Forward Scattering Radar (FSR) Target Signal Processing Using Wavelet Technique (WT)

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***Abstract*— Micro-sensor Forward Scattering Radar (FSR) is a network system that been used to detect and classify any ground target (personnel, vehicle) that crossing by or entering the coverage or restricted area. The efficiency of the classification performance is highly dependent on the information extracted from the signal. The choice of transformation techniques which can reveal the information of the target should be chosen carefully. Hence, this research will looks into Wavelet Technique (WT) which give scales and variation information respectively. This information will be extracted and become the input to the classification process. The result from the wavelet technique shows that we can find the similarity between signals of each target and dissimilarity between different targets.**

***Keywords*— Forward Scattering Radar (FSR), Wavelet Technique (WT), feature extraction.**

I. INTRODUCTION

In RADAR network, it mainly focused on covering area that had been designed, mostly in restricted area or hazardous area. One of the technologies that have been used in this network is micro-sensors Forward Scattering Radar (FSR). The system can detect any target, estimate any parameter and classify any of the ground target automatically Automatic Target Classification (ATC) that crossing the coverage area.

Classification of the target can be determined by the information gathered from the extraction process. The information that resulted by FSR is in time-domain signal has lack of target's information (the information is based on time and amplitude of the signal). Hence, in order to further analyze the signal, different domain should be used by applying different transformation technique such as Fourier transform, Wavelet transform, Laplace transform. The transformation through Fourier and Laplace transform, information about the frequency can be achieved while by applying wavelet transform, information about frequency, time and scale can be attained. Once the signal has been transform, the similarity and dissimilarity of the target's signature can easily be observed which can be used as the input to the classification process. To get better information, the right transformation technique should be used.

Hence, the purpose of this project is to apply Wavelet Technique (WT) in order to analyze different features in PSD of the target. In this paper, we will start with literature review of Forward Scattering Radar (FSR), Wavelet Transformation (WT) and Scaling Function. Then in Section III, the methods and techniques of obtaining transformation WT results are be presented, and in Section IV the result and some conclusion will be discussed.

II. LITERATURE REVIEW

1. Forward Scattering Radar (FSR)

Forward Scattering Radar (FSR) is introduced from bistatic radar which it is designed to operate in a fence-like configuration, detecting targets which pass between the transmitter and receiver, with the bistatic angle near 180 degrees [1].

FSR has advantages which are: better targets cross-sections, robustness to stealth targets, absence of signal fluctuations and reasonably simple hardware [1]. These advantages are applied in many situations; one of them is ground operations. Recently, micro-sensor FSR wireless network has been presented for awareness in ground operations [1]. The main objectives of FSR are the detection, parameter estimation (for example speed) and automatic target classification (ATC) of numerous ground targets (whether personnel or vehicles) entering or crossing its coverage area, shown in Figure 1.

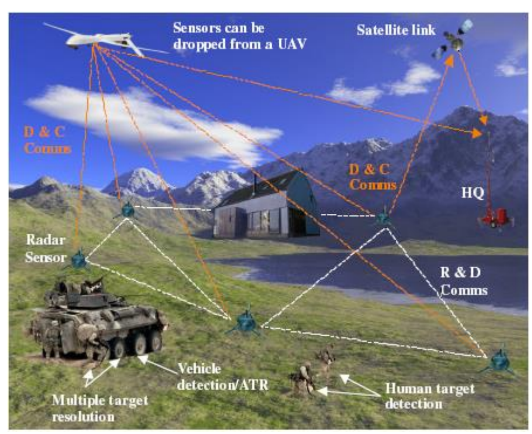

Figure 1: The concept of the FSR micro-sensors radar network (Sensors enlarged for visibility)

The unknown target classification can be detected and classified by using lower frequency of FSR. The targets signal are measured and filtered before they inserting into a block diagram of ATC algorithm as shown in Figure 2 [2].

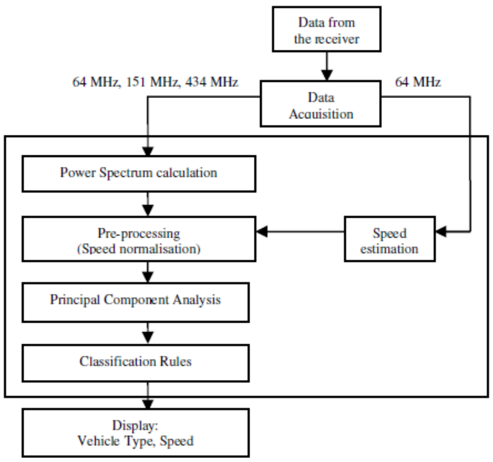

Figure 2: The block diagram of the ATC algorithm

The signal received at the receiver cannot be used directly as the input to the classification process. This is because there is some information hidden in it. Hence in order to reveal this information, transformation technique should be used such as Wavelet transform, Fourier transform, Laplace transform and Z transform.

2. *Wavelet Transform (WT)*

Wavelet Technique (WT) is more suitable to be used for non-stationary signal. This technique has been used in many applications for example data compression, signal processing, image processing, pattern recognition, computer graphics, the detection of aircraft and submarines and other medical image technology [3]. It gives a better time and frequency resolution which also known as multiresolution (MRA). WT covers all the hidden information (scale and variation) obtained from FFT and gives specific information of the crossing target (non-stationary target).

WT is the transformation from FFT signal as it provides the time-frequency representation. Time and frequency can be providing simultaneously, therefore giving a time-frequency representation of the signal.

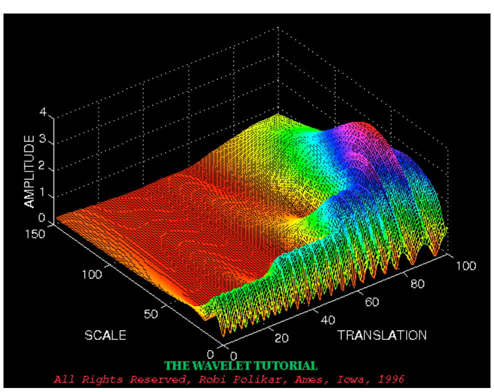

Figure 3: The wavelet technique signal in time-frequency (translation) with scale representation

Wavelet has two techniques or transformations that can be applied depend on the signal behavior – Discrete Wavelet Transforms (DWT) and Continuous Wavelet Transforms (CWT). Both of the techniques can be used for windowed, filtering, denoising, reconstruct, decomposing, extraction and compression. The CWT uses a continuous-time function which it divided into wavelets. It holds the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization [4]. A wavelet transform is a convolution of a signal *s(t)* with a set of functions which are generated by translations and dilations of a main function. The main function is known as the mother wavelet and the translated or dilated functions are called wavelets [4]. Mathematically, the CWT is given by:

$$W(a,b) = \frac{1}{\sqrt{a}}\int s(t)\psi\left(\frac{t-b}{a}\right)dt\,.$$

Where, b is translation time and a is the dilation of the wavelet. If the mother wavelet is in complex, the CWT is also in complex valued function. Or else the CWT is real. The power spectrum for CWT is equal to squared magnitude of CWT ($[W(a,b)]^2$) and it is application dependent which it depends on the type of mother wavelet used. For DWT, the wavelets are sampled separately by any wavelet transform. The difference with the Fourier Transform is it has time-based resolution which it captures both frequency and location time. The DWT of a signal x is calculated by passing it through a series of filters. First the samples are passed through a low pass filter with impulse response g resulting in a convolution of the two:

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k].$$

The signal x is also decomposed simultaneously using a high-pass filter g. The outputs giving the detail coefficients (from the high-pass filter) and approximation coefficients (from the low-pass). These two filters are related to each other and known as a quadrature mirror filter [5].

For every transformation of wavelet (DWT or CWT), they are using mother wavelets to function and evaluate. There are several types of mother wavelets which are *Haar*, *Daubechies*, *Symlets*, *Meyer*, *Morlet*, *Gaussian*, *Shannon* and *Mexican Hat*. In this paper, *Haar* wavelet is used as it is easy to analyze and evaluate the signal behavior.

Haar wavelet is a basic and simplest wavelet that normally used on decomposing signal. Its sequence of rescaled "square shaped" on -1 0 1 bit functions which together form a wavelet basis. *Haar* wavelet is a one type of orthonormal wavelet as its analysis is similar to Fourier analysis which allows a target function over an interval to be represented in terms of an orthonormal function basis. *Haar* wavelet is the first DWT function that been introduced. It transforms may be deliberated to simply pair up input values, storing the difference and passing the sum. This process is repeated recursively, pairing up the sums to provide the next scale [5].

3. *Scaling Function*

Wavelet function acts like a bandpass filter that picks the changes (i.e., details) of the signal. Evidently, one needs another type of functions (filters) to pick the "main" content of a signal. This is what a scaling function, which is essentially a lowpass filter [6].

For *Haar* wavelet, it has its own scaling function to operate with the DWT and CWT function. The scaling function for *Haar* is:

$$h_i(t) = \begin{cases} 1 & \text{for } t \in [\xi_1, \xi_2)\,, \\ -1 & \text{for } t \in [\xi_2, \xi_3]\,, \\ 0 & \text{elsewhere}\,. \end{cases}$$

Here $\xi_1 = k/m$, $\xi_2 = (k + 0.5)/m$, $\xi_3 = (k + 1)\, m$. The integer $m = 2^j$ ($j = 0, 1, \ldots, J$) indicates the level of the wavelet; $k = 0, 1, \ldots, m - 1$ is the translation parameter. The maximal level of resolution is J. The index i in the equation is calculated according to the formula $i = m + k + 1$; in the case $m = 1$; $k = 0$ we have $i = 2$; the maximal value of i is $i = 2M = 2J + 1$. It is assumed that the value $i = 1$ corresponds to the scaling function for which $h_1 = 1$ for $t \in [0, 1]$ [7].

III. METHODOLOGY

1. *Measured Signal*

The simulated signal from low frequency FSR network (car1, car2, car3 and car4) are displayed in time domain signal which does not give full details or information of the existing target. The targets have different time, amplitude and velocity (speed).

2. *Filtering I*

Before using the WT method, all the signals must be normalized and filtered by using Hamming Window and Butterworth low pass filter to remove noise. Frequency is set at 151 MHz.

3. *Wavelet Transform (WT)*

The basic idea by using WT is to represent the original time-series as a new sequence. Each of them is extracted and gives their features via WT. In this project, CWT is applied for extraction and using *Haar* wavelet as its mother wavelet function. Scaling function for *Haar* is calculated based on the central frequency and level of iteration. From WT, coefficient and scale-time domain are produced.

4. *Power Spectrum Density (PSD)*

Power spectral density function (PSD) shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak. The received signal spectrum at the sensor cannot be used directly as a feature vector for further processing, because its shape width is proportional to the speed of vehicle. After that, the transformed signal are normalized again by resampling the signal ratio and using DWT decomposition method.

5. *Filtering II*

The DWT decompose the transformed signal which the signal is calculated by passing it through a series of filters. The signal passed through a low pass filter with impulse response resulting in a convolution of the two. The decomposition of signal is depending on what direction of decomposition used either in row (r) or column (c). As this project using *Haar* wavelet, the level of iteration must be set to normalize the ripples of the transformed signal. For better view and reference, level 2 of iteration is set. After decompose, reconstruction of wavelet signal is used. The reconstruction is important because the decomposed signal may be lost some information during decomposition process. This process can be choose whether the coefficient of signal is extracted or reconstructed by using some commands ('*ca*', '*cd*', '*a*', '*d*' and '*cfs*').

6. *Analysis*

After both process of normalization, the transformed signals are plotted and displayed all the patterns of the target signals in coefficient (dB) and No. of samples (N). All patterns are analyzed and evaluated based on their behavior. If the transformed signal does not comply with the behavior of target signal, the transformation of signal is repeated and corrected on WT method.

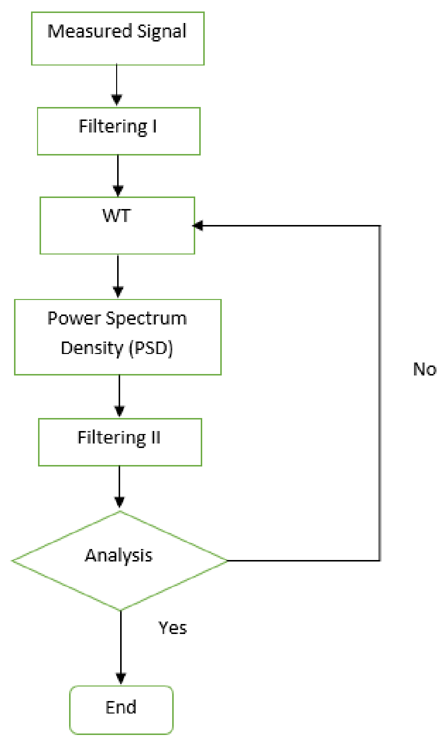

Figure 4: Step of signal transformation via WT

IV. RESULTS AND DISCUSSION

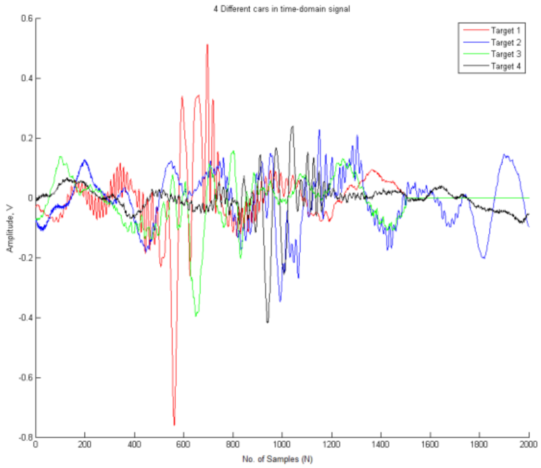

Figure 5: All target signals in time-domain signal representation

Figure 5 shows the measured signals in time-domain. .By just looking at the signals; it is difficult for us to determine the uniqueness and differentiation between of each target. Hence, we need to transform these time domain signals into different domain which can give clear information.

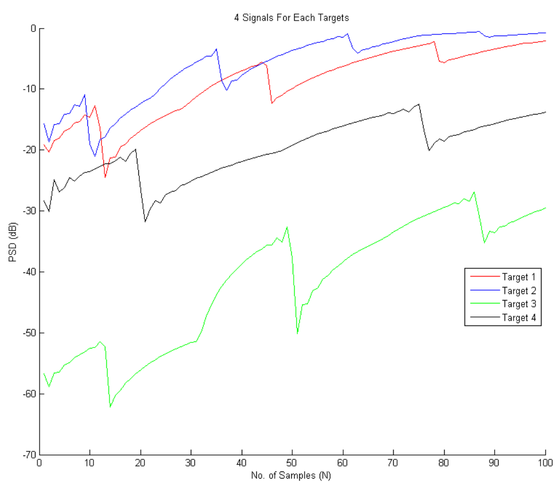

Figure 6: Four signals for each targets in PSD (Before decompose)

From Figure 6, signal from different target is transformed by using WT and represented in PSD. As we can observe each signal gives similar pattern but with different amplitude and slightly shifted from each other. However we need to understand the uniqueness of each target which is not clearly visible in this figure.

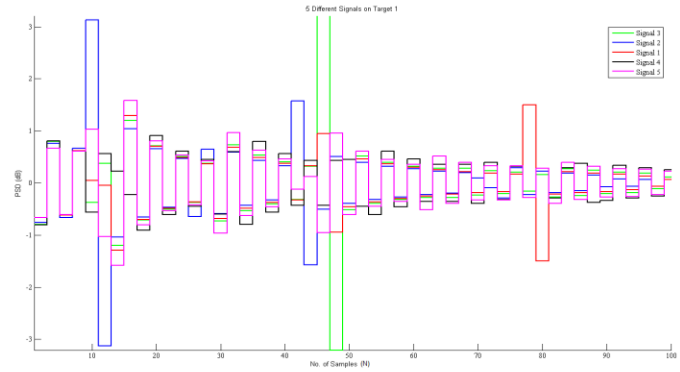

Figure 7: Five Signals for Target 1 in PSD after decomposed

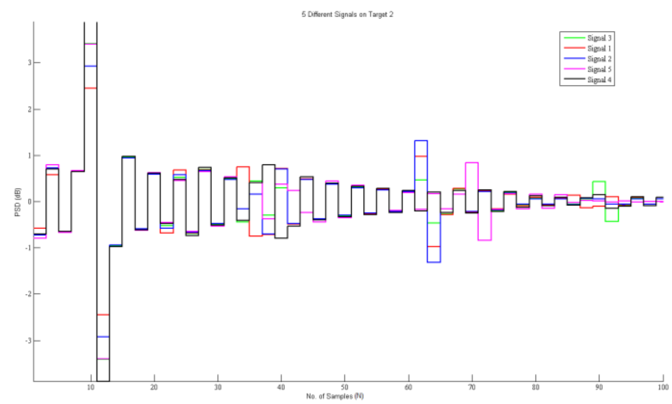

Figure 8: Five Signals for Target 2 in PSD after decomposed

Due to the invisibility; the normalization or decomposition of signals is taken place to equalize signals for each target. Two analyses have been conducted in order to see: 1) the similarity by using one target but with different signals and 2) the difference in the decomposed PSD for different targets. As we can see in Figure 7 and Figure 8, all target signals are in the same line and same pattern, but with slightly different amplitude of PSD. This means the similarity between each signals of the same target can be observed easily.

Four different targets using DWT filter decomposition at level 2

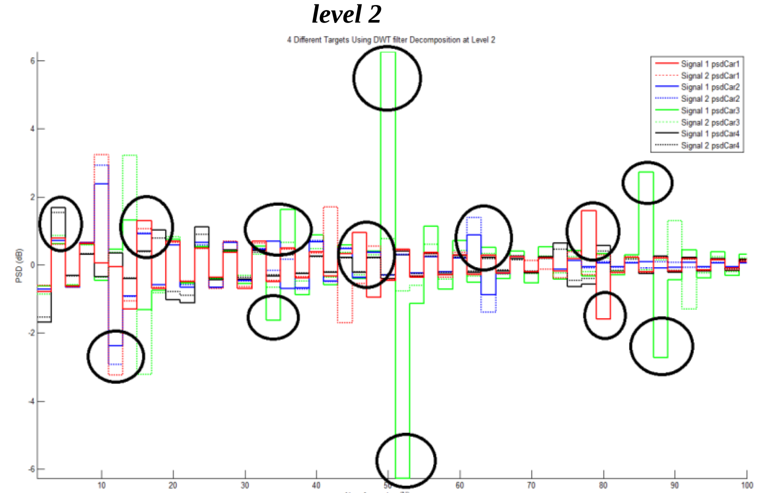

Figure 9: The Differences between All Target Signals in PSD

Figure 9 depicts the PSD for different target signal. As highlighted in the figure, the differences between each target become more visible as the amplitude of each target varies at different number of samples which give the unique identification about each target. This is due the different characteristics of the targets which it may has bigger or smaller (height and width) and has different shape of the object. Based on the differences, information about the target can be extracted and used for classification's input.

V. CONCLUSION

The features of all different targets are extracted by using Wavelet Technique (WT) and show their different signatures based on their amplitude and shifting which are represented by Power Spectrum Density (PSD) and Number of Samples (N). The signatures that had been displayed in the result are in square shape (*Haar*). This result suggests that the signatures of the target signals depend on the level of PSD which related to the velocity and shape of the target. If the target has low speed and bigger size, it may shows different patterns.

VI. FUTURE DEVELOPMENT

Further research in this project can be expanded by using a Wavelet Transform (WT) with different mother wavelet and decomposition [8]. Furthermore, the effectiveness of the technique can be analyzed by examine the performance of the classification process.

ACKNOWLEDGMENT

As the author of this paper, I would like to express my great gratitude to Dr. Nur Emileen Abd Rashid for her help, support, advice, guidance, supervision, encouragement and faith to me in accomplishing this project. I would also like to say thanks to my co-supervisor of this project, Mdm. Kama Azura Othman for helping me in understand the concept of wavelet techniques for my project. Finally I would love to say thanks to my family and my fellow friends for giving me encouragement to complete this project.

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