Simulation of Performance Comparison between Discrete Wavelet Transform and Discrete Cosine Transform Methods for Radar Signal Processing in High-Noise Area

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Abstract. Detection of low signal and determination target locations are tremendously important in the radar system. Performance of radar can be enhanced by improving the signal-to-noise ratio of the received signal at the receiver. In this paper, we demonstrate an algorithm in radar signal processing, due to extract the signal target in the place of noise. This algorithm is based on Discrete Cosines Transform (DCT) and Discrete Wavelet Transform (DWT) methods. DWT signal processing analyses and comparatives with mother wavelet Haar, Daubechies-12, Coiflet-5 and Symlet-8. In addition, DCT signal processing analyses and comparatives with the same window function and uses to restrict the signal. Window function has influenced the signal resolution in frequency domain. Window functions that are used in this research are Rectangular, Hamming, Hanning and Dolph-Chebyshev. The results of the simulation and analysis show that mother wavelet with DWT, wavelet Daubechies-12 and Symlet-8 gives the best performance while mother wavelet Haar gives a bad performance. Wavelet Daubechies-12 gives the biggest signal to noise ratio that is 32.0603 dB. Mother wavelet Symlet-8 gives 32.6589 dB. Mother wavelet Haar gives 14.6692 dB. Testing DCT window function, window Dolph-Chebyshev gives the best performance, which gives the best separation of the signal. Analysis of signal reflection that accepted by radar shows the result that DWT is giving better performance than DCT in breaking of noise.

1. Introduction
Radar (Radio Detection and Ranging) is a method of using electromagnetic waves to remote the sensor position, velocity, and identifying characteristics of targets. This is accomplished by illuminating a volume of space with electromagnetic energy in sensing the energy reflected by objects in the space. The strength of the receiving signal from the radar varies with the distance from the radar to the target and it also depends on the target radar cross-section. Radar cross section used to describe the amount of reflection and the scattering power of a target toward to the radar. Weak signal detection is a basic and important problem in a radar system. A solution of this problem increases the possibility of detecting smaller objects from great distances. Improvement of receiver output SNR traditionally is accomplished with pulse integration where the received signal consists of a number of pulse repetition intervals (PRI) before or after detection. However, pulse integration needs a number of pulses to improve the received SNR. For radar with fast scanning feature, the required number of pulses for one object may not inadequate, to perform pulse integration.
Wavelet Analysis and Discrete Cosine Transform (DCT) are two of the most successfully mathematical functions in the field of signal processing in the last twenty years. DWT uses wavelet filter to divide the data into different frequencies or components of the scale, and then analyzes each component with a resolution that corresponds to the scale. DWT is ideal to extract information from stationary or transient signals. So, DWT filter banks can be used to separate bands of different frequencies, without the explicit knowledge of radar parameters such as the PRF (Pulse Repetition Frequency). All functions that are used in the Discrete Wavelet Transform (DWT) is generated from the mother wavelet. So, the mother wavelet will determine the characteristics of the wavelet transform.

Discrete Cosine Transform (DCT) is a technique for converting a signal into base frequency components. Discrete Cosine Transform (DCT) closely related to the Discrete Fourier Transform (DFT), making the data represented in frequency domains. The results obtained from processing the signal using Discrete Cosine Transform (DCT) was analyzed and compared with the results obtained from processing the signal using Discrete Wavelet Transform (DWT).

Some researchers had intensively studied the performance of wavelet transformation in radar signal processing, including [1] which combined the analysis of wavelet packet, and higher-order statistics (HOS) to extract and determine the location of RF radar pulse in noisy areas. Another research has done by authors in [2] implementing the Discrete Wavelet Transform (DWT) on Filter Bank. Filters are used for filtering chaff clutter, which is a kind of distributed clutter that is manmade, also called passive jamming. And another research has done by authors in [3]. This research implemented the Discrete Wavelet Transform (DWT) on some banks to filtering rain clutter (interference from rain) from the signal of the received radar. In that research was compared between DWT filter bank and Fourier filter bank (FFT) [4] did research the simulation of FIR (Finite Impulse Response) digital filter by using the DCT (Discrete Cosine Transform). In this work, filtering of FIR with FFT and DCT was compared with the same method.

The authors used two methods, Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) for processing radar signals to filter noise and interferences. The purpose of this study to analyze the performance of the Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) to separate the signals received by the radar that consisting noise and interference and detecting desired target signals, especially for weak signals that were covered by noise and interferences. The hypothesis, DWT is more reliable for filtering noise, and DCT is more appropriate to filter interference (clutter).

2. Basic Theory

2.1. Radar Signal Processing

Block Diagram of a simple radar system is shown in Figure 1. The radio signal in the form of electromagnetic waves was generated by the transmitter and emitted through the antenna into space. The transmitted signal would propagate through the atmosphere at a speed near that of light in free space. This forward propagated wave has electric and magnetic fields in the ratio 120π ratios (≈377 Ω), which is the characteristic impedance of the atmosphere or free space. If the wave encounters an object with propagation characteristics (impedance) different from those of the medium, a fraction of energy hitting the object reflects. Reflected signal recovered by the radar are composites of target echoes, noise, and interference. Signal processing’s role is [5] to enhance the target echoes and suppress all other signals so that the target is easy to detect and correct information about the behavior of the target, including position, speed and characteristics.
The signals generated by radar may be a sinusoidal continuous wave and pulse [6]. For Continuous Wave (CW) Radars can be modeled by a pure sine wave, that is $\cos(2\pi f_0 t)$. Signals from a stationary target or stationary clutter, spectrum will be concentrated on $f_0$. The center frequencies of original signals from moving targets or interference (clutter) from moving targets will be shifted by $f_d$. $f_d$ is the Doppler shift. Doppler shift is the frequency shift of the echo signal caused by the target’s motion with respect to the radar. The Doppler shift is used both to measure the velocity of the target and to resolve targets occurring at the same time but moving at different velocities. The latter use is the method of discriminating moving targets from clutter. The Doppler shift is obtained by equation [5]:

$$f_d = f_t \left[ 1 + \frac{V_R}{c} \right] \left[ 1 - \frac{V_R}{c} \right]$$

(1)

where $f_t$ = the transmitted frequency (Hertz)

$V_R$ = the radial velocity difference between target and radar

$c$ = the velocity of propagation

if $V_R << c$

$$f_d \approx 2f_t \frac{V_R}{c}$$

(2)

As for pulsed radars, radar transmits and receives a series of pulses. The range can be extracted by the time difference (delay) between the pulses delivered by the pulse received. For the measurement of the Doppler frequency can be done in a way, that is: if an accurate measurement range available between two successive pulses, can be extracted from the Doppler frequency range Rate [6]:

$$R = \frac{\Delta R}{\Delta t}$$

(3)

$R$: Rate Range

$\Delta R$: Range between two sequential momentum.

$\Delta t$: delay (time)
An approach in equation (3) can work well, the whole range has not changed drastically in the interval Δt. Another way uses the Doppler Filter Bank. Digital Doppler filter bank is usually implemented using Discrete Fourier Transform (DFT) as shown in Figure 2.

![Figure 2. Digital Bank Filter.](image)

DFT is the main technique spectrum analysis. Radar uses spectrum analysis to separate the reflected wave from the desired target with wave reflection from the unwanted target or interference. The output of the Doppler Filter Bank is a Doppler bin. Doppler bins are a discrete bandwidth in which the echoes target are processed.

The Radar receives several forms of interference, which complicates the detection and target measurement process. The five basic kinds of interference, the noise, clutter, ECM, EMI and spillover. One of signal processing’s roles is to suppress these interfering signals.

- Noise, caused by the random motion of electrically charged particles which occurs at all temperatures above absolute zero, unavoidably generated in the radar’s receiver, with small amounts also from the antenna and transmission lines, and from external sources, principally the sun.
- Clutter is an unwanted signal echo from sea, land, and weather. It is a real echo signal which is usually suppressed from that desired targets.
- ECM (electronic countermeasures) or jamming is intentional interference generated to disrupt detection of echoes target.
- EMI (Electronic interference) is accidental interference from friendly sources, such as other radars, communication systems and friendly jammer.
- Spillover occurs mainly in continuous wave (CW) radars and is caused by operating the transmitter and receiver simultaneously. It is the leakage from the transmitter into the receiver.

### 2.2. Discrete Wavelet Transform (DWT)

Transformation of the signal is another form to represent a signal that does not change the information signal’s content. The wavelet transform has two series in development, namely: Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). All functions used in CWT and DWT transformation is generated from the mother wavelet by translation/shifting and scaling/compression. DWT and these coefficients are defined as:

$$W_j(s, \tau) = \langle f(t), \psi_{s, \tau} \rangle(t) = \int_R f(t) \psi^{*}_{s, \tau}(t) dt$$

Which \( f(t) \) is the signal in time domains, \( \psi_{s, \tau} \) is a wavelet and * denotes complex conjugation.

When the signal \( f(t) \) is passed through a set of filters that are defined by a wavelet family, that is can be obtained the output of DWT coefficients. These are coefficients describe the contents of the signal in the time-scale domain. The wavelet transforms two-channel, a discrete signal is separated into the low pass and high pass components [7] that is can be seen in Figure 3, \( h(k) \) is a low pass filter
as scaling filter and \( g(k) \) is a high pass filter as wavelet filter.

![Figure 3. The wavelet transformation processing.](image)

The next step is transforming approximation coefficients \( CA_1 \) into two parts using the same scheme, replacing the \( CA_1 \) and producing \( CA_2 \) and \( CD_2 \), and so on. For higher levels, the approximation coefficient is decomposed into approximation coefficient and detail coefficient on the next level. Figure 4 illustrates the decomposition DWT filter banks at level 3.

![Figure 4. The Decomposition of wavelet at level 3[8].](image)

The decomposition process consists of the filtering process and horizontal down sampling using LPF (Low Pass Filter) and HPF (High Pass Filter). To get back the original signal from the detail components and approximation components, by doing the reconstruction process. This reconstruction process aims to combine all detail components with approximation components. The reconstruction process is illustrated in Figure 5 [7].

![Figure 5. The processing of invers wavelet transforms.](image)

Mother wavelet is the basic function that is used in wavelet transform. Because the mother wavelet produces all the functions of the wavelet transformation through translation and scaling, then the mother wavelet will also determine the characteristics of the resulting wavelet transform. Therefore, it is necessary keeping record carefully, reviewing the application of wavelet and appropriate selection of the mother wavelet must be done to use wavelet transformation efficiently. This research will test the mother wavelet Haar, Daubechies, Coiflet, and Symlet.
2.3. Discrete Cosine Transform (DCT).

Discrete Cosine Transform (DCT) is a model Fourier Transform that is imposed on the discrete functions by taking part cosine of the complex exponential, and the results are also discrete. DCT is one important transformation in digital signal processing. DCT transform function from the time domain to the frequency domain. DCT was first introduced by Ahmad Natarajan and Rao in 1974. Discrete Cosine Transform of the series \( n \) of real numbers \( f(n) \), is \( F(k) \), \( k = 1, \ldots, N \), is formulated as follows:

\[
F(k) = \sum_{n=0}^{N-1} f(n) \cos(\frac{2\pi nk}{N}), \quad k = 1, \ldots, N
\]  

(5)

Unlike the Discrete Fourier Transform (DFT) which results in a complex variable with real and imaginary parts, then the results of DCT only be real with no imaginary. It helps a lot because it can reduce the calculation. In DCT, the magnitude value is the result of DCT itself and is not required phase.

3. Research Methods

This research will analyze the performance of the two methods for analyzing signals, namely the Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT), which will be applied to the processing of radar signals. The performance of the communication system is expressed as the ratio of signal to noise (S/N) [9]. General working steps are as follows:

1. Modeling some input signal conditions, which consists of a reflected signal from the target and interference and noise.
2. Analyzing the input signal by using the Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT).
3. Analyzing the performance of the output signal of DWT and DCT. In analyzing performance, the measured parameter is the signal to noise ratio and will be shown within the frequency plot for the separation of the components of the Doppler frequency of a signal. Signal to noise ratio is calculated by the equation [10]:

\[
SNR_{db} = 10\log_{10}\frac{\sigma_x^2}{\sigma_e^2}
\]

(6)

4. \( \sigma_x^2 \) is the power of x [n], the x [n] is the signal which is not distorted by noise. \( \sigma_e^2 \) is the power of e[n] which is the noise remaining after the processing, which is the difference between the output signal from the system after processing with DWT and DCT with a signal that is not distorted x [n].
5. The next step is analyzing the results of the performance of DWT and DCT in radar signal processing and writing conclusions.
6. The final step is plotting the signal spectrum of reconstruction results.

In analyzing the signal of using DWT steps are as follows:

1. After the signal s (n) is restricted from n = 0 to N-1, the next step to form the signal decomposition using wavelet transform. Family wavelet is used in this research are Wavelet Haar, Daubechies Wavelet, Wavelet Coiflet, and Wavelet Symlet.
2. The next step is setting the threshold of each coefficient. Noise separation is done by thresholding. And the last is reconstructing a signal of the remain coefficients.
3. The final step is plotting the signal spectrum of reconstruction results.

In the signal analysis using the DCT steps are as follows:

1. After the signal s (n) is restricted from n = 0 to N-1, then the signal is multiplied by a window function. Window functions are used Rectangular, Hamming, Hanning and Dolph-Chebyshev.
2. The next step is using equation (5) to change the signal s (n) into DCT coefficients. Results obtained from the DCT is the frequency components of the signal s (n).
4. Result and Analysis

Tests were conducted on some models of the input signal conditions, the overall model of the condition of the input signal to be tested lie in the same range bin and can be separated based on Doppler analysis if the velocity is different. The first input signal condition model has two signals with a Doppler frequency of 10 cycles and 16 cycles. The period of the signal is 100 seconds and the number of sampling points is 1000, with signals in Doppler frequency is 10 cycles with the amplitude 50 are the interference signal. The signal in Doppler frequency 16 cycles is a signal from the desired target with amplitude 1. The signal plot and spectrum can be seen in Figure 6.

The full spectrum of output DWT reconstruction, using the mother wavelet Haar, Daubechies-12, Coiflet-5 and Symlet-8 can be seen in Figures 7, 8, 9, and 10.
Figure 9. The DWT spectrum with Coiflet wavelet mother to the first input signal conditions model.

Figure 10. The DWT spectrum with symlet wavelet mother to the first input signal conditions model.

From the spectrum plot Figure 7, 8, 9 and 10 for the fourth mother wavelet tested produced the same image, the reflection signal from the desired target perfect apart from signal interference, so that the target can be detected although the amplitude is very small compared to the interference signal.

In analyzing signal by using DCT, will be tested several window functions used in signal restrictions, window function to be tested are Rectangular, Hamming, Hanning and Dolph Chebyshev. The window functions affect the resolution of the signal in the frequency domain which is output from the DCT. The simulation results for the first input signal conditions model using DCT can be seen in Figure 11, 12, 13 and 14.

Figure 11. The spectrum of DCT with a rectangular window for the first input signal conditions model.
Figure 12. The spectrum of DCT with a Hamming window for the first input signal conditions model.

Figure 13. The spectrum of DCT with Hanning window for the first input signal conditions model.

Figure 14. The spectrum of DCT with Dolph-Chebyshev window for the first input signal conditions model.

Figure 11 indicates that, with using of a rectangular window, signals intended target is covered entirely by the leak of the spectrum (spectral leakage) of the interference signal so that the signal from the desired target is very difficult to detect. From Figure 11 Rectangular window apparently, failure to separate frequency components of a signal. To use window Hamming, Hanning and Dolph-Chebyshev, visible signal from the desired target perfect apart from signal interference, so that the target can be easily detected, but Dolph-Chebyshev window gives the best results in the separation of the frequency components of a signal.

For the second input signal conditions model, the input signal consists of a signal from the target and interference and noise. Two signals with Doppler frequency of 10 cycles and 16 cycles. The period of the signal is 100 seconds and the number of sampling points is 1000, which signals its
Doppler frequency is 10 cycles with the amplitude of the interference signal 50 and signal Doppler frequency of its 16 cycles a signal from the desired target with amplitude 1. Noise used is Gaussian White Noise with power 20 dB. Noise is spread evenly on all Doppler bin. Plot signal and its spectrum can be seen in Figure 15.

![Figure 15](image)

Figure 15. The second input signal condition model and its spectrum.

The simulation results of using wavelet mother Haar, Daubechies-12, Coiflet-5 and Symlet-8 on DWT for application of noise removal can be seen in Figure 17 and 18. The signal to noise ratio obtained from the use of wavelet mother Haar is 14.6692 dB, Daubechies wavelet mother-12 is 32.0603 dB, Coiflet-5 wavelet mother is 31.0005 and symlet-8 wavelet mother is 32.6589 dB.

![Figure 16](image)

Figure 16. Signal and noise for the second input signal condition model.

![Figure 17](image)

Figure 17. The denoise Signal with wavelet mother Haar and Daubechies for the second input signal condition model.
Figure 18. The denoise Signal with wavelet mother coiflet and symlet for the second input signal condition model.

Spectrum reconstruction results from the remaining coefficients can be seen in Figure 19, 20, 21, and 22. From the results of the reconstruction visible spectrum that the signal from the desired target is still difficult to detect, because the amplitude is too small, and there are still remaining covering noise signal of the desired target.

Figure 19. The DWT spectrum with Harr wavelet mother for the second input signal conditions model.

Figure 20. The DWT spectrum with Daubechies wavelet mother for the second input signal conditions model.
The simulation results for using the DCT can be seen in Figure 23, 24, 25, and 26. From Figure 23 indicates that, for the use of window Rectangular, signals intended target covered entirely by noise and leaks spectrum (spectrum leakage) of the interference signal, so that the signal from the desired goals are very difficult to detect. To use window Hamming, Hanning and Dolph-Chebyshev, in Figure 24, 25 and 26, it appears that the window functions cannot reduce the noise, but it can only reduce spectral leakage. Because the noise is spread evenly into all the bin, and cover entirely a desired target signal, so that the signal from the desired target cannot be detected.

Figure 21. The DWT spectrum with Coiflet wavelet mother for the second input signal conditions model.

Figure 22. The DWT spectrum with Symlet wavelet mother for the second input signal conditions model.

Figure 23. The DCT spectrum with rectangular window for the second input signal conditions model.
Figure 24. The DCT spectrum with Hamming window for the second input signal conditions model.

Figure 25. The DCT spectrum with Hanning window for the second input signal conditions model.

Figure 26. The DCT spectrum with Dolph-Chebyshev window for the second input signal conditions model.

5. Conclusion
Based on simulation results and analysis in this research, it can be concluded:

1. In testing the wavelet mother Haar, Daubechies-12, Coiflet-5 and Symlet 8 on Discrete Wavelet Transform in separating the components of the Doppler frequency of a reflected signal received back by the radar, full reconstruction spectrum of results is obtained the same performance for the wavelet mother Haar, Daubechies-12, Coiflet-5 and Symlet-8. On testing in removing noise of a reflected signal received by the radar, from the signal to noise ratio (S/N) and the spectrum reconstruction of remaining coefficients, wavelet mother Daubechies-
12 and Symlet-8 produces the best performance and the wavelet mother Haar produce worst performance. The maximum signal to noise ratio is obtained from Daubechies-12 wavelet mother of 32.0603 dB. The maximum signal to noise ratio by using of Symlet-8 wavelet mother and Haar wavelet mother are 32.6589 dB and 14.6692 dB, respectively.

2. On testing Rectangular, Hamming, Hanning and Dolph-Chebyshev windows on the Discrete Cosine Transform (DCT) in separating the components of the Doppler frequency of a reflected signal received by the radar, the best performance spectrum results are obtained from the Dolph-Chebyshev window. The function window on the Discrete Cosine Transform (DCT) cannot reduce the noise, but only reduce leaks spectrum, because noise is uniformly dispersed in every bin.

3. Analysis of the reflected signal received back by the radar by using Discrete Wavelet Transform (DWT) give performance is better than using Discrete Cosine Transform (DCT), especially in eliminating noise.

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