

Feature Identification and Filtering for Engine Misfire Detection (EMD) Using Zirconia Oxygen Sensor

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Abstract. Vehicles as transportation are popular and mainly use among peoples around the world for various kind of purpose either personal or not. Over hundreds of year internal combustion engines widely used because of high efficiency and low maintenance compare to new technology which are using cells of battery. Nevertheless, emission cause of incomplete combustion such engine misfire normally occurs as well. For instances, some mechanical, sensors or actuators failure and environmental condition contribute to the engine misfire. The importance of engine misfire detection (EMD) is to ensure engine emissions not harmful to the environments and avoid damage of catalytic converter. By using low cost narrowband oxygen sensor to acquire air to fuel ratio (AFR) signal behavior under misfire condition and analyst by digital signal processing method using Discrete Fourier Transform (DFT) algorithm for Digital Butterworth Filter designation is discussed in this paper.

1. Introduction

There have many kind of internal combustion engine were invented since more than a century by many of inventors around the world. Otto cycle engine is one of internal combustion engine that is very popular until now since it was widely used in road vehicles such as cars and motorcycles. Otto cycle engine is four stroke engine where intake, compression, combustion and exhaust strokes takes place to rotate the crankshaft of the engine. However, while the engine combust the mix of air and fuel, there have possibility of unburned mixture because of combustion defect or engine misfire. Engine misfire would be defined as the engine lost its ability to ignite the mixture in the combustion chamber at a particular moment. It would be affected by unstable ignition system cause of faulty of ignition control or ignition coil cable leak, dirty intake manifold sensors, unsuitable air to fuel ratio (AFR), fuel injector faulty, and leaky combustion chamber would increase the potential of engine misfire^[5]. The frequent occur of engine misfire would damage exhaust catalytic converter and increase the harmful emission of exhaust gas to the environment and air pollution. In order to control the harmful exhaust emission, vehicle manufacturer must be agreed to the European Emission Standard where engine misfire must be compensated with the aid of close loop control system^{[6][12]}. Thus, in order to monitor engine misfire, various sensor can be used to get the signal and process for the engine misfire detection (EMD). Commonly the sensors involve in acquire engine misfire signal are knock

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sensor and pressure sensor^{[4][10]}. Moreover, it will increase subsystems of the engine and the cost as well. In another way, engine misfire would be able to detect by oxygen sensor which is already included in exhaust system for most of the vehicles^[11]. There have relationship of engine misfire and the oxygen sensor since the misfire contribute to inappropriate AFR. Basically, oxygen sensor measures the mixture of air and fuel in term of their ratio to identify either the mixture of air and fuel in the combustion chamber is good or not^[7]. In order to make sure the good combustion, it is depend on the stoichiometric ratio defines as the total mass of reactant is equal to the total mass of product. The stoichiometric ratio differences for different of fuel use to react with the air intake. For common vehicle's fuel such gasoline, the AFR will be 14.7 to 1, diesel is 14.5 to 1 and natural gas is 17.2 to 1^[8]. The combustion that produces more or less than the stoichiometric is incomplete combustion. The types of oxygen sensor consist of narrowband and wideband where the wideband would have bigger range of measurement^{[13][14]}. However, narrowband oxygen sensor is enough for the purpose to measure the stoichiometric point.

2. Digital Butterworth Filter

Signal detection from various kind of sensors have a lot of noise that need to be filtered. Digital signal filtering is widely used to replace analog type to filter the signal and it would be redesign to improve the performance such as processing speed and accuracy of signal filtering since digital signal filter algorithm that perform mathematic expression could be redesigned to change the coefficient to make robust an adaptive filter^[3]. Furthermore, it is consistence by using digital filter compare to analog which depends on electronic components such as resistor and capacitor as it would have different behaviour when the changes of temperature and affect the processing time of the signals. There was many algorithm of digital signal filter created over a decade ago and popularly used in automotive industry to build the control system of vehicles. Most popular digital filter is low pass or Butterworth filter. It is generally Infinite Impulse Response (IIR) that more advantage than Finite Impulse Response because of less computation needed and it can achieve high pass or band pass via transformations. Among many of signal emit by automotive sensors or oxygen sensor mainly produced high frequency noise and Butterworth filter is most suitable to remove the noise. Some of parameter need to consider is cut-off frequency, F_c . The signal and noise frequency need to be analyst to ensure only the noise will be eliminated and removed. Figure 1 shows Butterworth filter frequency response stop the frequency above the cut off frequency where only the signal with lower than cut off frequency is remained.

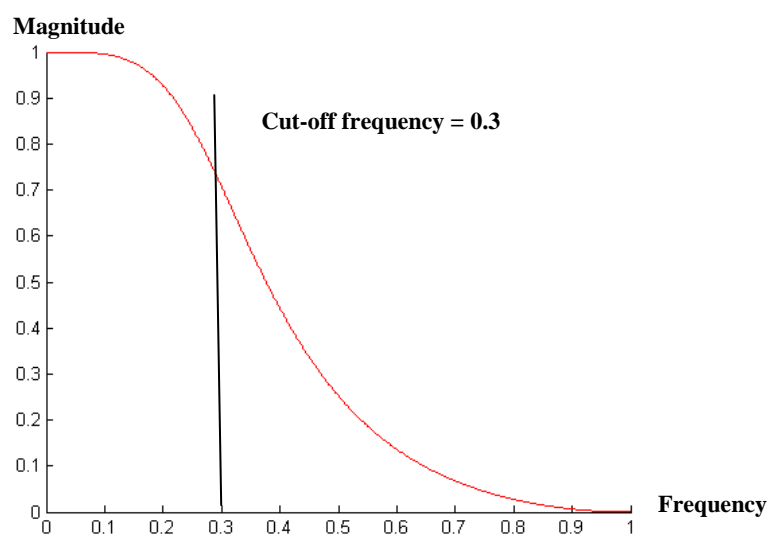


Figure 1. Butterworth filter frequency response

3. Discrete Fourier Transform

The Fourier transform is defined for continuous function. Here the signal most typically is assumed to be continuous. Fourier Transform is mathematical procedure discovered by a Jean Baptiste-Joseph Fourier in early 1800's^[1]. Discrete Fourier Transform (DFT) becomes popular and widely used in various signals processing application such as automotive, communication, entertainment and many other fields. DFT converts the acquisition signal in term of time-domain to frequency domain for frequency analysis. Eq. 1 is defined the forward DFT where $X(f)$ is the complex Fourier transform of $x(t)$, frequency, f and time, t are real variables^[2].

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j\left(\frac{2\pi}{N}\right)kn} \quad (1)$$

Correlation is measure of the presence of the signal with another to obtain the similarities. I Fourier transform the correlation of the signal measures similarities to sine and cosine waveform using DFT function to generate frequency bins of the signal. The properties of DFT are periodicity, linearity, time shift, modulation, symmetry and inverse DFT. Based on their properties, the detail analyse will be carried out related to the frequency of engine misfire signal in order to filter the noise.

4. Methodology

The usage of Otto cycle or four stroke engine vehicle being dominates among the peoples around the world. In directly, it is increase the emission of exhaust and harmful gas cause of engine misfire. Thus, four stroke engine used in this research to filter the noise of oxygen sensor signal. Engine control unit manage to control the amount of fuel need to be injected based on the amount of air intake. Then, ignite the mixture at particular time by actuating spark plug. The exhaust gas produce by the combustion flows into the exhaust manifold while oxygen sensor measures the level of oxygen in term of AFR. The signal produce by the oxygen sensor is acquired by using oscilloscope with 35 kHz of sampling rate and logging for further analysis. Flow chart in figure 2 summarized the process of oxygen sensor signal filtering in order to be used in EMD algorithm.

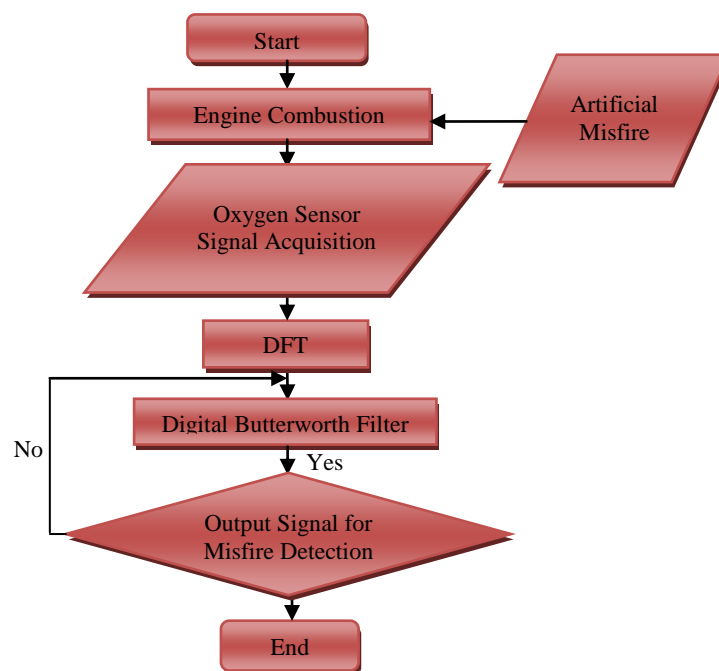


Figure 2. Signal filtering process flowchart

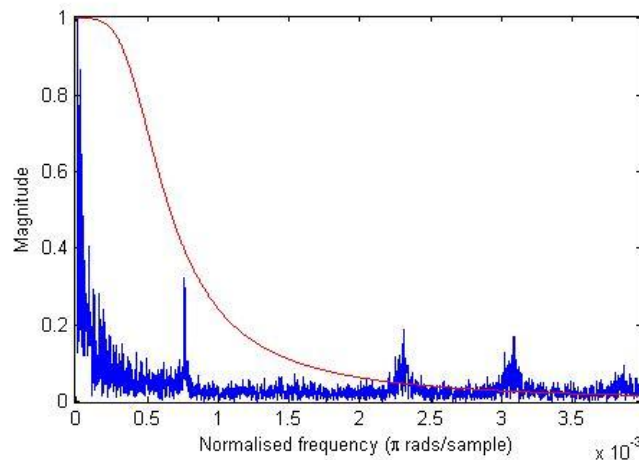


Figure 3. Frequency spectrum of signal

Artificial engine misfire is actuated to simulate engine misfire signal in order to analyse the pattern and signal frequency while the misfire event occurs. It was designed using a microcontroller to control fuel injector behaviour to produce misfire in the combustion chamber. By transforming time to the frequency domain of the sampled signal, the frequency of noise would be observed. The magnitude of the signal will be higher than the noise as in figure 3. Thus, a Butterworth filter is designed to cut or cancel the noise frequency that is higher than the misfire signal. By setting the cut-off frequency, the filter frequency response as the red line in figure 3 shows noise frequency is eliminated.

5. Result and Discussion

By using an autonomous engine misfire detector, the signals need to be filtered and noise reduction needs to be considered so that they can be easily recognized by the EMD program. Good signal filtering increases the detection accuracy. Signal-to-noise ratio (SNR) is measured as the reference for EMD performance. Based on analysis data, SNR after the filtering process using a digital Butterworth filter is 34.7626 compared to the non-filter signal, which is 15.9759.

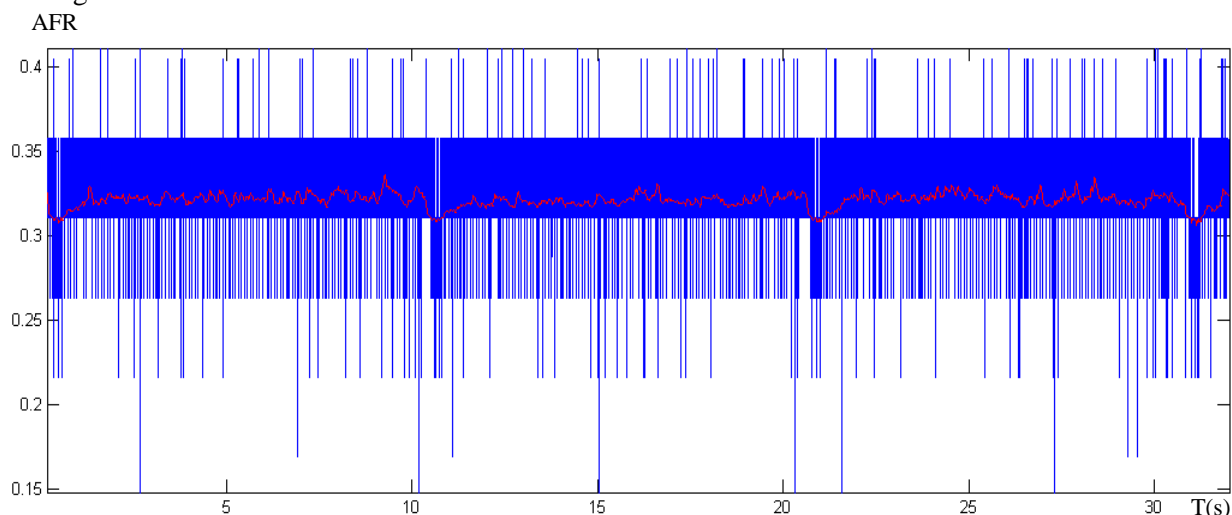


Figure 4. Before and After Filtering of Signal

By referring to figure 4, the oxygen sensor signal acquired by oscilloscope would have noise with different frequencies. Using DFT to present the frequency of signal and noise, there was more noise signal compared to the signal. The red line shows in figure 4 the result of the filtered signal, where it is more smooth and has less noise. The signal drops when a misfire occurs because of lean combustion. In

this research, engine misfire was simulated by reducing amount of fuel inject indirectly effect to AFR. Table 1 presents number of misfire at particular time.

Table 1. Number of Misfire Actuate at Particular Time

Misfire	Time (s)
1 st	0.8
2 nd	10.8
3 rd	20.8
4 th	31

6. Conclusion

Otto cycle engine widely produced based on the study of vehicles statistics around the world and the emission of exhaust gas increases. As the result shown the signal of oxygen sensor acquired by oscilloscope would be filter to reduce noise and increase SNR. Filtered signal have less of noise easily to be recognized. Thus, it would increase the efficiency of EMD algorithm to compensate engine misfire while the engine is running. Moreover, the frequency analyst using DFT is obtained to present the frequencies of signal and noise. The designation of second order Butterworth filter based on the result shown in frequency spectrum and the cut off frequency that was set has reduce noise produce by oxygen sensor.

7. References

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