FEATURE EXTRACTION IN RADAR TARGET CLASSIFICATION

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Abstract

This paper presents experimental results of extracting features in the Radar Target Classification process using the J frequency band pulse radar. The feature extraction is based on frequency analysis methods, the discrete-time Fourier Transform (DFT) and Multiple Signal Characterisation (MUSIC), based on the detection of Doppler effect. The analysis has turned to the preference of DFT with implemented Hanning windowing function. We assumed to classify targets-vehicles into two classes, the wheeled vehicle and tracked vehicle. The results show that it is possible to classify them only while moving. The feature of the class results from a movement of moving parts of the vehicle. However, we have not found any feature to classify the wheeled and tracked vehicles while non-moving, although their engines are on.

Keywords

DFT, Doppler effect, MUSIC, microphonic effect, radar target classification, radar target identification, radar target recognition

1. Introduction

Due to the ambiguity of the meanings of terms used in the particular area of signal processing, we have differentiated three terms and their meanings: *Radar Target Recognition, Radar Target Classification*, and *Radar Target Identification,* which stand for three levels of signal processing considered in this paper. *Radar Target Recognition* determines a type of a target, e.g., MIG-29 aircraft, AH-64 helicopter, T-72 or ABRAMS tank, etc. *Radar Target Classification* determines the class of a target, for example, whether the target belongs to a wheeled or tracked vehicle, helicopter, aircraft (especially jet or propeller), clutters, etc. Finally, *Radar Target Identification* determines whether the target belongs to a particular organization, and can differentiate between the "friend" and "foe" target. We use *Radar Target Recognition* also as a superior term to designate any of the above terms. The last meaning can be considered also as a particular case of signal recognition. The differentiation of the last two meanings results from a context.

There are several physical effects, which can be used as a basis for *Radar Target Recognition* to detect the above characteristics. Considering active radars, the effects are as follow: the skin, Doppler, nonlinear, polarization, and resonance effects [2]. The effect that can be detected depends on: the radar signal parameters, incident angle, shape of the target, movement of the target including the movement and vibration of moving parts of the target, material of the target including conductivity, dielectric constant, permeability, and even semiconductor nonlinearity in junction of metal parts.

A radar target recognition process consists of the following four steps of which the first is considered the most difficult:

i) Extracting features from the backscattered electromagnetic waves from a known target,
ii) Establishing the database of these features for a known target,
iii) Extracting features of an unknown target with a real-time signal processor,
iv) Comparing the features of an unknown target with those in the database and making decisions.

In this paper we are interested in *Radar Target Classification* of vehicles into two classes, the wheeled and tracked vehicles, by means of active radar. In active radar, *Radar Target Classification* is based on a determination of radar target characteristics depended on the reflection of radio waves also called the secondary radiation from a target. The radar target characteristics are as follow:

i) The radar cross section;
ii) The spectral and time characteristics of the echo containing information on parameters of target movement, shape, dimensions, modulation caused by a rotation of turbines or propellers, and by a vibration of parts of a vehicle;
iii) The polarization characteristics of the echo.

In this paper we are interested in extraction of the features of known targets. We have detected and analyzed Doppler effect by means of the Multiple Signal Characterization (MUSIC) algorithm and Welch's procedure of the discrete Fourier Transform (DFT). The analysis was done in the frequency domain. Doppler effect, DFT, and MUSIC are described in the following part.

The second part of this paper gives theoretical basis on the spectral analysis used. The third part describes our experiment. In the fourth part we present the results we have obtained. Our conclusions are given in the fifth part.

2. Theory

Due to the fact that in this paper we are interested in detection of Doppler effect, we describe it in this part of our paper. We here also describe the used methods of frequency analysis, DFT and MUSIC.

2.1 Doppler Effect

Depending on whether a distance between an active radar and target is increasing or decreasing, the received signal frequency f, compared to transmitted signal frequency f_o, is decreasing or increasing, too. The frequency shift f_d is called Doppler frequency. If a target is moving at the constant radial velocity v_r, the received signal frequency f, is given by the form [6]

$$f = f_o \pm f_d = f_o \pm \frac{2 v_r}{\lambda} \qquad (1)$$

where the transmitted signal wavelength

$$\lambda = \frac{c}{f_o} \qquad (2)$$

where c is the propagation velocity of radio waves. The signs + and – are related to a decreasing or increasing distance between a radar and target, respectively.

2.2 Spectral Analysis

To analyze a received signal in the frequency domain we used well known DFT and MUSIC.

DFT

In order to process the data we used the Welch's procedure of DFT. The DFT spectrum is described as

$$S_{\mathrm{DFT}}(k+1) = \sum_{n=0}^{N-1} x(n+1)w(n+1)e^{-j2\pi\frac{nk}{N}}, \quad k = 0,\ldots,(N-1) \qquad (3)$$

where k is the number of equally spaced frequencies f, N is the number of the acquired signal samples $x(n)$; $w(n)$ are the coefficients of a windowing function (Hanning, in our case).
The coefficients of the Hanning window are

$$w(n) = \frac{1}{2}\left(1 - \cos\left(2\pi\frac{n}{N+1}\right)\right), \quad n = 1,\ldots,N \qquad (4)$$

MUSIC

The second method of the spectral analysis we used was MUSIC defined as [5]

$$S_{\mathrm{MU}}(f) = \frac{1}{\mathbf{a}^*(f)\mathbf{W}\mathbf{W}^*\mathbf{a}(f)} \qquad (5)$$

where the frequency steering vector $\mathbf{a}(f)$ is in the form of

$$\mathbf{a}(f) = \begin{bmatrix} 1 \\ e^{-j2\pi f} \\ e^{-j2\pi f\cdot 2} \\ e^{-j2\pi f\cdot 3} \\ \vdots \\ e^{-j2\pi f\cdot(N-1)} \end{bmatrix} \qquad (6)$$

$\mathbf{W}$ is the noise subspace of the input autocorrelation matrix $\mathbf{R}$ obtained from the weighted signal samples $x(n)$ by the eigenvector decomposition, and the symbol * is the conjugate transpose operator.

Autocorrelation matrix can be decomposed into the signal subspace matrix $\mathbf{S}$ and noise subspace matrix $\mathbf{W}$. For this system we can write

$$\mathbf{R} = \mathbf{S} + \mathbf{W} \qquad (7)$$

There is the restriction: the number of sinusoids, which the received signal consists of, must be lower than the size of the autocorrelation matrix $\mathbf{R}$. If not, the MUSIC algorithm does not work successfully.

If the received signal consists of D complex sinusoids, there are $(N\text{-}D)$ noise subspace eigenvectors, which the noise subspace matrix $\mathbf{W}$ consists of. N stands for the size of the autocorrelation matrix. So that the size of the noise subspace matrix $\mathbf{W}$ is $(N\text{-}D)\times N$.

3. Experiment

The results presented in the following part were obtained by processing the data of the active pulse radar with the transmitted pulse power of the 250 W, pulse repetition frequency (PRF) of the 4 kHz, pulse width of the 400 ns, and J frequency band. We acquired the output signal of the coherent-on-receive channel of the subject radar. The maximal signal sampling was given by the PRF of the 4 kHz. The sampling interval was up to 1.6 sec. The range element of a target was 300 m away from the radar. We provided different incident angles. As a target we used wheeled and tracked vehicles, and reference non-moving fixed target, a building and pole. We ran out two experiments in order to extract features to classify targets.

In the first experiment, we tested non-moving vehicles and looked for differences between frequency spectra of received signals while their engines were on or not. We tried to detect a feature caused by vibrating parts of the vehicle. The differences are due to Doppler effect.

In the second experiment, we tested moving vehicles and according to the known differences between a movement of certain parts of tracked and wheeled vehicles we assumed it was possible to find differences between the spectra of those classes of vehicles.

4. Experimental Results

The primary aim of the frequency analysis was to find the target features, which are to classify targets.

We analyzed received signals by both DFT and MUSIC in order to select the more suitable method of the frequency analysis to extract the features to classify targets.

Selection of Spectral Analysis Method

We ran out a number of analysis tests of the both frequency analysis methods. The tests, using MATLAB, were differentiated in the number of signal samples, length of overlapping and non-overlapping windows, and type of windowing functions. Examples shown on Fig. 1 and Fig. 2 present differences between the methods. MUSIC is more sensitive than DFT although it has processed less signal samples (N=128) than DFT (N=256). However, the much bigger time demand of MUSIC made it less suitable. So that the tests resulted in preference DFT with Hanning windowing function.

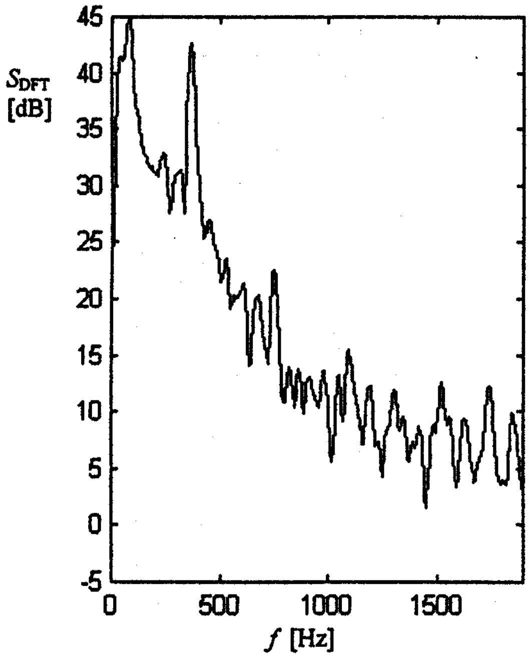

Fig. 1 An example of a spectrum of a wheeled vehicle obtained by DFT, N=256

Feature Extraction

We realized we did not detect any Doppler effect (Doppler frequencies) caused by a vibration of a target mainframe or its non-fixed parts (the first experiment) while non-moving. That is it was impossible to detect differences between spectra of non-moving wheeled and tracked vehicles while their engines were on or not. We could estimate it resulted from the transmitted pulse power, distance between a target and radar, or/and the coherent sum of different single contributions was too low to be detected.

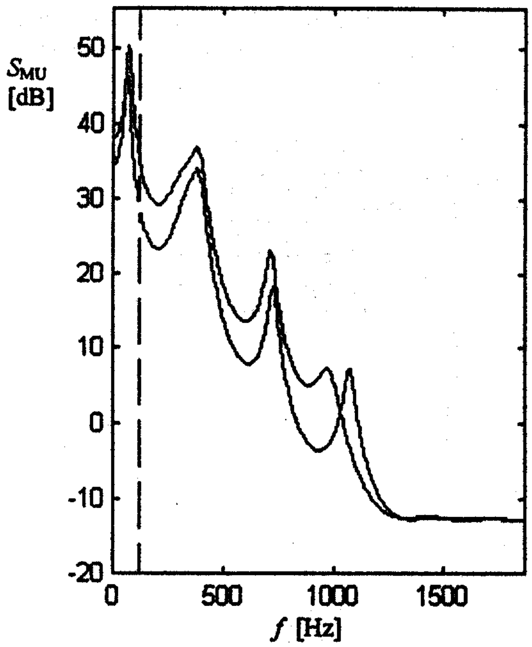

Fig. 2 An example of a spectrum of a wheeled vehicle obtained by MUSIC, the same conditions and vehicle as on Fig. 1, but at two different radial velocities, N=128

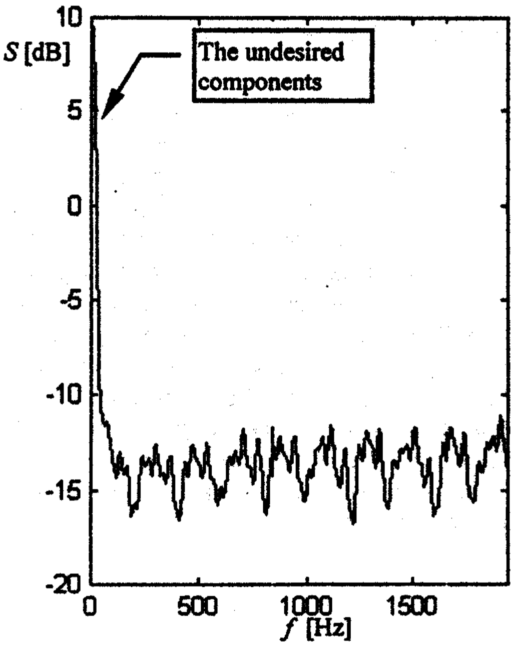

Fig. 3 The spectrum of a non-moving wheeled vehicle

However, in the second experiment, we detected Doppler effect due to a movement of the moving target mainframe and movement of its moving parts while the distance between the target and radar was changing. In this experiment we figured out it was possible to find differences between spectra of wheeled and tracked moving vehicles.

In each case, we excluded the undesired frequency components under approximately 110 Hz, which are due to radar system errors, a movement of the engine exhaust, etc.

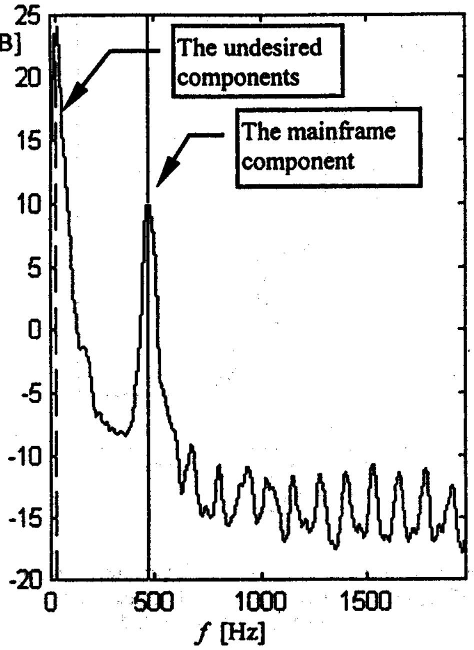

Fig. 4 The spectrum of moving wheeled vehicle

Fig. 3 and Fig. 4 show the example of frequency spectra of a non-moving and moving wheeled vehicle, respectively. There is no significant spectral component except the mainframe component in Fig. 4, which is due to a movement of the target mainframe. However, the spectrum of a moving tracked vehicle (Fig. 5, Fig. 6) consists of not only the mainframe component but also of the several classifying frequency components due to moving parts of the tracked vehicle which are to classify the vehicles into two classes, the wheeled and tracked vehicles. There is a shipment of the mainframe component on Fig. 5 and Fig. 6, which results from a different radial velocity. The number and level of the classifying components depend mainly on the incident angle.

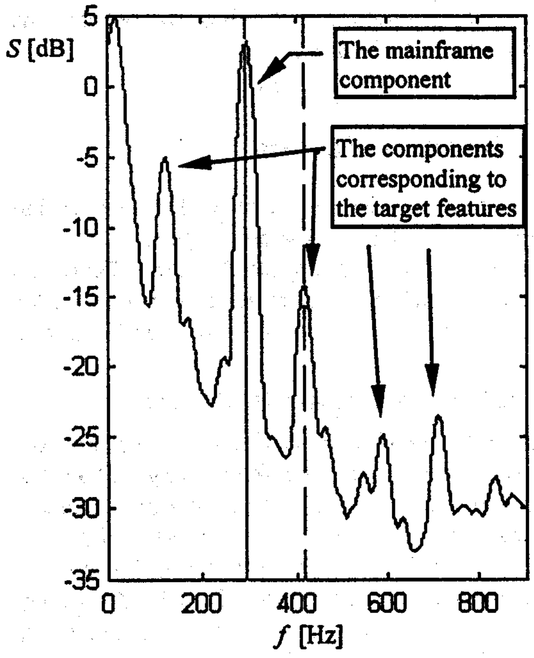

Fig. 5 The spectrum of a moving tracked vehicle

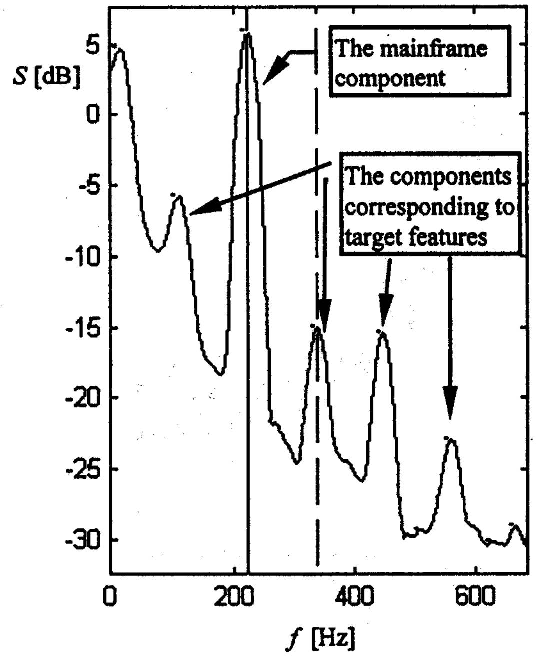

Fig. 6 The spectrum of a moving tracked vehicle, the radial velocity and incident angle are different from Fig. 5

5. Conclusion

The results of our experiments present it is possible to detect differences between spectra of moving wheeled and tracked vehicles for the purpose of Radar Target Classification by a spectral analysis method using the radar signal mentioned above. Both DFT and MUSIC are suitable in extracting features. However, MUSIC is more sensitive and more time demanding compared to DFT [1]. Furthermore, we assume an analog spectral analysis using narrow band active 2[nd] order filter [3], [4], too.

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