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Utilization of Microphone Sensors and an Active Filter for the Detection and Identification of Detonation (Knock) in a Petrol Engine

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Abstract

This research proposes a new method for detecting detonation (knock), that is to say the use of microphone sensors and active filters are combined with the identification of the vibration pattern of the engine sound.This is because,in terms of increasingthe fuel efficiency and power of a petrol combustion engine, the problem of detonation is a very serious issue. For this reason, the accurate, rapid and real time detection and identification of detonation also still needs to be developed. Microphone sensorsare inexpensive anddo not need to be mounted on the engine itself, meaning they are not exposed to heat, although the signal processing needs to be conducted carefully. The engine sound is recorded through a microphone and a Sallen-Key active filter is used to filter the detonation signal. Then the signal is processed to obtain the results of the regression of its function envelope. Identification is carried out using the method of calculating of the Euclidean distance of the function envelope regression from the reference signal. This is to make a determination of whether there is a detonation or not. This method is conducted with the help of Matlab. The findingsare that this method is able to detect and identify detonation signals.

Keywords: microphone, knock, petrol combustion engines, active filters, Euclidean distance

1. Introduction

Microphone sound sensors until now have not been used for the detection of detonation in automobiles. Most of the knock sensors used to detect the engine vibration are piezoelectric accelerometers which detect the occurrence of detonation. The detonation phenomenonis quite complicated to explain, however,in simple terms it is an uncontrolled burning (misfire) that occurs by itself (auto ignition) during the compression stroke, making the machine vibrate hard. There is also decreased power, overheating, a waste of fuel and the engine will be quickly become damaged. Detonation will also occur when the fuel is lower quality and when ignition occurs too early. However, when the timing of the ignition is late, the engine power will decrease drastically. Therefore, the ignition is always arranged so that the timingis as early as possible but not until detonation. Thus, detonation detection is very important in establishing the exact time of ignition (Heywood, 1988).

A microphoneused with an activefilter can be used to capture and separate the sounds of engine vibrations when there is detonation given a frequency of detonation vibration of 5-10 kHz. Other sensors used in the detection of detonation include: the most accurate pressure sensor in the cylinder (Galloni, 2012), but these sensors are expensive and not durable; an optical sensor with a quartz window in the combustion chamber which is often constrained by the presence of a crust on the surface of the chamber (Merola et. al., 2007); an ion current sensor in the combustion chamber (Zhang et. al., 2009), which is often constrained by the electrode being burnt. Now, the most widely used is the vibration sensor (knock sensor) in the form of an accelerometer (Vulli et. al., 2008), but because it is installed inside the engine, the heat will affect the sensor's performance. Acoustic emission (AE) technique has been used in the method of identifying injector faults at diesel engine (Elamin et. al., 2010).

Signal filtering is carried out in order to separate the detonation signal from other signals and is done by usinga Sallen-Key active filter,the excellence of which is well known, a type of active high frequency filter (HPF = high pass filter). Other filtration methodsthat have been used include: the band-pass-filter (Galloni, 2012); the Kalman filter method (Ker, et. al., 2006), with, wavelet packet transform (WPT) (Hou et. al., 2009), the time-frequency analysis based on STFT (Vulli et. al., 2008) with real mother wavelet method (Zhang et. al., 2009), the wavelet and fuzzy method (Borg et. al., 2005).

The identification is achieved by creating a regressed function envelope for detonation signal so that the the Euclidean distance between the function envelope and the reference signal can be calculated. Other methods that have been used include: the Dimensionless Knock Indicator (DKI) method (Brecq et. al., 2002); the ARMA (Auto Regressive Moving Average) method (Ettefagh, et. al., 2009), an identification method using the vibration pattern recognition wavelet from the accelerometer sensor on the engine (Thomas et. al., 2007).

So the purpose of this research is to propose a new method for a real time system to capture the engine vibration sound signals through the use of sensor microphones, and the use of a Sallen-Key for active filtering, in order to detect and identify the detonation signal in a petrol combustion engine.

1.1 Active Filters

A popular active filter circuit was made by Sallen-Key in 1954 (Kendall-Su, 2002) which is referred to as a biquad active filter (level two) and for a pass high-frequency filter (HPF) is shown in Figure 1.

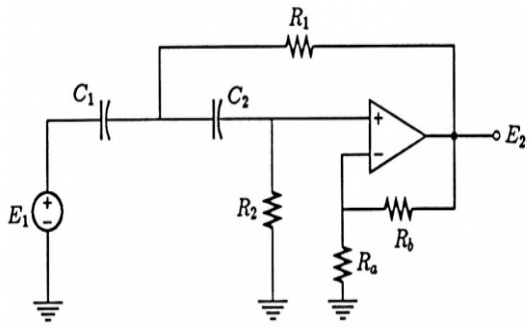


Figure 1. HPF Sallen-Key circuit op-amp (Kendall-Su, 2002)

Analysis of the Sallen-Key HPF circuit (Figure 1) with op-amp is as follows (Kendall-Su, 2002):

$$\frac{E_2}{E_1}=\frac{\mu s^2}{s^2+\left(\frac{1}{R_2C_2}+\frac{1}{R_2C_1}+\frac{1+\mu}{R_1C_1}\right)s+\frac{1}{R_1R_2C_1C_2}} \tag{1}$$

Or

$$H_{HP}(s)=\frac{E_2}{E_1}=\frac{Gs^2}{s^2+\left(\frac{\omega_c}{Q}\right)s+\omega_c^2} \tag{2}$$

Where :

Frequency limits: $$\omega_c=\frac{1}{\sqrt{R_1R_2C_1C_2}} \tag{3}$$

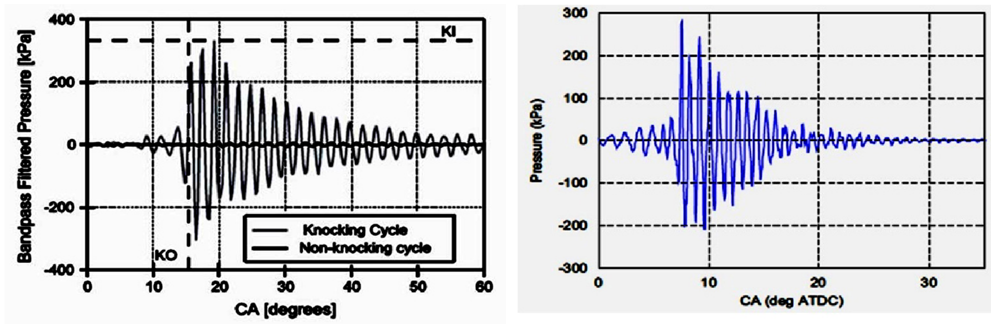
Quality: $$Q=\frac{\frac{1}{\sqrt{R_1R_2C_1C_2}}}{\frac{1}{R_2C_2}+\frac{1}{R_2C_1}+\frac{1-\mu}{R_1C_1}} \tag{4}$$

Magnification: $$G=\mu=1+\frac{R_b}{R_a} \tag{5}$$

1.2 Detonation Wave Pattern

The detonation vibration wave pattern has already had a lot of researchers who have worked on it, including work on the characteristicsof detonationsthat create the wave patterns as shown in Figure 2: (a), (b) that have similar pattern shapesasthe tip ofan arrow.

Shape of a normal engine vibration wave pattern with detonation pattern, expressed as an image in Figure 3 (a) normal vibration (no-knock) is without or slightly spike and Figure 3 (b) knock vibration has pattern shapes as the tip of an arrow:



(a) (b)

Figure 2. Shape of a detonation vibration pattern (knock): (a) Rothamer et.all (2012), (b) Galloni (2012)

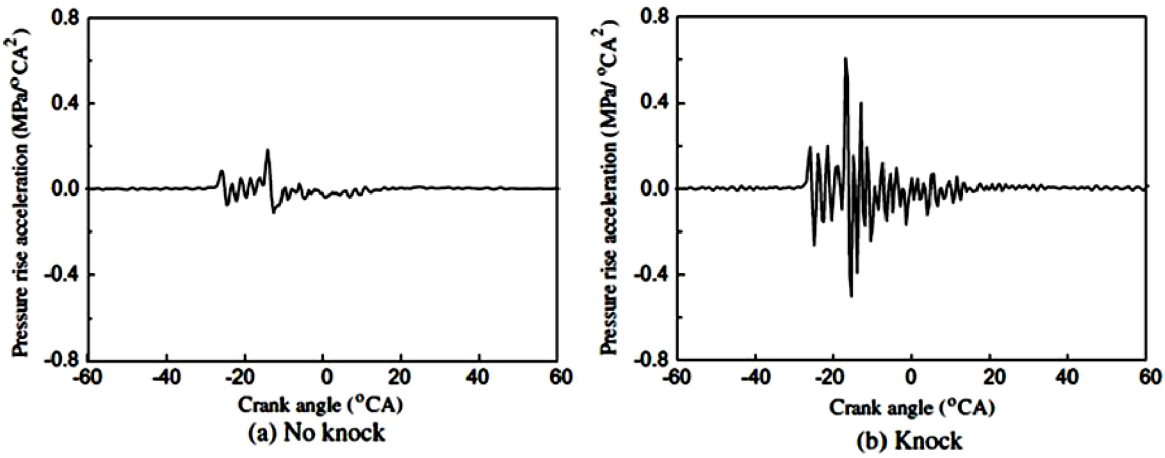


Figure 3. Patterns of normal vibrations (no-knock) and detonation (knock) (Hou et. al., 2009)

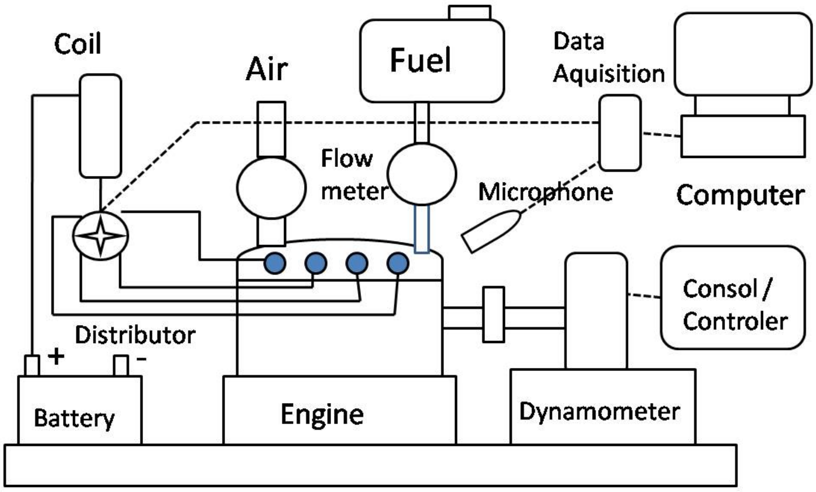
1.3 State Hypotheses and Their Correspondence to Research Design

Pattern recognition method existing for detecting detonation was conducted by Thomas et.all 2007 using the accelerometer sensor which records the vibration machine. Signal processing performed by the analysis of the time scale wavelet network, to make a decision or an assessment of the magnitude of engine detonation.

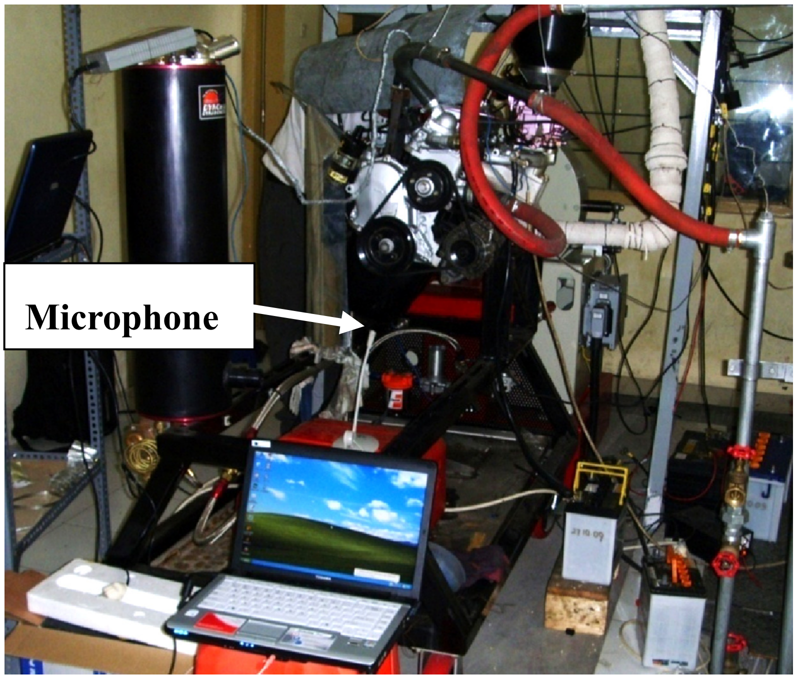
The new method proposed in this research is a diagnostic method based on pattern recognition as well, but the method of signal processing and other equipment are different. This new method uses a microphone as a sensor to capture the sound of the engine vibration. Filtering is done with Sallen-Key active filter. Development detonation vibration pattern is done by making the envelope function and regression. For identification is done by calculating the euclidean distance of the reference signal. So with this new method is expected to detect and identify detonation well.

2. Method

The research was conducted using a 1995, 1600 cc, Suzuki Escudo car, mounted on an ETB (Engine Test Bed),with the eddy-current dynamometer type of Dyno-Mite-200 hp, which has data acquisition equipmentfor temperature, air flow, fuel flow, torque, rotation and is controlled by a brake and throttle, as shown in Figure 4. To record data on the engine vibration sound, a microphone and ignition sensors were mounted, and the data was recorded onto a computer at a speed of 44.1 kbps. To get the sound of detonation, the engine was started and revved with maximum throttle, until the sound of detonation (knocking) occurred.



(a)



(b)

Figure 4. Engine Test Bed (ETB), (a) schematic, (b) picture

Samplingis carried out at a speed of 44.1 kbps to record both the signal from the microphone and the ignition timing signal and is connected to the data acquisition tool and recorded onto a computer. The recording signal obtained by the microphone is then filteredusing a Sallen-Key type active filter with high frequencies (HPF), with the frequency cut-offs: (cut-off frequency): at 5 kHz, with a value of R1 = R2 = 1 kΩ and C1 = C2 = 33 nF. Frequencies higher than 10 kHz are limited by the characteristics of the microphone.

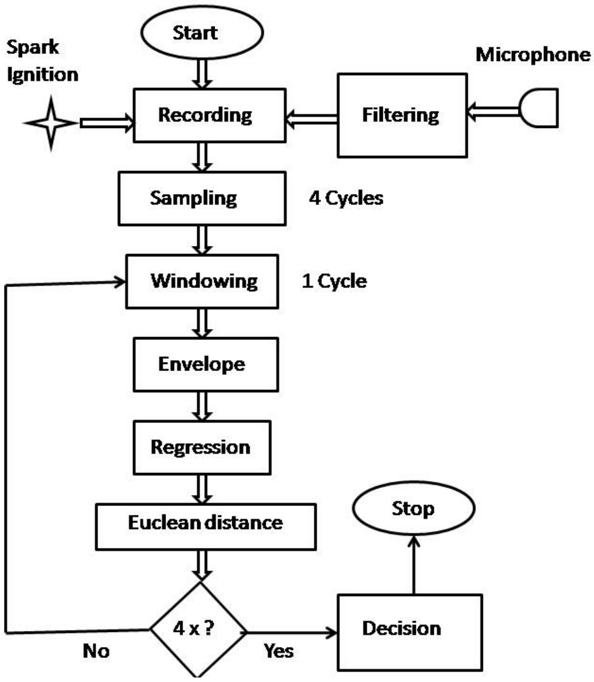


Figure 5. Data processing of detonation sound vibration patterns

Figure 5 shows the detonation sound vibration patterns data processing, starting from the recording using the computer, and then the carrying out of the sampling of the data from the 4 cycles of ignition (4 cylinder) so as to conduct the analysis, which is done by clipping each cycle. The one cycle sample is then analyzed further by making the envelope function and normalizing it in order to obtain the appropriate form of reference standard.

After getting the envelope function in a standardized form, regression is carried out to get a clearer pattern. A Euclidean distance calculation is then performed on the regression function according to this formula (Molinaro at.all, 1995):

$$d^2(v_i, v_j) = \sum_{k=1}^{p} (p_i(k) - p_j(k))^2 \qquad (6)$$

The Euclidean distance result is then assessed: if it is closer to the normal pattern, it means the detonation did not occur and if it is closer to the detonation pattern, it means the detonation occurred.

3. Results

3.1 Filtering

The filter used is a Sallen-Key HPF as seen in Figure 1, with μ = 1, then equation (1) after the data is input will be obtained:

Transfer function: $$\frac{E_2}{E_1} = \frac{1089.s^2}{1089s^2 + 66.10^6 s + 10^{12}}$$

Cut-off frequency: $$\omega_c = 30{,}303 \quad rad/\sec$$

$$f_c = \frac{\omega_c}{2\pi} = 4.825 \quad Hz$$

Once the analysis is done based on the Bode-plot of Matlab, the graph shown in Figure 6 is obtained:

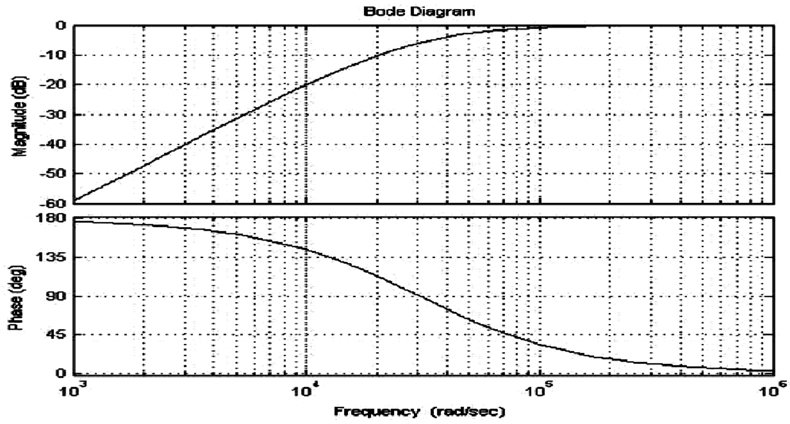


Figure 6. A Bode-plot analysis for the Sallen-Key HPF

The sound of the engine and ignition signal captured by the microphone is shown in Figure 7, recorded as a 20000 data signal in normal engine operating conditions, with no detonation (no-knock), it can be seen that the FFT does not indicate the presence of high-frequency components (> 5 kHz).

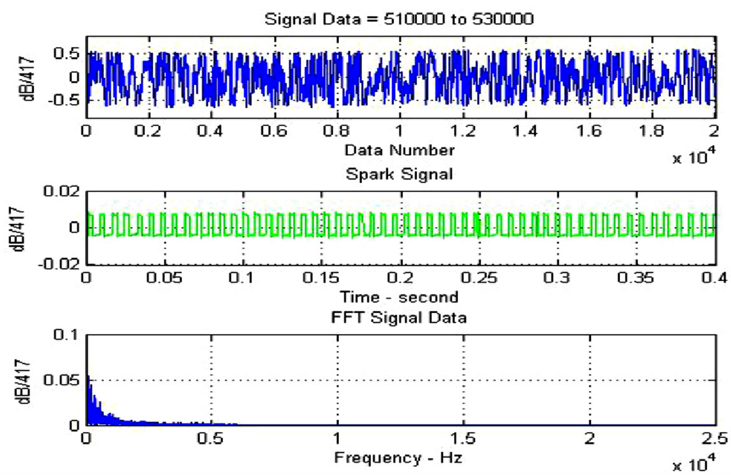


Figure 7. A recorded engine sound signal in normal conditions and its FFT

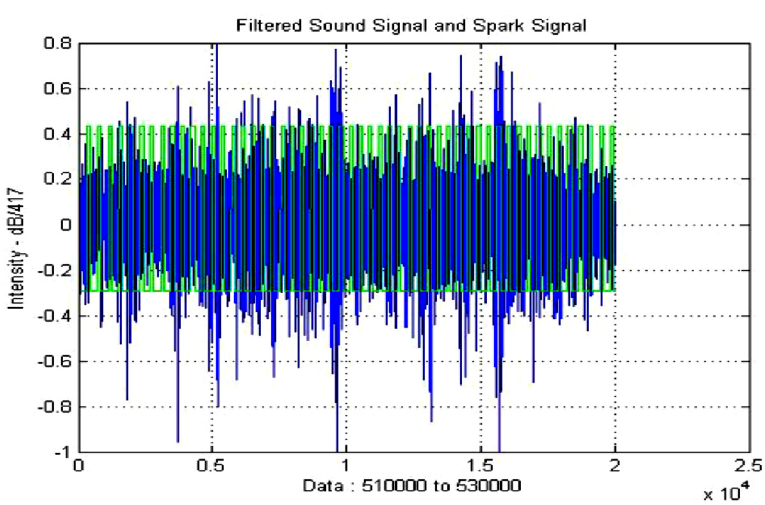


Figure 8. A recorded engine sound signal in normal conditions that has been filtered

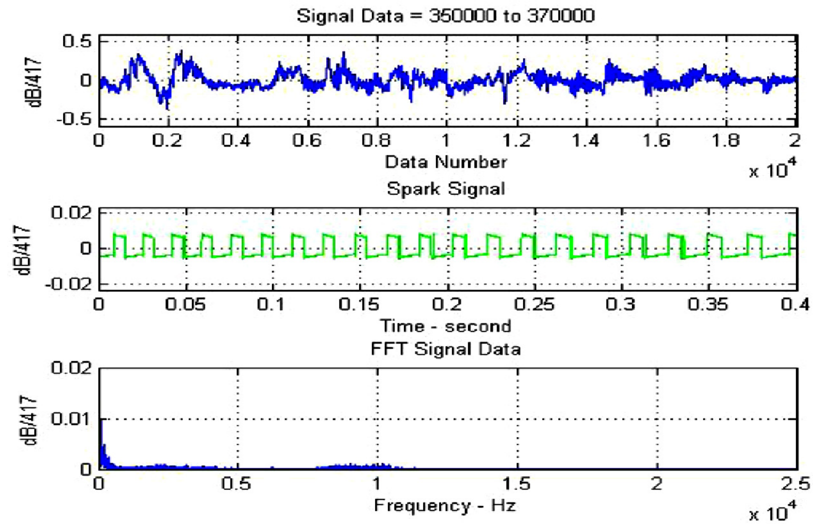


Figure 9. A recorded engine sound signal in detonation conditions and its FFT

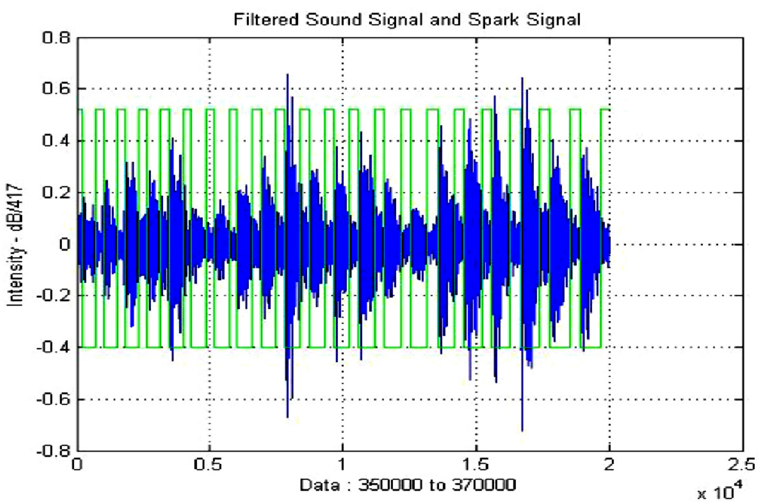


Figure 10. A recorded engine sound signal in detonation conditions that has been filtered

The results of the filtering of the normal engine sounds (no-knock) combined with the ignition signal shown in Figure 8 turned out to show a fairly evenly distributed signal without spikes.

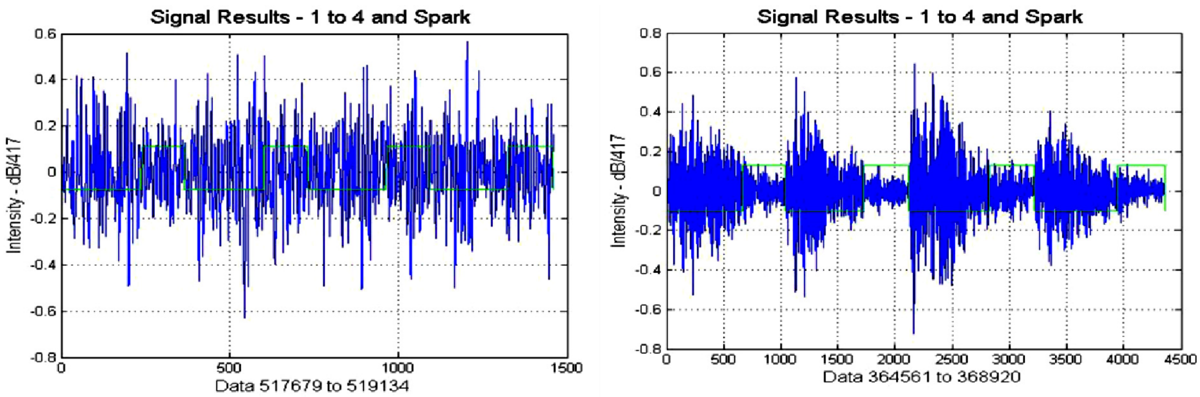
Figure 9 shows the recorded microphone signals are combined with signals from the FFT ignition and the engine sound signal when detonating (knocking). It can be seen on the FFT display that there is a high frequency component (> 5 kHz).

The results of the filtering of the sound signal from the engine in detonation condition (knocking), combined with the ignition signal shown in Figure 10, clearly shows the signal spikes.

3.2 Sampling

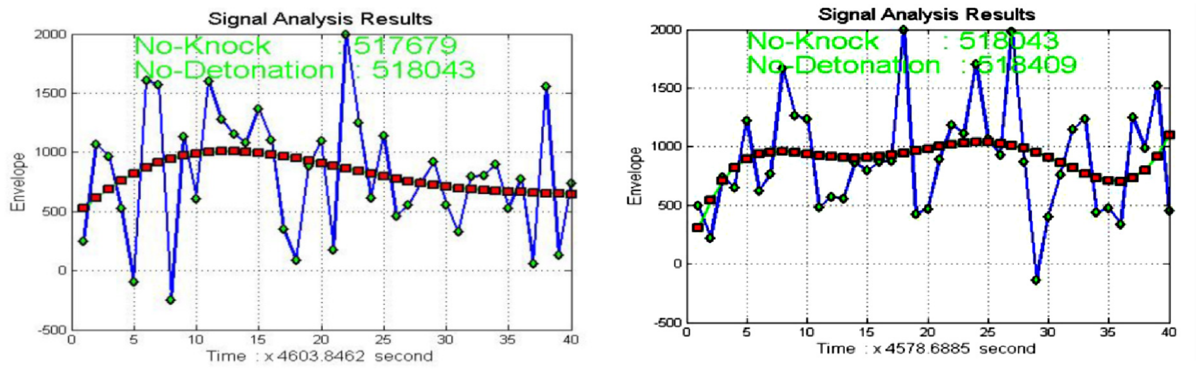
Sampling the 4 cycle ignition (4 cylinder) is carried out for the next process. Figure 11 shows a sample of the sound signal from an engine in normal conditions (no-knock) which looks fairly even and has no spike in the signal.

The signal sample for the engine in detonation conditions (knocking) for 4 cycles of ignition (4 cylinder) shown in Figure 12 shows that the signal pattern spikes), as if forming a triangular or delta pattern.



(a) (b)

Figure 11. Taking the signal sample for a 4 cycles ignition for engine in: (a) normal engine (no-knock), (b) detonation conditions (knock)



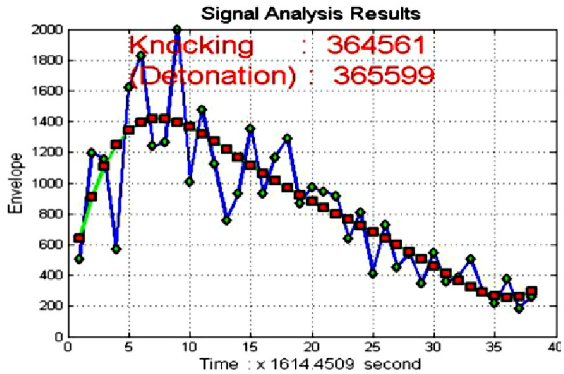
(a) (b)

(c) (d)

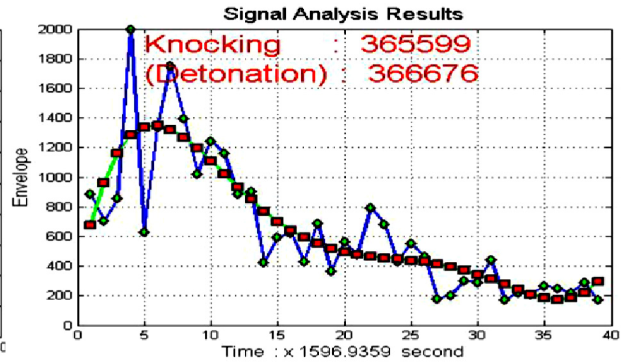
Figure 12. The envelope function and regression, a) cycle 1, b) cycle 2, c) Cycle 3, d) cycle 4, for the engine noise signal in abnormal conditions (no-knock)

3.3 Windowing and the Formation of the Function Envelope

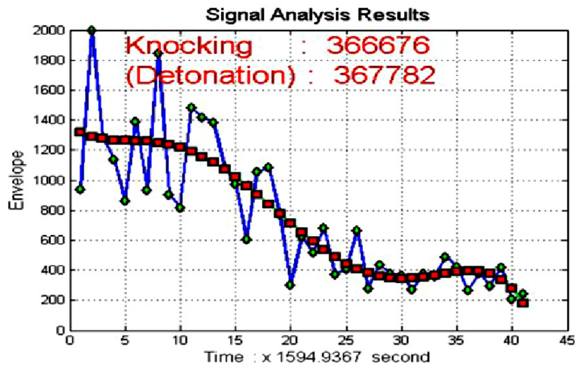
The formation of the envelope function of the signal is conductedfor one cycle using the windowing sampling method to find the form of sound vibration pattern that is obtained. Before further processing, the signal sample is normalized beforehand in order to provide a standardized form and proceed with the formation of the envelope function. Then a regression can be made from the envelope function in order that the form of the pattern more clear. Figure 13 a) cycle 1, b) cycle 2, c) 3 cycles, d) cycle 4 shows the results of this process for the engine sound signal in normal conditions without detonation (no-knock).



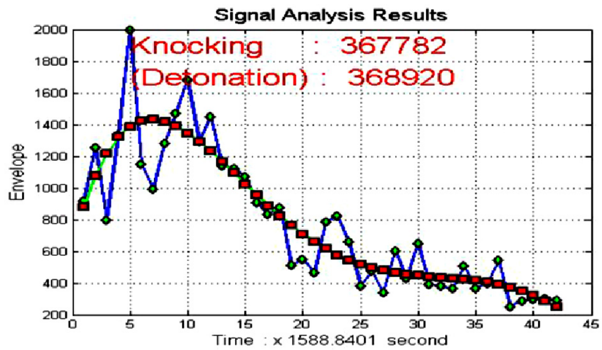
(a)



(b)

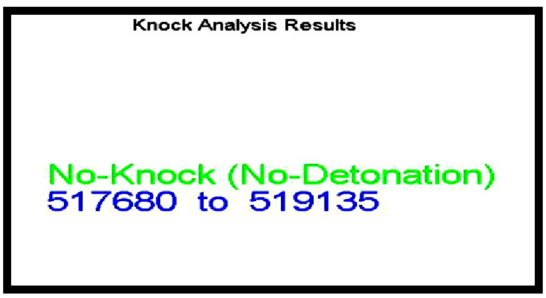


(c)



(d)

Figure 13. The envelope function and regression, a) cycle 1, b) cycle 2, c) cycle 3, d) cycle 4, engine noise signal in the condition of detonation (knocking)



(a) Normal (No Knock)

(b) Detonation (Knocking)

Figure 14. The result of the detonation of analysis: a) and b)

Figure 14. a) cycle 1, b) cycle 2, c) 3 cycles, d) cycle 4 shows the results of the noise signal processing for the enginein the condition of detonation (knocking), which begins with sampling (windowing), the creation of the envelope function and continued creation of the regression to be clear pattern of the sound vibrations that occur

3.4 Identification of Detonation

The identification of detonation (knock) is done by measuring the Euclidean distance between the regression pattern andthe reference signal, in accordance with the formula (6), for each cycle. The results of the distance measurements on each cycle will give a determination: whether it is the detonation signal (knock) or not. In the four cycles tested, in case of detonation (knock) on two consecutive cycles, it may be decided that the moment of detonation had occurred (knocking) in the engine. Figure 15 shows a determination that the signal is a) normal engine, detonation does not happen, and b) engine detonation (knocking).

4. Discussion

When compared between normal signal (Figure 7) with a detonation signal (Figure 9), for the recording of sound source signals is not much difference, but analysis of the FFT becomes obvious difference, which is normal for there is no signal of high frequency components, while for the detonation signal contained many high frequency components. Furthermore, after the high-frequency pass filter (HPF), the wave pattern on the normal signal looks uneven (Figure 8), while the detonation signal seen a lot of turbulence (Figure 10). It is proved that: Sallen-Key filter has been able to work well.

The difference will be more noticeable again in the sampling process, which takes 4 cycles of ignition, ie in Figure 11: a) for normal signals, the wave form pattern visible signal evenly, while in Figure 11: b) for the detonation signal, the wave form pattern, the display agitation like the tip of a child arrows. This is in accordance with reference Figure 2.

Figure 11: a) Normal signal (no-knock), cut by one ignition cycle into 4 pieces, to be made normalization. Of the 4 pieces, having made the function of the envelope, and then made the regression, the results as shown in figure 12: a), b), c), d). Similarly Figure 11: b) signal detonation (knock), cut, normalized, made envelope function and regression, the results as shown in figure 14: a), b), c), d).

Comparison of the wave form pattern of regression between Figure 12 : a), b), c), d), the normal signal (no-knock) with Figure 13 : a), b), c), d), the signal detonation (knock) are as follows: normal signal (no-knock) looks close to flat while the detonation signals (knock) high corrugated. Each signal calculated its Euclidean distance to the reference Figure 3. The results of his calculations to make a decision, indicating the right thing, the signal Figure 12 is normal (no-knock) and Figure 13 is a signal detonation (knock), as given in Figure 14 a) and b). This means that the method has been proven correct.

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