A NOVEL APPROACH BASED ON CURVELET TRANSFORM FOR WEAK RADAR SIGNAL DETECTION

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Abstract— Localization and detecting weak signal are the challenging tasks in radar systems. Radar performance can be enhanced by mounting the receiver output signal-to-noise ratio (SNR). In this paper, a novel approach based on Curvelet transform for detecting weak radar signal is proposed. We applied the curvelet transform and modulus maximum to detect the locations of laser radar echo signal. Localizing the received signal plays key during the detection of signal in noise. The parameters like SNR, RMSE and curvelet coefficients are evaluated and the simulation to real radar signal is verified by MATLAB. The statistical result shows that the proposed method effectively improves the signal noise rate of the weak signal.

Keywords— Curvelet, Weal signal, Radar system, signal-to-noise ratio (SNR), MATLAB.

I. INTRODUCTION

Radar is one of major applications of electronics and signal processing. The radar echoes are used to identify a target on the radar scope. The radar echo power varies according to the distance from radar transmitter to goal and the radar cross section of the target. Pulse radar that uses pulses as the radar signal is being used in aviation control, weather forecasting, and ships. The power of the received signal by the radar varies with the distance from radar to the goal and is also dependent on the target radar cross-section. The detectable radar range is given as a function of the SNR of the acknowledge output through the well known radar equation, in radar systems; weak signal detection is a fundamental and major problem. Solution of this problem increases the possibility of detecting lesser objects from great distances. Development of receiver output SNR is conventionally accomplished with pulse integration where the received signal consists of a number of pulse recurrence intervals (PRI) before or after detection.

However, pulse integration requires a number of pulses to enhance the received SNR. For radar with quick scanning feature the required number of pulses for one object may not be enough, to perform pulse integration. Curvelet analysis and higher-order statistics are two of the mostly blooming tools in the field of signal processing in the last twenty years. We propose integrating commonly techniques and display how such a combination can enhance the quality of RF-pulse detection and localization in noisy environment. The problem addressed here concerns the de-noising and localization of received RF radar pulse immersed in noise. In the noise was separated using a non-linear time-frequency filter, which is based on the discrete windowed Fourier transform. It is known that the curvelet transform gives better localization in the time-frequency domain than the discrete windowed Fourier transform.

In the proposed work we will use the Curvelet transform for de-noising the RF radar pulses. In current years, Curvelet transform (CT) is used in the area of image processing as a better tool for time-frequency domain signal analysis. This suggests that the radar echo pulse in noise is obviously detected by using CT. However the method of pulse discovery using CT has not been reported. In this paper, we offer two methods based on CT for improving the receiver output SNR, and observe the development factor of SNR by a computer simulation using simplified signal model. These methods have a useful that the receiver SNR is enhanced by using only 1 pulse, and can be used with the conformist method i.e. integration of radar pulses.

The organization of the paper will be as follow. Section 1 describes introduction, Section 2 will give related work, section 3 will give a short introduction to Curvelet Transform. Section 4 and 5 will describes the proposed technique and simulation results for the proposed technique. Section 6 shows Integration of radar pulses and Section 7 conclude the paper.

II. RELATED WORK

Weak signal detection is a fundamental and important problem in radar systems. The detectable radar range is determined by the radar equation, and radar performance can be enhanced by increasing the receiver output signal-to-noise ratio (SNR). Many Researchers worked in this area and in this section of some paper reviewed as a part of literature.

- Naoki Ehara et.al (1994) proposed a method based on wavelet transform, has been used primarily for data compression in image processing. Signal analysis can performed by wavelet transform using the wavelets that are localized in both time and frequency domains, improved results can achieved than traditional method of pulse integration in time domain. Using statistical simulations that assume white Gaussian noise is achieved internally in the receiver, we demonstrate that an enhancement of approximately 8 dB in SNR is obtained for only one pulse and high performance radar can be obtained using this method. This technique can also be applied for signal detection in other digital communications.

- Jianhua sun et.al (2010) Presented distinct transmission characteristics under the wavelet transform (WT) domain and the various distribution characteristics in frequency domain. An Innovative approach for detecting weak signal laser radar based on wavelet transform has been proposed. In several cases, wavelet decomposition can be used to de-noise a digital signal submerged by mass noise. Conflictingly in our approach, we applied the wavelet decomposition and the modulus maximum to detect the position of laser radar echo signal. Simulations demonstrate that the proposed method is more proficient than utilizing wavelet decomposition in a clutter environment.
- Subhani Shaik et. al (2016) introduced a new method based on curvelet transform and support vector machine to recognize and classification of power quality disturbances. Curve let transform is used to excerpt features of power quality disturbances and support vector machine (SVM) is used to generate a multi-class classifier that can classify power quality disturbances according to the extracted features. Experimental results show that the proposed method can identify and classify different power quality signals, efficiently, precisely and consistently, even under noisy conditions and attain higher identification rate, much enhanced convergence property and less training time compared with the method based on SVM.
- Uppu Ravi Babu et.al (2016) projected a novel feature detection algorithm based on curvelet transform for spectrum sensing. The received signal is processed by Curvelet transform and then the test statistics are obtained by examining the feature of the signal in the novel domain that is compared with the threshold to decide the presence of the useful signal. To make the detection process faster Principal Component of Analysis (PCA) is used to determine an optimal feature set. In addition, the proposed method is low in complexity, which makes it typically suitable for real time spectrum sensing in cognitive radio system.

II. CURVELET TRANSFORM

Candes and Donoho invented a novel multistate transform named curvelet transform which was intended to represent signals and other singularities onward curves much more proficiently than long-established transforms, i.e., using fewer coefficients for a known accuracy of rebuilding. Curvelet is a best dimensional overview of the wavelet transform intended to represent signals at different scales and different angles. It is a special member of the multi scale calculation transforms, whose structural elements hold the parameters of dimension and location, and orientation parameter more, which cause curvelet transform has well orientation characteristic. The performance of characteristic detectors naturally very high, for this cause they accomplish the classic characteristic of the major Unit signal which is dissimilar from that of noise.

In order to enhance the detection performance, the received signal needs to be transformed into other domain, in which the characteristic of the major Unit signal is more obvious. When the conversion is orthogonal, if they attained non-zero coefficients of the major Unit signal after transformation are less, i.e., the main Unit signal can be represented by less mechanism of orthogonal functions, the characteristic of the major Unit signal in the novel domain is more clear. We begin with the Curvelet transform for the inventing of signals whose base band signals have rectangle cover to process the signal, which is also an orthogonal alteration. The discrete curvelet transform helpful to represent intensity values of an image with given by the function f (α1, β2), β1 = 0, 1, M1 - 1, β 2 = 0, 1,..., M2 - 1, whose discrete Fourier transform (DFT) is

$$\hat{f}(m_1, m_2) = \sum_{\alpha 2=0}^{M2-1} \sum_{\alpha 1=0}^{M1-1} f(\alpha_1, \alpha_2)\, e^{-2\pi i}(m_1 \alpha_1 / M_1 + m_2 \alpha_2 / M_2)$$

The discrete curvelet transform is now a disintegrate into the curvelet coefficients such that

$$f(m_1, m_2) = \sum_{j=1}^{j} \sum_{l=0}^{L_j-1} \sum_{k_1=0}^{K_{jl,1}-1} \sum_{k_2=0}^{K_{jl,2}-1} c_{jlk} s_{jlk} (\alpha_1, \alpha_2)$$

Where n= (m1, m2), s is the curvelet on level j with orientation l and spatial shift n.

$$\sum_{jlk} |cjlk|^2 = \sum_{y1,y2} + \quad |f(\alpha 1, \alpha 2)|^2$$

The discrete curvelet transform provides a disintegration of the image f into J detail levels, with Lj orientation on every level, and K jl,1 × K jl,2 spatial shifts for each Where n= (n1, n2) and s is the curvelet on level j with orientation l and spatial shift n. additionally, the curvelet transform preserves l2-norms, i.e.

$$\sum_{jlk} |cjln|^2 = \sum_{x1,x2} + \quad |f(\alpha 1, \alpha 2)|^2$$

The discrete curvelet transform provides a disintegration of the image f into J detail levels, with Lj orientation on every level, and Njl,1× K jl,2 spatial shifts for each directions. The curvelet s is defined through its discrete Fourier transform as

$\bar{s}jok(m_1,m_2) = {}_{Uj}(m_1,m_2)\ e^{-2\pi i}(n_1m_1 / K\ j_{0,1} + n_2m_2 / N\ j_{0,2})$ and $\bar{s}jlk = ST^{\theta_1}\ \bar{s}jon$

Here, S_θ is called as shearing matrix, which shears the grid on which the curvelet is evaluated by an angle $Ø_l$. The slopes defined by the angles $Ø_l$ are equi-spaced. v_j is a frequency window function with compact support.

III. INTEGRATION OF RADAR PULSES

Here we describe one of the traditional signal enhancement method integration of radar pulses". The radar maximum detectable range R max is determined by radar equations. There exist hundreds of versions of the radar range equation. Below is one of the more fundamental forms for a single antenna system (same antenna for both transmit and receive). The target is considered to be in the center of the antenna beam. The maximum radar detection range is

$$\text{Received Signal at Target} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$

Similar to a receiving antenna, a radar goal also intercepts a piece of the power, but reflects (reradiates) it in the path of the radar. The quantity of power reflected toward the radar is resolute by the Radar Cross Section (RCS) of the goal. RCS is a feature of the target that represents its size as show by the radar and has the dimensions of area.

$$G_r = \frac{4\pi\sigma}{\lambda^2} \quad \text{and Reflected Signal from target} = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \frac{4\pi\sigma}{\lambda^2}$$

The equation for the power reflected in the radar's route is the same as equation [6] except that Pt Gt, which was the unique transmitted power, is replaced with the replicated signal power from the goal, from equation [3]. This gives:

Replicated Signal Received Back at I/P to Radar Receiver = $\frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \frac{4\pi\sigma}{\lambda^2} \times \frac{G_r \lambda^2}{(4\pi R)^2}$

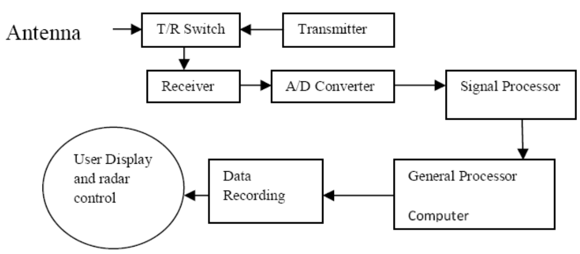

Figure 1: Signal receiving, processing and controlling

IV. PROPOSED METHOD

Here we propose two methods for the radar signal detection. One is a method which uses the wavelet as a matched filter, and the other is a method by integration of some CT coefficients that are obtained by using different scale parameters. Fig.1 shows the block diagram of the radar systems. The video signals after the detection is indicated on the radarscope via the video amplifier in the figure. The CT is a filter in both time and frequency domains. The relation between the radar echo signals and the curvelet, it will be considered that the CT coefficient is maximum, when the best scale parameter is used. First, we propose the signal detection method by the CT coefficients using optimum curvelet which has a flat scale parameter. This method forms a corresponding filter whose impulse response is the optimum curvelet and the radar echo signal is detected by translating the optimum curvelet in the time domain. In the curvelet transform, the scale parameter is excess compared with the novel signal, because the shift parameters and the CT coefficients correspond to the time and the amplitude of the unique signal, respectively. We consider the successful use of the scale parameter and we proposed the signal detection method by integration of some CT coefficients that are obtained by using different scale parameters. It is simply understood that the CT coefficients of noise take both plus and minus values on the similar shift parameters. This method is performed by integration of CT coefficients that are attaining by varying the scale paramet.er in some point on the same shift parameter.

The following step-by-step procedure is used for detection Weak Radar Signal.

AIM: a novel approach based on Curvelet transform for detecting weak radar signal.

INPUT: Radar Weak signal

PROCEDURE:

i. The input characteristic vector is processed by applying Curvelet Transform. In realistic application, merely discrete signal can be accord by computer, so we consider the performance of the detector based on discrete Curve let transformation.

$$CT^D(j, l, c) = \sum f(m, n)\ Ø^D_{j,l,k}(m, n)$$

Where a = (A_1, A_2) is spatial location parameters and $Ø^D_{j,l,a}(m, n)$ is digital curvelet waveform

Curve let coefficients CT^D in discrete domain are given by

$$CT(j, l, a) = (f, Ø^D_{j,l,a}) = \int f(x)\ \bar{Ø}^D_{j,l,a}(x)\, dx$$

ii. The pertinent features passing through an proficient classifier called support vector machine to develop the multi-classifier feature vector. This can be done as follows

$\varphi_i = \max_r F_{i,r} - \min_{r:\ \tau i,r < \delta yi,r} Fi, r$

Set: $p = \arg\ \max\{\psi i\}$

Set for r = 1. . . a: $D_r = \frac{F\,p,r}{Ap} - \tau_{p,r} + \delta r$,

y_p and $\theta = \frac{1}{a}\sum_{r=1}^{a} Dr - \frac{1}{a}$

Call: $\bar{\tau}^*_p$ =Fixed Point Algorithm ($\bar{D}$, θ, ∈/2).

Set: $\Delta\bar{\tau}_p = \bar{\tau}^*_p - \bar{\tau}_p$

Update for i = 1. . . m and r = 1. . .a:
$F_{i,r} \leftarrow F_{i,r} + \Delta\tau_{p,r} K(\bar{x}_p, \bar{x}_I)$
Update: $\bar{\tau}_p$ -$\bar{\tau}^*_p$

- **iii.** First-rate character set is determined by support vector machine to make the detection procedure faster. Optimization problem can be solved by reducing Lagrange function.

$$L(w, w_{io}, \emptyset, \lambda, \acute{u}) = \frac{1}{2}\|\boldsymbol{w}\|^2 + CT\sum_{i=1}^{N} \emptyset_i - \sum_{i=1}^{N} \emptyset_i \acute{u}_i - \sum_{i=1}^{N} \lambda_i [Y_i (w^T{}_i y_i + w_{io}) - 1]$$

- **iv.** The equal Karush-Kuhn-Tucker (KKT) conditions that the minimize of above equations has to assure are

$$\lambda_i [Y_i (w^T{}_i y_i + w_{io}) - 1 + \emptyset_i] = 0, \quad \acute{u}_i\emptyset_i = 0, \quad \acute{u}_i \geq 0, \quad \lambda_i \geq 0 \quad i=1, 2\ldots\ldots\ldots..N$$

- **v.** OUTPUT: Detecting weak radar signal using Curvelet Transform is achieved.

V. RESULTS AND DISCUSSION

The detection of radar weak signals using curvelet transform is implemented and we consider the rectangle pulse as a transmitted radar signal. The replicated signal for a target is transformed by mixing with the local oscillator signal. This process set limits to the bandwidth of the received signal. The relation between the bandwidth and the pulse width on the condition that the SNR of receiver output is maximum. This band limited signal outcomes in a Gaussian pulse approximately. Therefore we utilize the Gaussian pulse as a radar echo signal. The sampling interval of a signal is determined by the Nyquist's theory. We use the Laplacian Gaussian Cuvelet and join with Gaussian noise whose average is zero. Noise standard deviation is changing as a parameter. We assume that the clutter is eliminated totally by CFAR (Constant False Alarm Rate) or MTI (Moving Target Indication) process. First, we calculate CT coefficients of the radar echo by fixing the shift parameter at the center of the radar echo, and search an best scale parameter. Using this method to calculate the radar signal with CT coefficients for weak signal. It also calculates parameter of the signals for bypass weak signal during processing. SNR of the signal is calculated for echo of CT coefficients for better efficiency. The following results are varied using MATLAB.

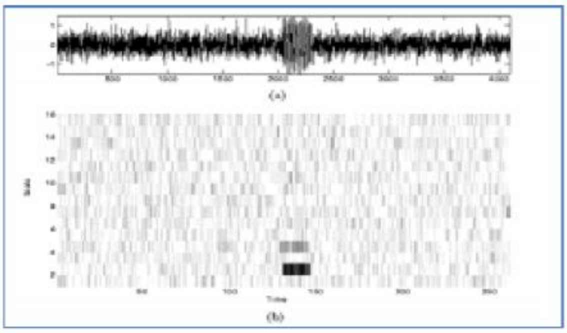

Figure 2 (a) Received noisy radar pulse x(n), SNR = −4 dB. (b) The Curvelet coefficients of x(n), J = 5.

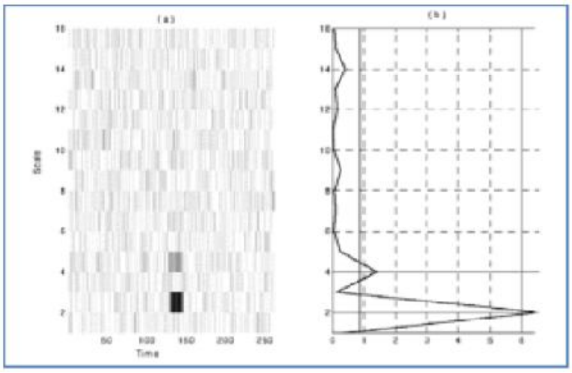

Figure 2. (a) The curvelet of x (n). (b) The kurtosis of the curvelet packet.

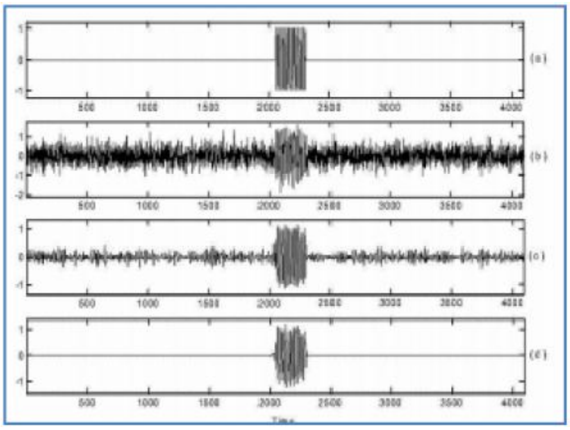

Figure 3. RF radar pulse z(n) (b) The received noisy RF radar pulse x(n), SNR = −3 dB (c)Rresult of the first stage (d) The result of the second stage (step 5).

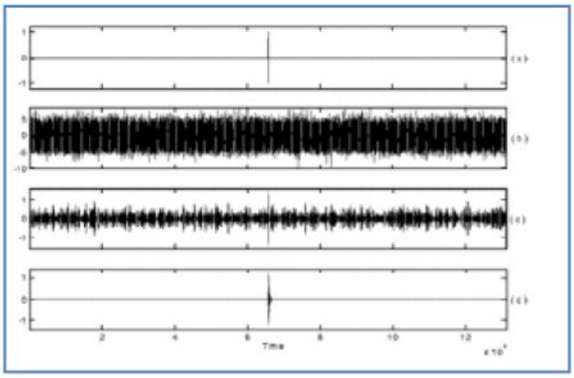

Figure 4. (a) Clean signal (b) Noisy signal SNR = −25 dB (c) de-noised signal after the first stage (d) de-noised signal after the second stage (step 5)

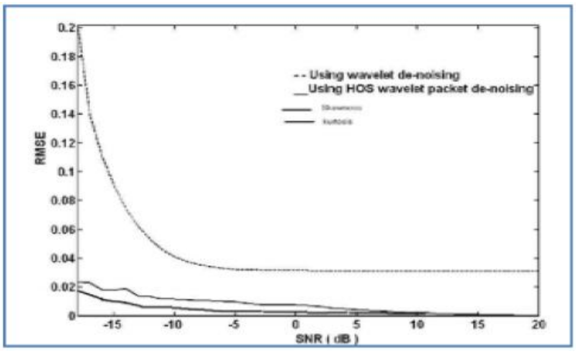

Figure 5. RMSE as a function in SNR for the proposed technique and the curvelet in MATLAB.

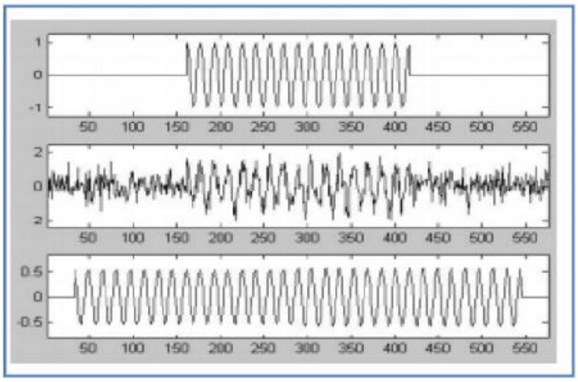

Figure 6.Result for signal de-noising using cur detecting weak radar signal curvelet transform.

CONCLUSION

Localization and detecting weak signal are the challenging tasks in radar systems. Radar performance can be enhanced by mounting the receiver output signal-to-noise ratio (SNR). In this paper, a novel approach based on Curvelet transform for detecting weak radar signal is proposed. We applied the curvelet transform and modulus maximum to detect the locations of laser radar echo signal. Localizing the received signal is important during the detection of signal in noise. The parameters like SNR, RMSE and curvelet coefficients are evaluated and the simulation to real radar signal is verified by MATLAB. The statistical result shows that the proposed method effectively improves the signal noise rate of the weak signal. By the curvelet transform, we find that the SNR is enhanced more than 8 dB only 1 pulse compared with the original signals. This value corresponds to the integration of 7 pulses in the "integration of radar pulses", and to 90 percent development of radar detectable range for a target which has the same radar cross section. Localizing the received signal is important during the detection of signal in noise. The parameters like SNR, RMSE and curvelet coefficients are evaluated and the simulation to real radar signal is verified by MATLAB. The statistical result shows that the proposed method effectively enhances the signal noise rate of the weak signal.

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