Rate of Fire Measurement Based on Audio Signal Processed by Using Wavelet Transform and Peak Detection Algorithm

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***Abstract*—** Assault rifles when burst firing will produce noise with big sound intensity. This noise can be used as an audio signal to measure the rate of fire. However, this audio signal needed to be processed using wavelet transform to avoid noise before it was processed using a peak detection algorithm. The difference in time each peak detected will be converted as the rate of fire. This research is a method to measure the rate of fire results average of accuracy 99.06%.

***Keywords*—** audio signal, peak detection algorithm, rate of fire, wavelet transform.

I. INTRODUCTION

Small arms and light weapon must be in good shape before it can be used by soldier on a mission There are several variables that needed to be measured to know the performance of weapon, they are accuracy, initial velocity, and rate of fire. These variables value must be matching with the specifications of the weapon so it can be said that the weapon is ready to be brought by soldier on a mission.

This research purpose is to know how to measure rate of fire based on weapon audio signal so it can be implemented for rate of fire measurement instrument. Rate of fire is the number of rounds fired per weapon per minute [1]. This is one of the important variables to know the performances of weapon, especially for assault rifle and machine gun. Instrumentation is needed to measure this value because it must be calculated fast. Assault rifle has rate of fire value 460 – 900 RPM [2], so it would be impossible to calculate it without instrument.

Assault rifle when do burst firing will produce sound. This sound can be identified as audio signal. As each shot in burst firing would produce sound, theoretically we could precisely count how many shots happened in burst firing.

To identified each shot we must know how the audio characteristics of its shot. Audio signal recording usually stored of amplitude each sample point, and the sampling rate. The amplitude of each point can be viewed by waveform of signal. In this research, waveform of signal produce by burst firing will be analyzed to measure rate of fire.

Peak detection algorithm is an algorithm used to identified peaks in time series data. Identifying and analyzing peaks (or spikes) in time-series data can be important in many applications. Peaks indicate notable event such as sudden increase in amplitude of signal. [3]

Each shot in burst firing will produce its own audio signal. To count how many shots had happened we can use peak detection algorithm. As each shot will have its own peak that can be detected by using this algorithm. Rate of fire measurement can be done by record time on each detected peak.

Audio signal produce by burst firing has noise that can be influencing the waveform and confusing the peak detection algorithm. Since the noise signal of the burst firing has high amplitude, peak detection algorithm cannot perform well. We need to process the audio signal before to get the desired waveform and implement peak detection algorithm.

The Wavelet Transform (WT) is a technique for analyzing or processing signals. It was developed as an alternative to the short time Fourier Transform (STFT) to overcome problems related to its frequency and time resolution properties [4]. In contrast to STFT having equally spaced time-frequency localization, wavelet transform provides high frequency resolution at low frequencies and high time resolution at high frequencies [5]. The Discrete Wavelet Transform (DWT) is a special case of the WT that provides a compact representation of a signal in time and frequency that can be computed efficiently. This process had been implemented on many processing such decomposition, detection, recognition, image retrieval *et al* [6].

Audio signal and noise from recording of burst firing can be separated by using wavelet transform. The desired signal has higher frequency, and the noise has lower frequency. Since the DWT will separate signal into two new wavelet (detailed coefficients and approximation coefficients) that has higher and lower frequency. By this reason DWT can be implemented as processing before audio signal processed using peak detection algorithm.

II. METHOD

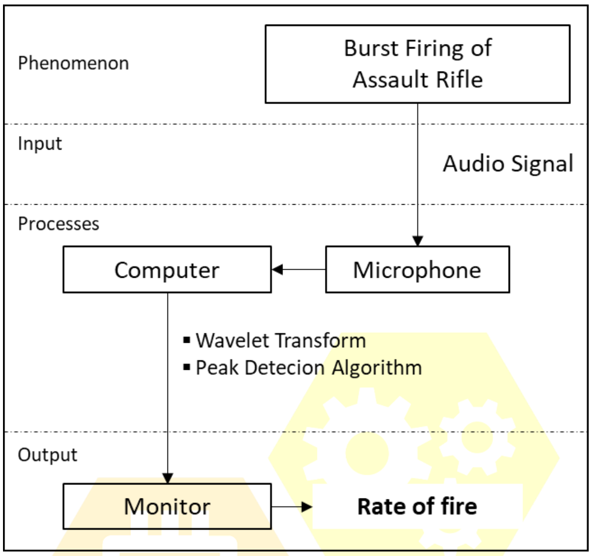

Figure 1: *Data Collecting Scheme*

Burst firing of assault rifle as phenomenon in this research will produce sound. The sound as audio signal from it will be the input that will be captured by microphone and processed by computer. Processing that will be given to signal was wavelet transform and peak detection algorithm. The final output rate of fire will be shown in monitor.

Signal processing such as wavelet transform, peak detection, and rate of fire calculation will be programmed using python. PyWavelets packages was used to do wavelet transfrom [7]. And peak detection algorithm was done by using scipy.signal packages.

A. Audio Signal Recording

An assault rifle was used as sample in this research. Then we recorded its audio while this weapon did burst firing and measure its rate of fire using standardized rate of fire measurement instrument. This measurement would be used to compare the results of this research. This work was done indoor.

Audio signal recorded using WCD9375 microphone with tas256xsw driver and sample rate of 44100. Then the waveform of this recording is analyzed to be processed on the next step.

B. Wavelet Transform

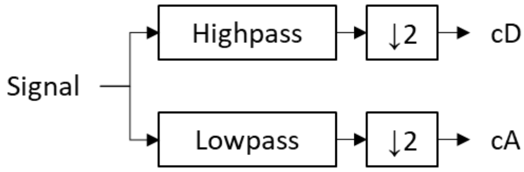

Figure 2: *Wavelet Transform*

The discrete wavelet transform (DWT) of a signal is defined based on approximation coefficients (cA), and detail coefficients (cD). The approximation coefficients at a higher level are passed through a highpass and a lowpass filter, followed by a downsampling by two to compute both the detail and approximation coefficients at a lower level [4]. As shown in figure 2 cD was the result of signal processed by highpass filter, cA was result of signal processed by lowpass filter. Waveform by this process will be analyzed so it can be implemented to peak detection algorithm.

C. Peak Detection Algorithm

Waveform of the signal processed by wavelet transform will be processed by peak detection algorithm. Each peak detected by this algorithm represent each shot in burst firing. Time of the peak detected will be stored to calculate rate of fire.

III. RESULT AND DISCUSSION

A. Raw Audio Signal

Sound produces by burst firing was captured by microphone, then recorded and stored in computer. How many shots happened in burst firing was counted and sound intensity was measured using sound level meter. As shown in Table 1 there are 4 data, Data 1 and Data 2 is burst firing 3 shots, then Data 3 and Data 4 is burst firing 6 shots. Sound intensity measured was in range 101.8 dB to 102 dB. It's mean we need to record audio signal produces by burst firing using microphone that has recording range sound intensity higher than 102. Microphone WCD9375 has recording dynamic range up to 109dB, so it can be used for this purpose.

Table 1: *Count Shot and Sound Intensity*

Data	N	Sound Intensity (dB)
Data 1	3	101.8
Data 2	3	101.8
Data 3	6	102
Data 4	6	102

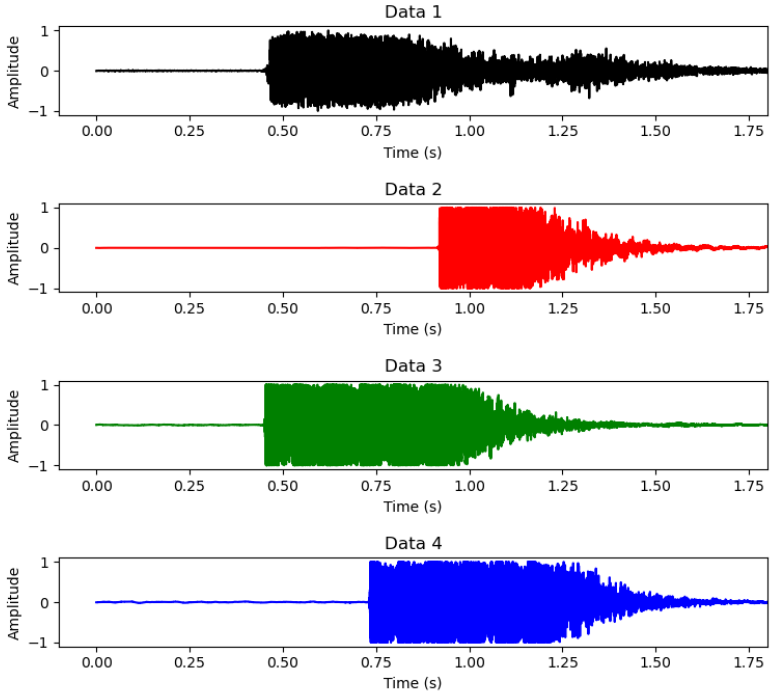

Figure 3: *Waveform of Raw Audio Signal*

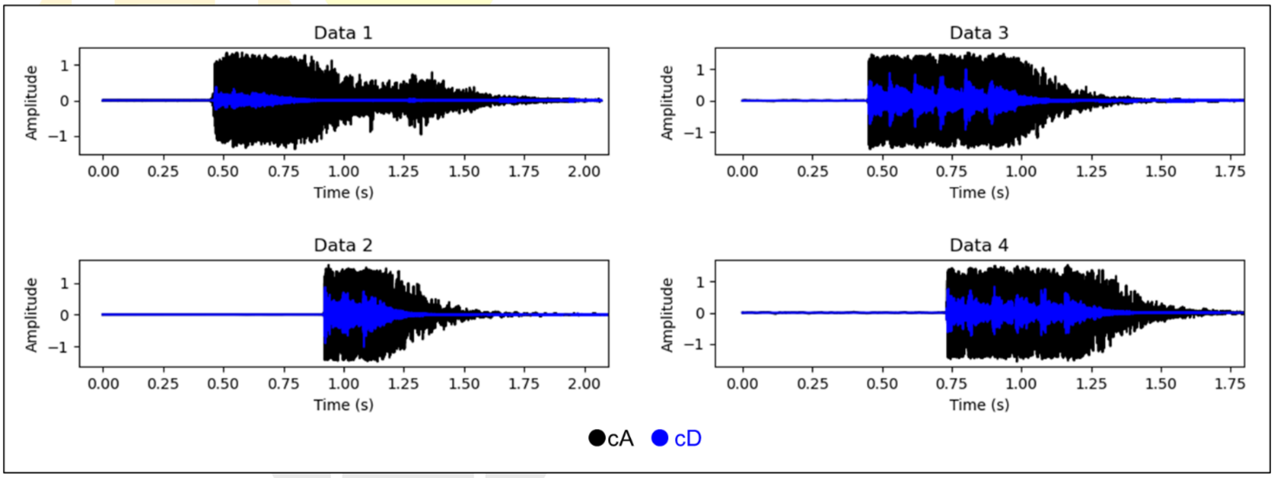

Figure 4: *Waveform of cA and cD from Wavelet Transform*

Raw signal is a signal that hasn't been given any signal processing. It's a signal that recorded by microphone and directly stored to computer. Figure 3 shown the waveform of raw signal of audio signal from burst firing. As shown in the figure 3 x axis is sampling points in time and y axis is amplitude that had been normalized. It can't be seen clearly that in Data 1 and Data 2 is audio signal from 3 shots or in Data 3 and Data 4 is audio signal from 6 shots. That's mean signal processing is needed to make the waveform of signal show how many shots has happened clearly.

B. Wavelet Transform of Audio Signal

Raw signal that has been stored then processed using wavelet transform. This process will produce two new signal, cA and cD. Figure 4 shown waveform of signal after processed by wavelet transform. Black colored graph is cA from wavelet transform, and blue colored graph is cD from wavelet transofrm.

Waveform of cD shown repetitive pattern that has equal amount with the shot had happened while recording audio signal. Amplitude of cD in Data 1 was too low compare to amplitude of cA, it made repetitive pattern on it was not so clear. But we can see clearer in figure 6. Data 2, 3, and 4 shown repetitive pattern clearly that has equal amount with the shot had happened. Based on this result, waveform of cD wavelet transform can be processed advanced to be detected its peak to calculate rate of fire.

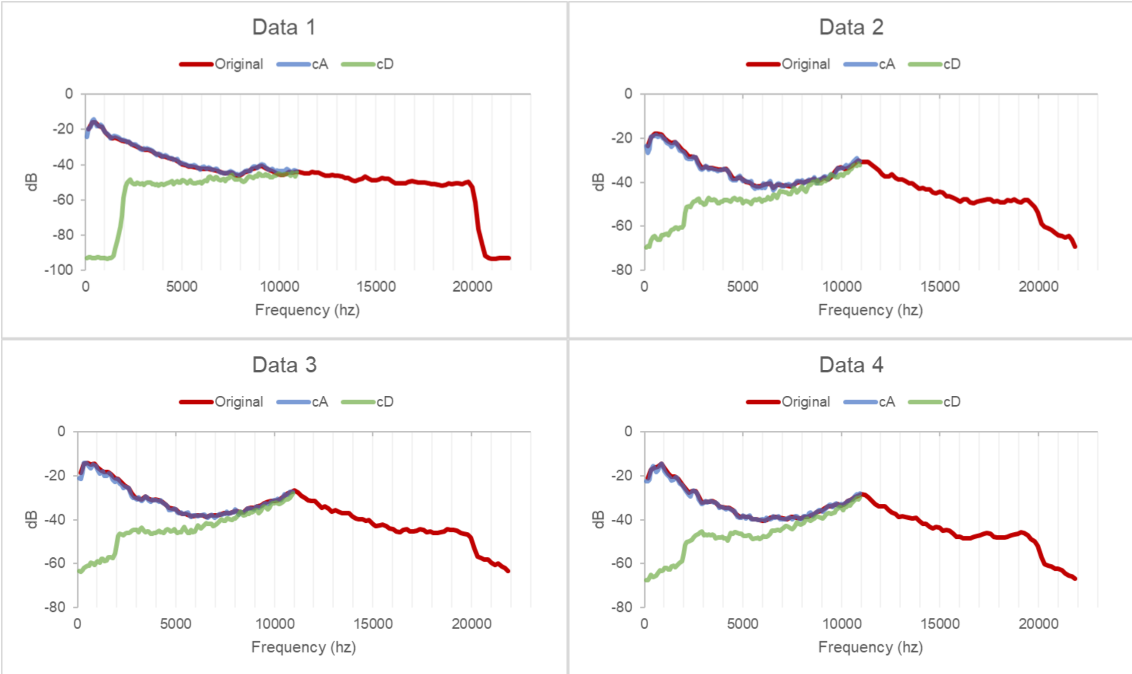

Figure 6: *Frequency Distribution of Signal*

cD from wavelet transform has information for high frequency signal. As it said before that initial signal that become cD signal has been processed by high pass filter. It’s mean that the audio signal that needed are in high frequency. It can be seen in Figure 6 that shows frequency distribution of each signal, the higher frequency has more intensity than the lower frequency in cD for each data. After original signal processed by wavelet transform range frequency of cA and cD became a half of its original. This is because of results from wavelet transform will be down sampled by 2.

C. Peak Detection on Waveform of cD

Repetitive pattern from wavform of cD signal always have a peak. Each peak will be considered as 1 shot from burst firing. However, before the signal given peak detection algorithm, signal still had to be processed before. First process was normalization data to make its amplitude range between -1 and 1. Then, the next process was absolute value function, so the amplitude will always in positive number.

Normalization data was done to make the max amplitude value on each data is 1, no matter its sound intensity. This will help reference parameter that will be consider as peak in pattern.

Furthermore, this process will give flexibility of recording distance, because after normalization all of audio signal will always only has amplitude value between -1 and 1.

Absolute value function was needed because in one pattern there are two peaks, one peak on above, and other on below. This absolute valu function will make one pattern on waveform of cD will only had 1 peak. And this process will make the amplitude always in positive value.

Peak detection algorithm needs some properties reference to be defined as a peak. In this research two properties were used as peak parameters. They are height and distance. Height properties reference defined amplitude value to be detected as a peak. And distance properties defined the shortest distance (x axis) before it can be detected again as a peak.

Height properties reference was set to 0.5. This mean samples point which has amplitude value more that 0.5 will be detected as peak. Every peak in one data does not have the same height of amplitude, so we can’t set the height properties to 1. The height property was set to 0.5 because the lowest amplitude of peak is 0.52, so the height properties must be below the lowest amplitude of peak to make the algorithm work properly.

Distance properties was set to 50ms. This mean the shortest time of each peak is 50ms. Distance properties should be defined because in one pattern of peak sometimes has more than one sample that has value more than the height properties that has been set. The highest rate of fire that still possible to be measured by this set is 1200rpm. And because of the sample in this research has ideal rate of fire up to 800, the algorithm in this set should be enough to measure its rate of fire.

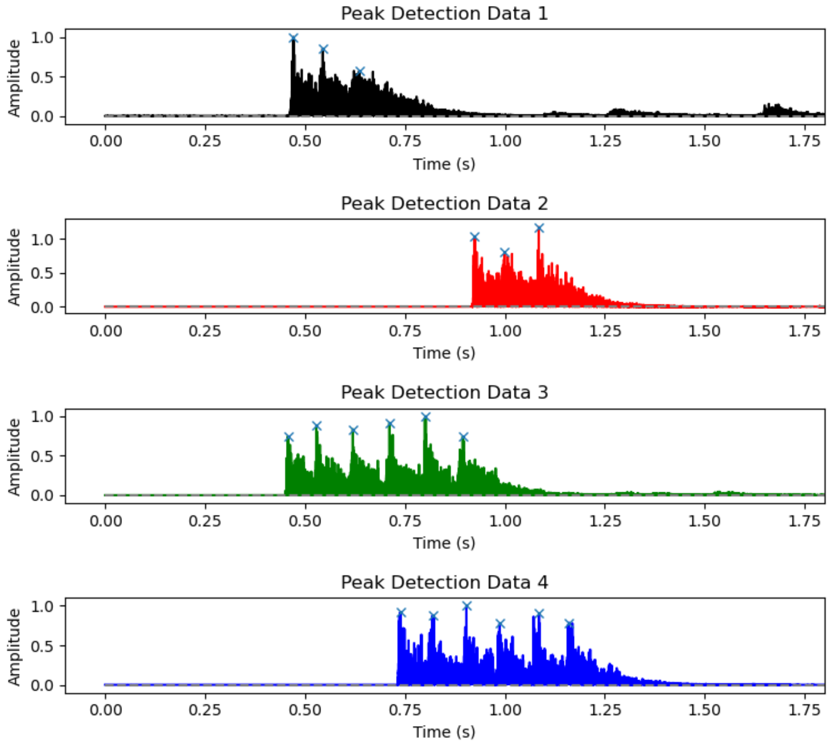

Figure 6: *Peak Detection on Waveform of cD*

D. Rate of Fire Calculation

Table 2: *Rate of fire calculations*

		Data 1	Data 2	Data 3	Data 4
Shots		3	3	6	6
Peak Detected	1	470.88 ms	924.04 ms	457.37 ms	738.19 ms
	2	544.35 ms	999.18 ms	528.12 ms	819.59 ms
	3	635.87 ms	1084.54 ms	619.46 ms	903.58 ms
	4			711.25 ms	986.71 ms
	5			801.63 ms	1085.08 ms
	6			894.69 ms	1159.86 ms
Rate of Fire	Measured	755	751	698.6	713.7
	Calculated	736.13	750.70	693.44	717.09
	Error	2.50%	0.04%	0.74%	0.47%
	Accuracy	97.50%	99.96%	99.26%	99.53%
Average of Accuracy		99.06%			

Each time peak detected by the algorithm was stored and will be used to calculate rate of fire. Formula 1 will be used to calculate rate of fire.

$$rof = \frac{60}{n} \cdot \sum_{i=1}^{n} \frac{1}{(t_i - t_{i-1})}$$

Formula 1 – Rate of fire calculation

Rate of fire can be calculated using the average of one divided by difference time of each peak in second. To get rpm unit the calculation should be multiplied by 60.

Calculated rate of fire by this algorithm was compared with measured rate of fire by rate of fire measurement that had been recorded before. Table 2 shown time peak detected by the algorithm, measured rate of fire, calculated rate of fire, and accuracy of the calculation. As shown in table above the average of accuracy of this calculation is 99.06 %. The most accurate calculation was in Data 2 with 99.96% of accuracy. And the least accurate was in Data 1 with only 97.50% of accuracy.

IV. CONCLUSION

Peak detection algorithm can be used to calculate rate of fire. However, the audio signal should be processed by wavelet transform before. Waveform of cD from wavelet transform had peaks count which are equal to the shots in burst firing. This method calculation to measure rate of fire had average accuracy of 99.06%.

V. RECOMENDATION

This research needs to be continued. Places where audio signal was recorded in this research is only in indoor, so outdoor test can be the next research to know how the waveform of its audio signal and can the same signal processing used to calculate rate of fire. Maximum rate of fire that can be measured by using algorithm in this research is 1200, it would be better to modify the algorithm to reduce the limit of its capabilities.

ACKNOWLEDGMENT

The author would like to thank for PT Pindad Persero and Defense Technology Faculty of Indonesia Defense University for their support, facility, and encouragement to publish this paper.

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