Feature extraction of noise signal in motorcycle by Fast Fourier Transform

M Delina* and P A Nurhusni

Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta, Jl Rawamangun Muka No 1, Jakarta 13220, Indonesia

*mutia_delina@unj.ac.id

Abstract. This research aimed to study the feature of noise signal from various exhausts in motorcycles by the Fast Fourier Transform (FFT). The noise signal was examined into three different features; energy, entropy, and zero-crossing rate. The energy and entropy defined the noise came from an exhaust or non-exhaust, while the zero-crossing rate distinguished normal and racing-exhaust. The results showed that the energy of an exhaust noise was always in the range of 2.4 to 2.8 joule. The entropy of exhausts racing was observed in the range of 0.00 to 0.05 joule. When the acceleration pedal was on, the entropy was become higher. The zero-crossing rate of racing exhaust was in the range of 0.00 to 0.05, the non-racing exhaust was in the range 0.05 to 0.1.

1. Introduction
The noise pollution is overgrowing in the environment because of road traffic development [1] and building construction increment [2]. The noise, which is known as the undesirable intensity of wave [3], always annoyed the surrounding. Noise measurement has been conducted by several studies such as the measurement of commercial microwave noise temperature [4], measuring the exhaust noise from muffler on an excavator [2], noise measurement inside railway vehicles [5], the exhaust noise investigation of aircraft gas-turbine engines [6], and traffic noise measurement [7], to overwhelm it. Because the noise has terrible effects on the health, for example, the hearing damage [8]. This noise level was measured in decibel [9,10].

The exhaust of cars and motorcycles produces the traffic noise, which is the most often experienced everywhere [11]. The Indonesian Police Department sets the noise limit of the exhaust is 77 dB for the lowest cylinder capacity (below 80 cm). This study was focused on the characterization of the exhaust’ noise using the Fast Fourier Transform (FFT) to define the noise signal: a racing or non-racing exhaust. The racing exhaust is produced from a modified exhaust, while the non-racing exhaust is attained from a standard one. The exhaust noise was also divided into two conditions; the acceleration pedal was on and off.

2. The methods
This research was conducted by recording the noise signal from motorcycles' exhaust. The noise signal was clustered into four categorizes (non-racing exhaust with the acceleration on, non-racing exhaust with acceleration off, racing exhaust with the acceleration on, and racing exhaust with acceleration off).
There were eight noise signals for each categorize, therefore there was 32 recorded noise signals. The noise signal was recorded in 30 seconds. The recording tool was set 10 to 30 cm from the exhaust.

FFT has been widely applied in the signal-processing and analysis [12]. When there are a big number of data signals which uniformed distribution, the data signal can be processed by applying the Fast Fourier Transform (FFT).

\[
f(x_j) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} f(x_k) e^{-i2\pi kx_j/D}
\]

where \(D\) is the volume, \(N\) is the number of data and \(x_j = \frac{D_j}{N}\) is the space or time. In the following step, the recorded noise signal was imported to the Mathlab program and analysed. The program categorized each recording signal into several frames and then analyzed it, known as the feature extraction. Each frame's duration was three seconds. The program analyzed the feature based on the energy, entropy, and zero-crossing rate. These three features were obtained from the recorded signal. The noise energy is obtained from the following equation

\[
E(i) = \frac{1}{W_L} \sum_{n=1}^{W_L} |x_i(n)|^2
\]

where \(E\) is the noise energy, and \(W_L\) is the signal frame’s size. Entropy is the irregularity changes in the energy level of the noise signal. Entropy is able to detect the significant changed of the energy. For example, the entropy of noise signal changed when the acceleration pedal is on. The entropy \(H\) is defined as follow

\[
H(i) = -\sum_{j=1}^{K} e_j \cdot \log_2(e_j)
\]

where \(e_j = \frac{E_j}{E_i}\). The zero-crossing rate is the rate of the noise signal change along the zero exist. The zero-crossing rate is defined as follow

\[
Z(i) = \frac{1}{2W_L} \sum_{n=1}^{W_L} sgn[x_i(n)] - sgn[x_i(n - 1)]
\]

where the \(sgn()\) is the signum function which is defined as

\[
sgn[x_i(n)] = \begin{cases} 1, & x_i(n) \geq 0 \\ -1, & x_i(n) < 0 \\ \end{cases}
\]

The extraction was repeated as the number of frames. Finally, the features were plotted in a 3D and 2D diagram.

3. The results and discussion

The results were plot in the 3D and 2D diagram. In the 3D diagram, the \(x\)-axis was the noise energy (joule), the \(y\)-axis was the entropy (joule), and the \(z\)-axis was the zero-crossing rate. The zero-crossing rate is the rate of sign-changes along a signal. Figure 1 was plotting the 34 extracted noises. The condition was defined as racing and non-racing exhaust, whereas acceleration was on and off. The red dots were the noise recording of non-racing exhaust, whereas the blue dots were the noise recording of the racing exhaust. The crosses were the noise recording with the accelerate was on, and the bullets were the noise recording with the accelerate was off.

The 3D diagram showed that red dots or the noise of non-racing exhaust were in the button of the diagram. It means the non-racing exhaust has lower energy and entropy. While the position of the blue dot was higher than the red dots, it means the racing exhaust’s energy and entropy were higher than the
The 3D diagram was then split into two 2D diagrams; Figure 2(a) showed the plot of entropy as the function of energy and Figure 2(b) showed the plot of zero crossing rate as the function of energy.

**Figure 1.** 3D diagram of energy, entropy and zero-crossing rate of the noise.

Figure 2(a) shows the entropy as the function of energy. The entropy of non-crossing and crossing exhaust was in the range of 0 to 0.05 joule. While when the acceleration was on, the entropy was higher with the range of 0.15 to 0.3 joule. Figure 2(b) showed the zero-crossing rate as the function of energy. The diagram showed that the exhaust energy was always in the range of 2.4 to 2.8 joule, and the zero-crossing rate was in the range of 0 to 0.1. At this stage, the difference between exhaust and the non-exhaust noise was identified as well as racing and non-racing exhaust. The energy of an exhaust was always in the range of 2.4 to 2.8 joule. The zero-cross rate of the non-racing exhaust (blue dots) was in the range of 0 to 0.05, while the racing exhaust (red dots) was in the range of 0.05 to 0.1.

**Figure 2.** (a) the plot of energy as the function of entropy and (b) plot of zero crossing rate as the function of energy.

4. Conclusion
The Fast Fourier Transform was able to characterize the noise signal based on the energy, entropy, and the zero-crossing rate. The noise energy of exhaust was detected in the range of 2.4 to 2.8 joule. While the entropy of exhaust racing was observed in the range of 0.00 to 0.05 joule. When the acceleration
pedal was on, then the entropy was become higher. The zero-crossing rate was able to identify the noise of exhaust into racing and non-racing exhaust. The zero-crossing rate of a racing exhaust was in the range of 0.00 to 0.05, while the zero-crossing rate of non-racing exhaust was in the range of 0.05 to 0.1.

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