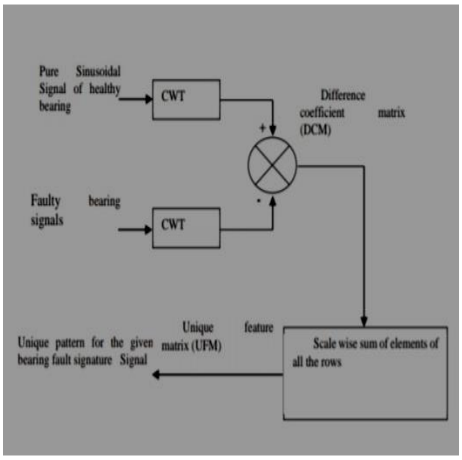


Figure 8

DERIVING SIGNATURE THROUGH MATLAB

Syntax

```
wt = cwt(x)
wt = cwt(x,wname)
[wt,f] = cwt(__,fs)
[wt,period] = cwt(__,ts)
[wt,f,coi] = cwt(__,fs)
[wt,period,coi] = cwt(__,ts)
[__] = cwt(__,Name,Value)
[__,coi,fb] = cwt(__)
[__,fb,scalingcfs] = cwt(__)
cwt(__)
```

SYNTAX DESCRIPTION

- wt = cwt(x) returns the continuous wavelet transform (CWT) of x
- wt = cwt(x,wname) uses the analytic wavelet specified by wname to compute the CWT.
- [wt,f] = cwt(__,fs) specifies the sampling frequency, fs, in Hz as a positive scalar
- [wt,period] = cwt(__,ts) specifies the sampling period, ts, as a positive duration scalar
- [wt,f,coi] = cwt(__,fs) returns the cone of influence, coi
- [wt,period,coi] = cwt(__,ts) returns the cone of influence, coi
- [__] = cwt(__,Name,Value) returns the CWT with additional options specified by one or more Name,Value pair arguments
- [__,coi,fb] = cwt(__) returns the filter bank used in the CWT. See cwtfilterbank.
- [__,fb,scalingcfs] = cwt(__) returns the scaling coefficients if the analyzing wavelet is 'morse' or 'amor'
- cwt(__) with no output arguments plots the CWT scalogram

Now load filename of the fault bearing vibration data.

Plot the healthy and fault bearing vibration data using the following syntax.

plot((1:numel(filename))./60, filename)

xlabel('mins')

ylabel('nm/s^2')

grid on

title('signature of fault bearing vibration')

When we are ready with the experiment, CWT is applied to the unprocessed vibration data received from the fault and signature is derived for different types of faults. The example of CWT signatures for varied faults is shown below. Hence, by seeing the signature formed by CWT one can classify different type of fault. Thus the CWT demonstrate to be a productive medium for recognising the faults and the data can be treated with Artificial Neural Network and then this fault identification technique can be made online [9-11]. Shown in Figure 9 and 10

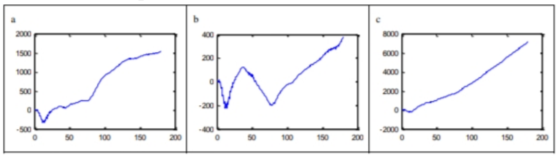


Figure 9

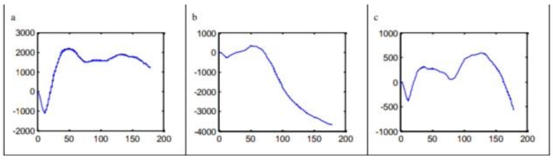


Figure 10

5. Conclusion

The application of Continuous Wavelet Transform to detect vibrations produced by faults in wheel of a pedal cycle is demonstrated in this paper. This reveals that CWT is a constructive mechanism for analysing fault data. Thus we conclude that CWT signature can be used as fault classification tool in fault diagnosis.

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