Advanced signal processing assignment

I. Task 1

The main point of this report that removes noise efficiently is understanding the characteristic of the term signal not only in frequency domain but time domain to achieve eliminating only the noise element from a contaminated signal. In this report, the work adopts No. 18 signal as the term to analysis the performance in noise removing by using different methodologies. The signal is divided into 5 parts (Fig.1) by distinguishing whether it is a regular signal or not. With using this method, the main elements which assemble the segment signal can be observed more evidently in frequency domain and easily to analysis the signal for noise removing rather than considering the whole signal.

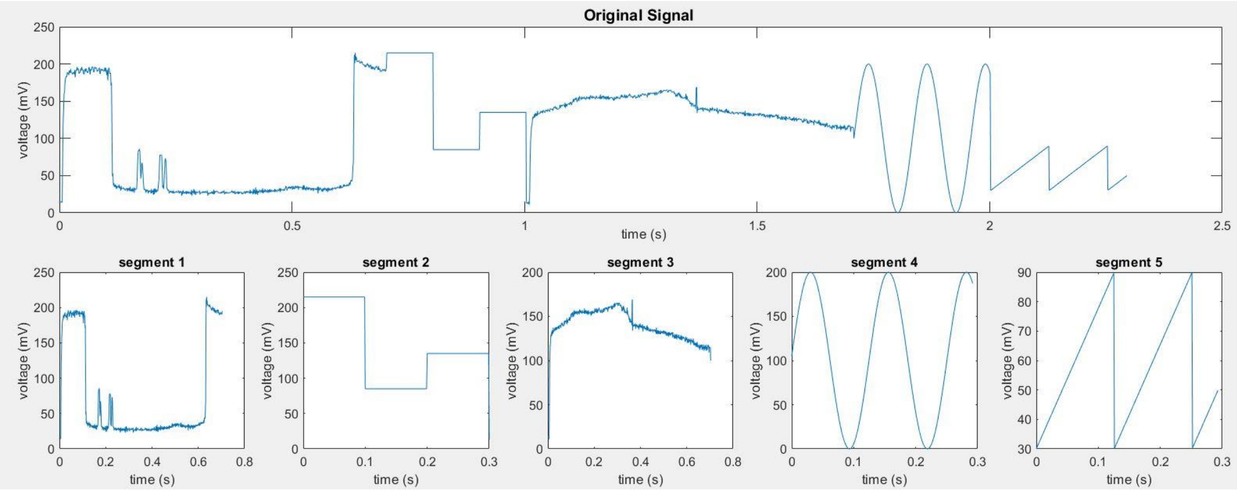

Fig. 1

In time domain, to analysis the signal more precisely, the work exploits 0.1ms for time interval initially. However, the signal frequency in each segment will increase significantly which leads to the higher sample rate is needed and each frequency elements would be too close to be observed due to the range of frequency domain is extend. Therefore, the work adopts 1ms time interval and 1khz sample rate to shrink the spectrum but ensure keeping high frequency element of the original signal when analysing. In addition, the main point to analyse the signal in time domain is observing not only the frequency of the signal and magnitude but distinguishing whether the term signal contains small variation element. As a result, the algorithm employs moving different filter (MDF) which using the simplest high pass filter h[1,-1] to observe the variation between each continuous data after using convolution. Moreover, to evaluate the performance of noise removing, the work exploits the function in MATLAB library to calculate peak signal to noise ratio (PSNR) which provide a functionality of detecting magnitude variation and phase shifting between the original signal and polluted signal by calculating the average noise power in per point. Furthermore, to observe the characteristic in the frequency domain, the work employs fast Fourier transform(FFT) to analysis each frequency components which compose the term signal by using $\frac{1}{(2^{\log_2 segmen\ length})}$ as the frequency interval.

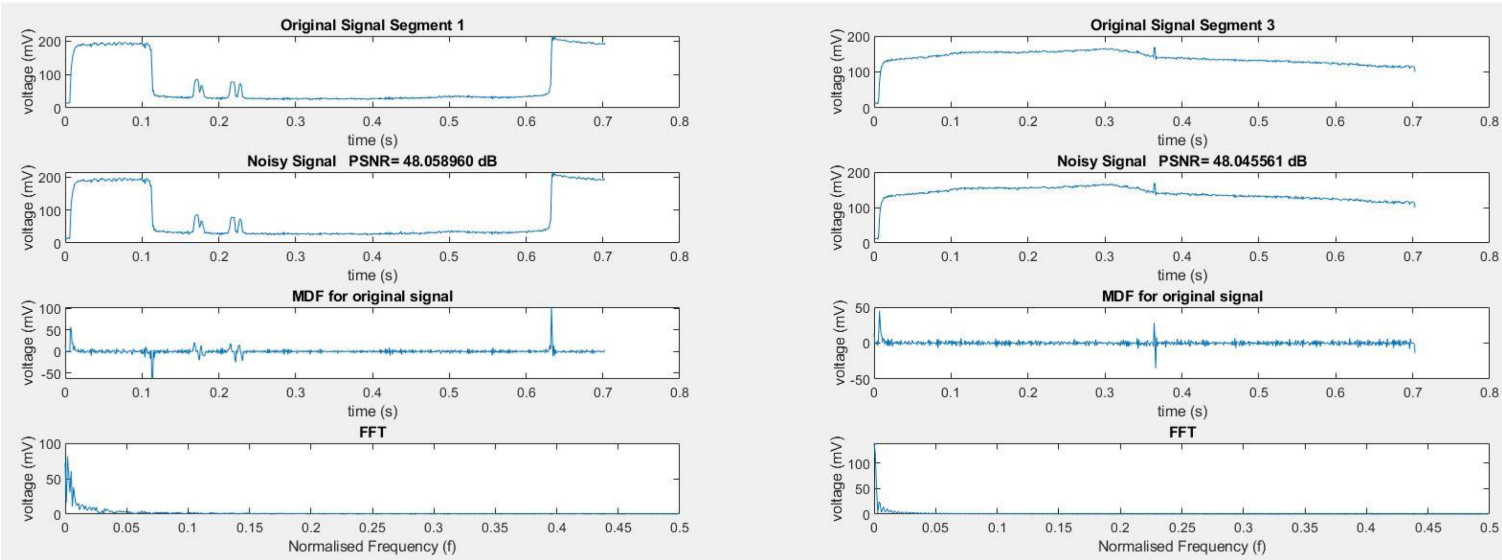

Fig. 2

The result of each segment operating FFT and MDF are demonstrated in Fig. 2 and Fig 3. According to these figures, each of the PSNR value is around 48 dB, which means the signal has approximately 1 mV variation in each of the data. For the signal segment 1 and segment 3 (Fig. 2), the figure of these signal pass through the MDF fluctuate evidently, it proves the original signal may contain some low magnitude but high-frequency element during in these periods. In addition, when analysing each of signal in the frequency domain, the main power of the components concentrate in 0 to 0.1 fs and with some weak element distributing in the rest of the spectrum. Therefore, it is tough to remove noise from a contaminated signal due to some components in the original signal have similar characteristic with noise element.

Furthermore, in segment 2 and segment 5 (Fig. 3), the MDF provides the signal characteristic that the spike signal only happens when the figure changing and contribute a high magnitude variation in MDF. In FFT, it shows that square wave is assembled by harmonics sin wave with odd frequency and sawtooth is combined by odd and even harmonics. Both of the main components concentrate on low frequency and the power of other components decrease by increasing frequency. Based on the characteristic, the efficient strategy to eliminate the noise from the square wave is removing the element with even frequency. According to the analysis in FFT, the sawtooth wave is composed of a wide frequency range of the components which are distributed from 0 to 0.3 fs. The method to improve PSNR might be removing the frequency which higher than 0.3 fs.

In addition, the variation in sine wave changes slowly, and the main component concentrates in low frequency as well. The frequency of the sine wave is around 8 Hz due to it takes 1.25s to complete a cycle. Surprisingly, by using FFT, the result shows that the components of the signal are not only composed of 8 Hz element but contain other components with small magnitude. By removing the high-frequency element, it could slightly improve PSNR performance.

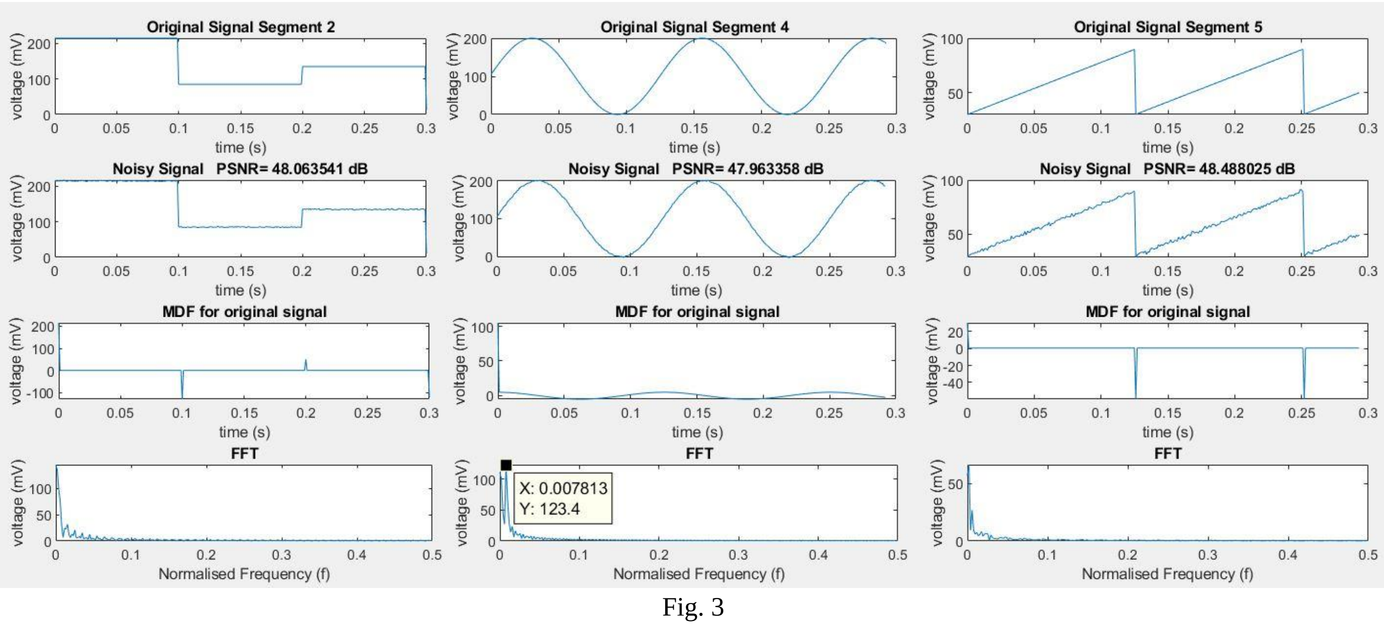

Fig. 3

II. TASK 2

In this section, the principle to remove the noise is eliminating the element which does not belong with the original signal in the frequency domain, and that is mentioned the result in task 1. For instance, in segment 2, the square wave is composed by harmonics sin wave with odd frequency. Therefore, the algorithm employs a threshold to eliminate the component which is below it in even frequency, and the performance of noise removing is illustrated in Fig. 4. It is clear that in Fig. 4 some element's magnitude in even frequency is higher than the original one. Although the value of these components after operating by the algorithm is lower than the original one, the gap decreases significantly comparing with the noisy one Fig. 4. By using this method, the performance of PSNR is improved slightly from 48.06dB to 48.20dB.

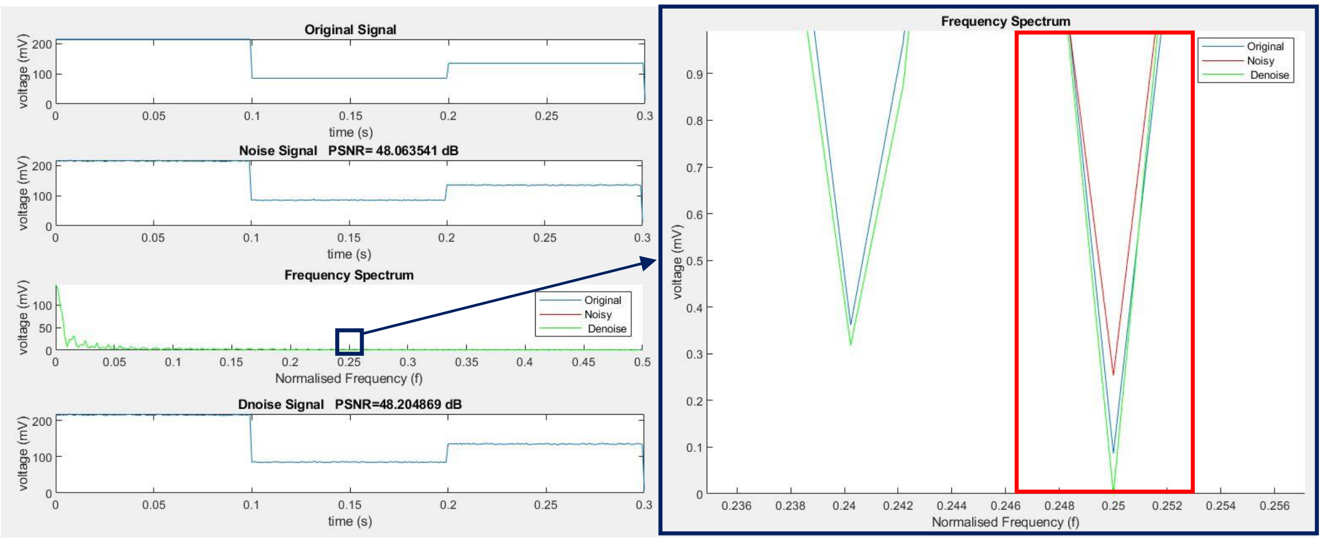

Fig. 4

In addition, for other segments, due to the components are distributed irregularly in the spectrum, the method using in the square wave is not compatible anymore. Therefore, by using a threshold to remove the component, which is below it is an efficient method to improve PSNR. To optimise the performance of PSNR, the algorithm adopts a for loop that increasing threshold 0.01 each loop until 2 to find the highest PSNR by storing the higher one when comparing the value in each step. Due to the different signal characteristic in each segment, the performance of PSNR by using different threshold in each segment are demonstrated in Fig. 5. According to figure 5, each of the PSNR declines slightly due to the algorithm starts eliminating the original components when the threshold exceeds a specific value.

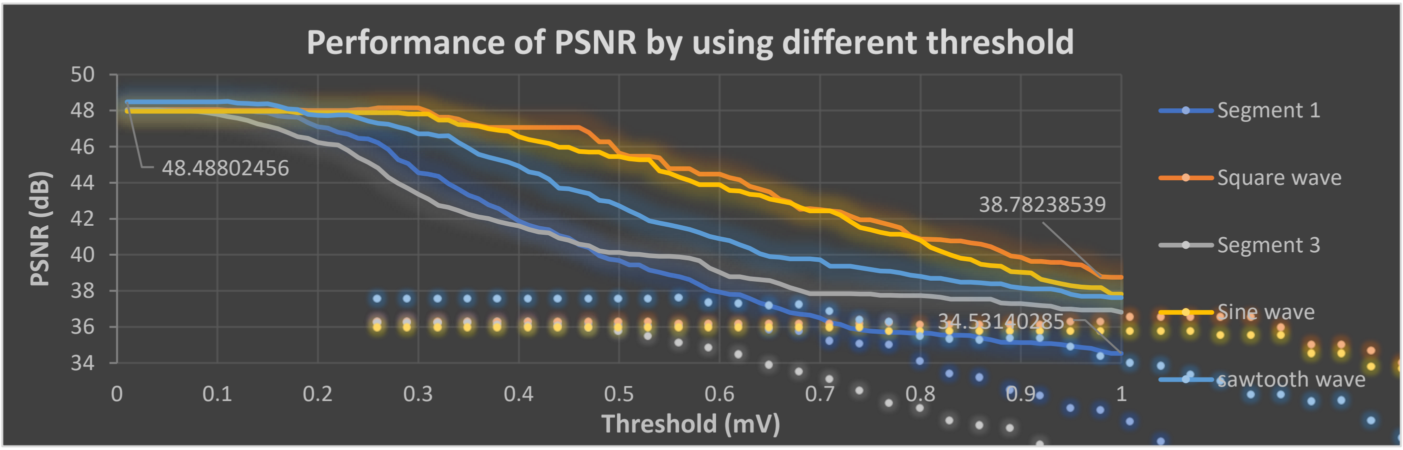

Fig. 5

Based on the analysis, the final threshold value to optimised each section of the performance has been shown in Fig. 6. In segment 1 and 4, the value of PSNR still stays remain with around 48dB as the noisy one due to some of the noise component has combined with the original one. It leads to the algorithm can not distinguish the noise element form them because of the magnitude of noise in each frequency is still uncertain. Similarly, due to the sawtooth wave is composed by the regular odd and even harmonics, by eliminating the component which is out of this role, the value of PSNR is improved slightly with an increase of 0.02dB. According to Fig. 7, it shows the comparison between noisy signal and the recovered one. It is clear that by using the methodology above the value of PSNR can be enhanced slightly form approximately 48.09dB to 48.11 dB.

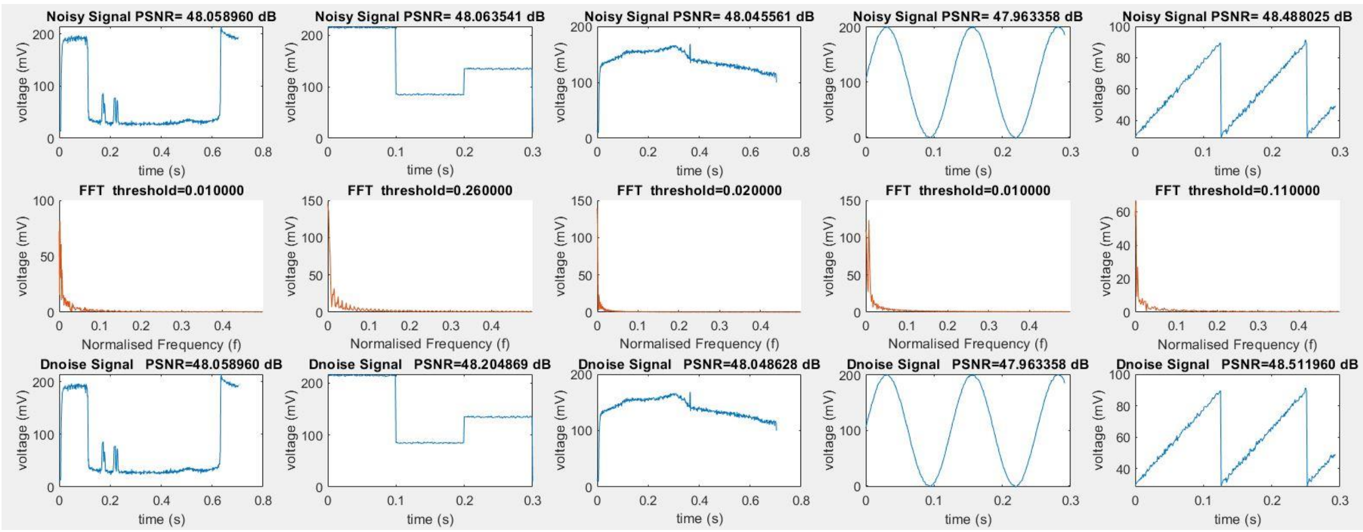

Fig. 6

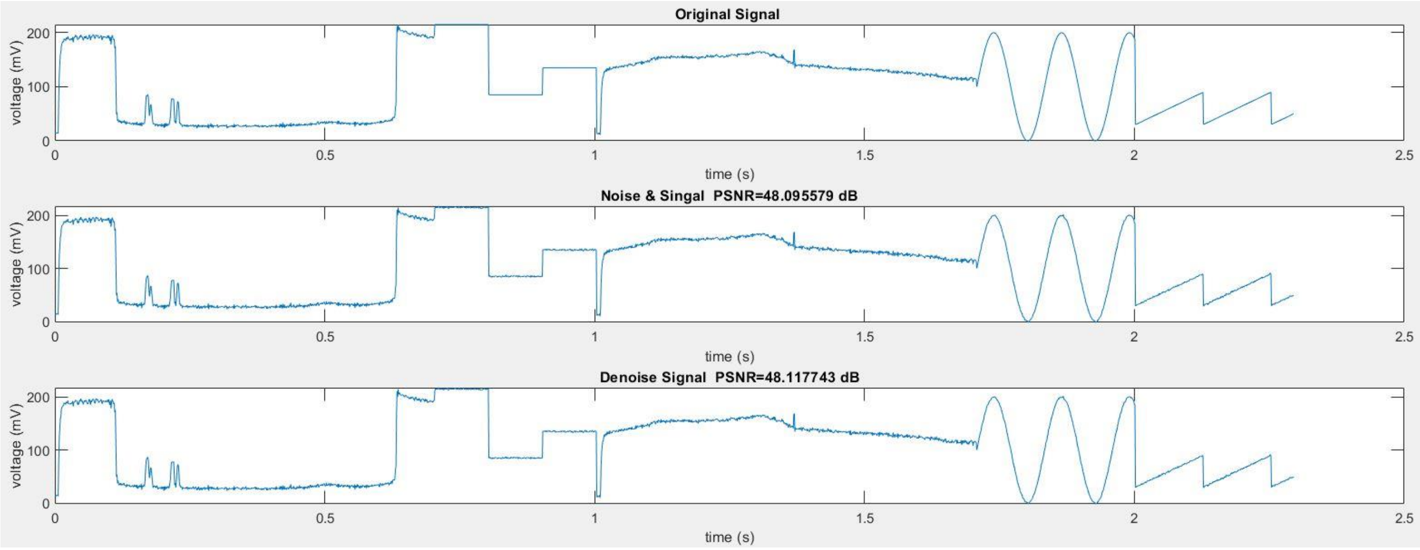

Fig. 6

Initially, the work exploits a frequency threshold to eliminate the noise element whose frequency is higher than it. However, even by using this method, the issue still can not be alleviated due to the strategy not only removes the noise element but also clear the original components with high frequency. Therefore, it leads to a dramatic decrease in PSNR value which is worst than the noisy one. In addition, as mentioned, the main reason why the PSNR can not be improved significantly is the components of noise have integrated into the original one. Therefore, without measuring the magnitude of noise in each frequency point, the signal can not be recovered efficiently. Moreover, by using for loop to find the best threshold, it proofs that using the average of the noise magnitude in the frequency domain as a threshold is not accurate due to the different characteristic of segment signal.

III. TASK 3

In this section, to analysis the relationship between N and PSNR flexibly, the algorithm adopts a method to adapt the different length of the segment for executing any size of DCT transform. Firstly, the algorithm will check whether the length is multiple of N before executing the transform and divide it into several parts to fit the size of the transform matrix. Each piece of data is executed by DCT and using the threshold to eliminate the coefficients whose magnitude after absolute is lower than the threshold to contribute the fluctuated elements removing. Furthermore, if the length is not divisible by N, the program creates a new matrix whose length is the same as the length of remain element for executing the remain data to prevent the data from distortion. To optimise the PSNR in each segment, the algorithm exploits the for loop to find the best threshold which using the same strategy in part 2. By using this methodology, the noise elements can be eliminated and recover it to the original figure as shown in Fig. 7.

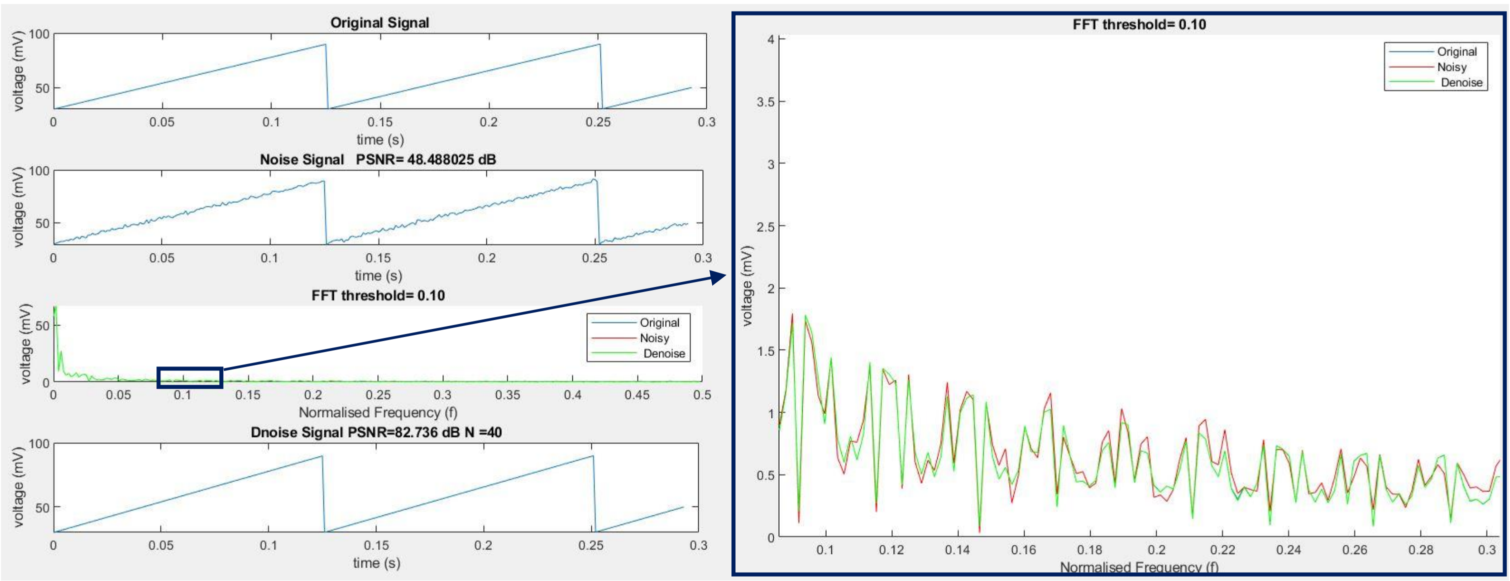

Fig. 7

* Note: Green figure covers on almost all the original one

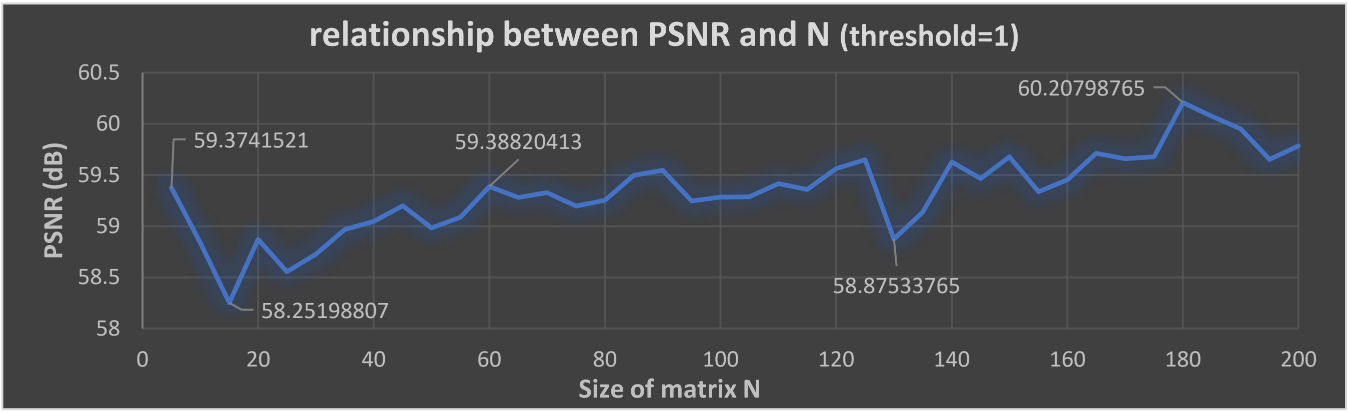

Fig. 8

In addition, the relationship between PSNR and the size of DCT matrix by using the same threshold is demonstrated in Fig. 8. Due to the transform provides more coefficients and higher resolution when sampling to detect the term segment, the trend of the figure grows up evidently by increasing the using size of the matrix. Moreover, due to the increasing of N, it provides more accurate sampling signal which can concentrate the magnitude of the original components with corresponding frequency on a coefficient to prevent them from being separated into several coefficients with lower magnitude and being eliminated by the threshold. However, the performance of PSNR fluctuates remarkably due to the analysis using the same threshold in every segment signal, which leads to the PSNR decreases significantly in some segments.

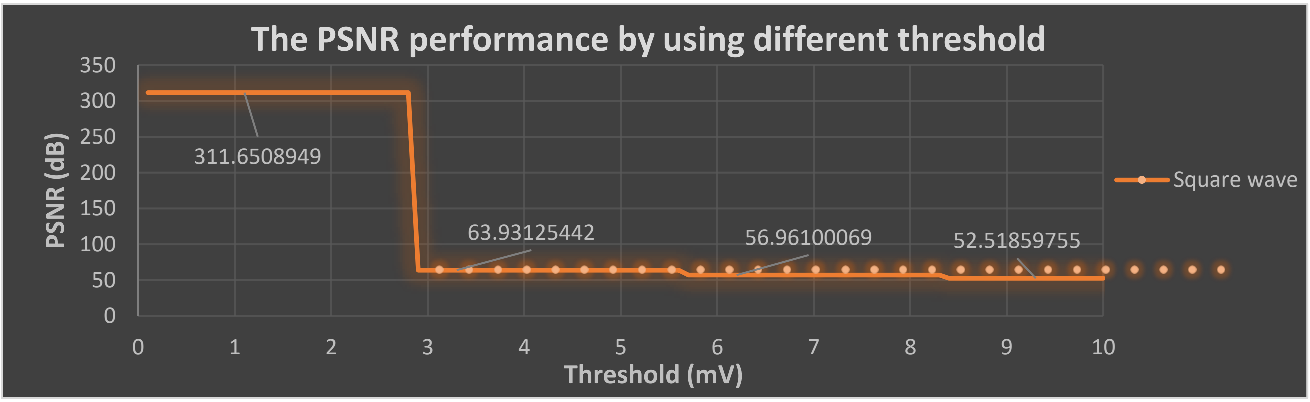

Fig. 9

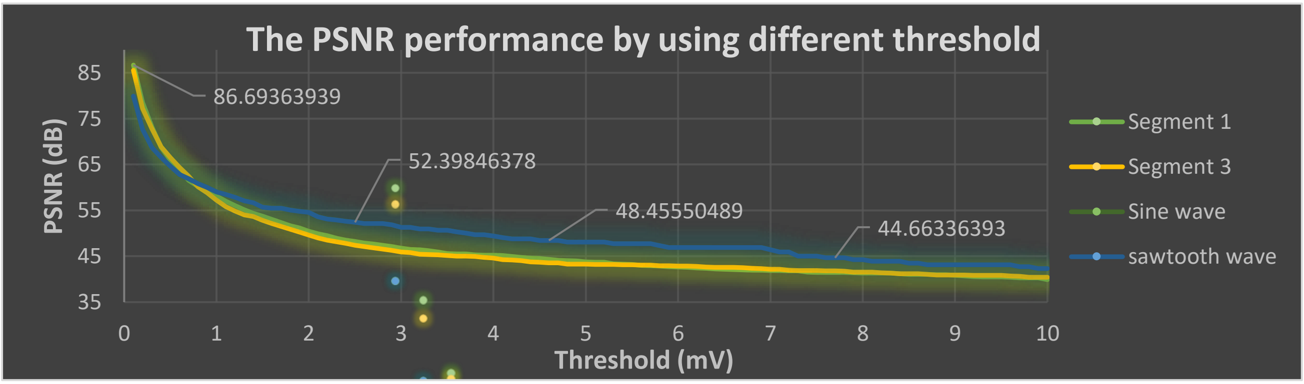

Fig. 10

According to Fig. 9 and Fig. 10, they demonstrate the relationship between the performance of PSNR and threshold by using 40x40 DCT. The improvement of PSNR in the square wave is around 311 dB which is the largest one among these segments. However, the performance decreases considerably when the threshold exceeds 2.9mV due to the coefficient which is stored the original component is removed by the algorithm. In addition, other segments have a similar trend that the value of the performance starts with the highest value with around 86.7dB PSNR and generally decline when growing the threshold. In these segment, due to the original segment is composed by several elements with low value as noise element in DCT domain, if the threshold is higher than these components the several original components will be destroyed and lead to a lower PSNR.

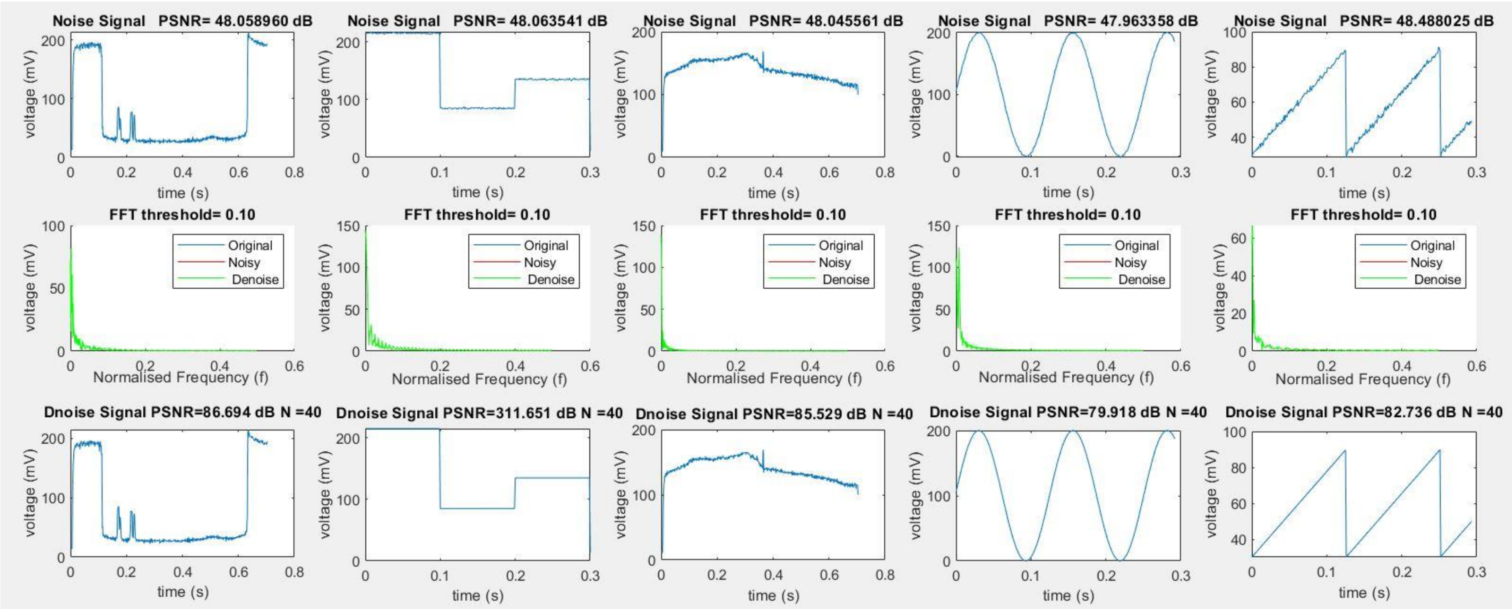

Fig. 11

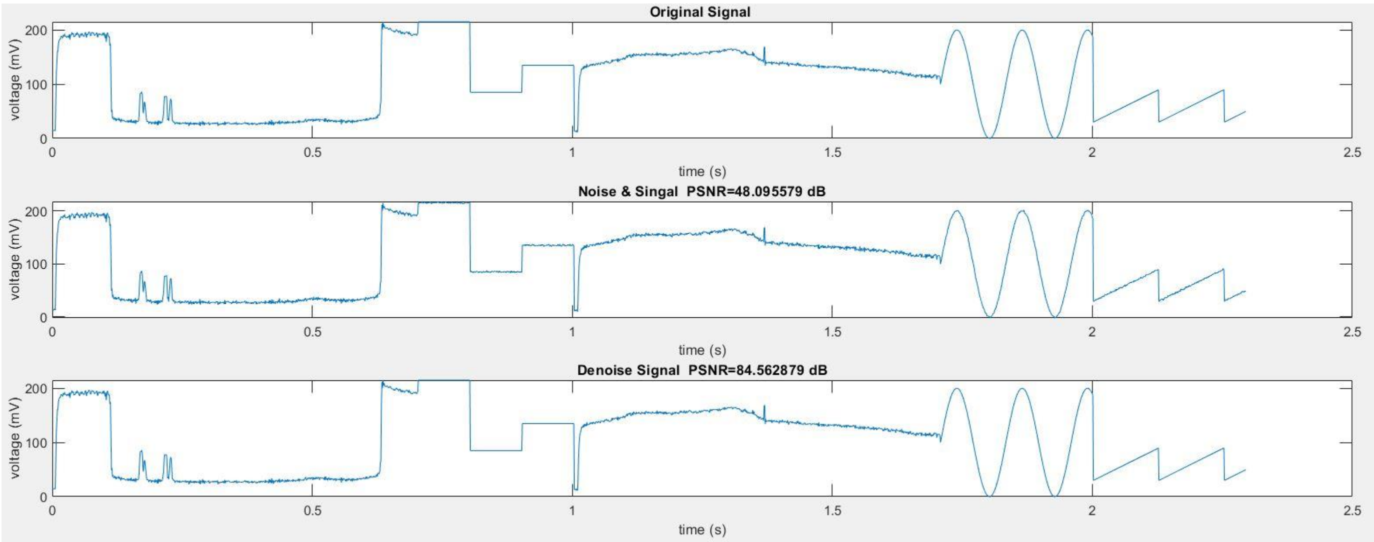

Fig. 12

In addition, by using for loop to find the optimised threshold, each segment is improved considerably and reconstructed to the original signal as shown in Fig. 11, and Fig. 12. Due to the power compaction in DCT, the main energy of the component is concentrated in some parameter and using others to represent the small variation in a different frequency. It is good for data compression due to the transforms adopts the less data to represent the original figure but losing detail. Therefore, based on this concept, the noise components which are distributed into the whole spectrum can be eliminated efficiently by removing these tiny value of the coefficient.

IV. CONCLUSION

In conclusion, although both FFT and DCT are the family of orthogonal transforms, DCT is more suitable for this application with a considerable improvement of PSNR. In addition, due to the FFT is represented the result in complex number comparing with the one in DCT, the result of the latter one is more intuitive due to it is demonstrated in real number. Moreover, the advantage for using DCT transform to denoise is the transform provide a function to analyse the small variation in different frequency more accurately than FFT. Therefore, by removing these zero-value, the performance is improved better than using FFT.