Chapter 7

Summary

Radar is a powerful tool for detecting and tracking airborne and land-based targets by day and night. Nowadays, it is seen as a genuine solution to the problem of target recognition. Recent events showed that cooperative means of identification such as the IFF (Identification Friend or Foe) transponders carried by most aircraft are not entirely reliable and can be switched off by terrorists. For this reason, it is important that target identification be obtained through measurements and reconnaissance based on non-cooperative techniques.

This thesis investigates the signal and image processing techniques that can be used for non-cooperative target recognition (NCTR). The problem of NCTR has always been a topic of interest in military/peacekeeping operations, that is, to improve situational awareness. There are a number of radar techniques that can be applied to NCTR. Among some of the more promising methods are high-range resolution (HRR), jet engine modulation (JEM), micro-Doppler (m-D) and inverse synthetic aperture radar (ISAR). In particular, this thesis investigates the ISAR and m-D techniques that can be used for NCTR.

For target recognition applications, mainly those in military surveillance and reconnaissance operations, a blurred ISAR image of the moving target has to be refocused quickly so that it can be used for real-time target identification. Advanced time-frequency methods for focussing distorted radar images were developed. These methods provide improved target detection and imaging in SAR/ISAR.

We developed a time-frequency S-method-based approach for real-time motion compensation, image formation and image enhancement of moving targets in ISAR and SAR. This approach performs better than the Fourier
transform by drastically improving images of fast, manoeuvring targets by increasing the SNR in both low and high noise environments. Previously, the S-method is used for one-dimensional time-series analysis to reveal time-varying information embedded in signals. For the first time, the S-method was further analyzed and the algorithm was developed for radar imaging. The effectiveness of this method is demonstrated through the application to simulated and experimental data sets. This part of the work is published as:

“Focusing ISAR images of moving targets in real-time using time-frequency-based method.,”
T. Thayaparan, L. Stankovic, P. Suresh, K. Venkataramaniah.
Proceedings of International Radar Symposium, IRS-2010, Lithuania.

The reassigned smoothed Wigner-Ville distribution (RSPWVD) was proposed to refocus distorted ISAR images. The advantage of this method is that it drastically reduces the blurredness in the cross-range direction. This method gives better results than the standard Fourier transform, spectrogram and smoothed pseudo Wigner-Ville distribution. The RSPWVD is used to analyze the non-stationary signals in the past. In this study, this distribution was further studied and the algorithm was developed to refocus distorted ISAR images. The effectiveness of the proposed method is demonstrated with the experimental radar data. This part of the work is published as:

“ISAR Imaging of Moving Targets Based on Reassigned Smoothed Pseudo Wigner-Ville Distribution.,” P. Suresh, T. Thayaparan, K. Venkataramaniah.
Proceedings of International Radar Symposium India, IRSI-2011, India.

In our study, we compared the different time-frequency methods in focusing distorted radar images. It is found that the images obtained using short-time Fourier transform (STFT) are more clear than the images obtained using smoothed pseudo Wigner-Ville distribution. But the drawback of the STFT is that time and frequency resolution depends on the width of the window function used in calculating STFT. If the proper window size is not chosen, then it may not give good result. The comparison shows that RSPWVD can significantly improve the focussing of ISAR images. However, the quantitative analysis demonstrates that RSPWVD is computationally expensive. Among all the possible methods, the analysis showed that methods based on S-method are computationally simple and
efficient, and perform better than the remaining methods that are considered in this study. For the first time, the quantitative analysis is studied and compared for the ISAR images. This part of the work is communicated as:


Radar m-D signatures are of great potential for identifying properties of unknown targets. The m-D parameter estimation from radar returns has great potential for use in target identification applications. The m-D motion parameters have gotten applications in indoor and outdoor radar detection and automatic gait recognition systems.

We introduced a new procedure for an m-D analysis, namely, the adaptive chirplet decomposition incorporated with the time–frequency analysis in order to extract the m-D features of radar returned signals from targets. The new procedure has been successfully applied to SAR data scene collected by the US Navy APY-6 radar. Results show that the proposed methodology is an effective tool for extracting m-D features. This part of the work is published as:


We further demonstrated the application of adaptive chirplet decomposition-based method incorporated with the time–frequency analysis for extracting m-D signatures from radar signal returns of helicopter targets. In order for the extraction of m-D features to be realized, the time domain radar signal is decomposed into stationary and non-stationary components based on the parameters of the chirplet bases, particularly chirp rate and variance. The components are then reconstructed by applying the inverse chirplet transform. After the separation of m-D features from the target’s original radar return, time-frequency analysis is then used to estimate the target’s motion parameters. The findings show that the results have higher precision after the m-D extraction rather than before it, since only the rotational components are employed. This proposed method of m-D extraction has been successfully applied to helicopter. This part of the work is published as:
A novel approach was studied and developed based on Fourier–Bessel transform (FBT) and time–frequency (TF)-based method in conjunction with the fractional Fourier transform (FrFT), for extracting m-D radar signatures from the rotating targets. This approach comprises mainly of two processes, with the first being the decomposition of the radar return, in order to extract m-D features, and the second being the TF analysis to estimate motion parameters of the target. In order to extract m-D features from the radar signal returns, the time domain radar signal is decomposed into stationary and nonstationary components using the FBT in conjunction with the FrFT. The components are then reconstructed by applying the inverse Fourier–Bessel transform (IFBT). After the extraction of the m-D features from the target’s original radar return, TF analysis is used to estimate the target’s motion parameters. This part of the work is published as:

“Extracting micro-Doppler radar signatures from rotating targets using Fourier-Bessel Transform and Time-Frequency analysis.”,

P. Suresh, T. Thayaparan, K. Venkataramaniah.


We further demonstrated the application of FBT and TF-based method in conjunction with the FrFT, for separating non-stationary signals whose frequency components overlap both in time and frequency domain. Results demonstrate the effectiveness of the proposed method for detecting maneuvering target in a heavy sea clutter. This part of the work is published as:

“Non-Stationary Signal Separation using Fourier Bessel transform and Time-Frequency analysis “,

P. Suresh, T. Thayaparan, K. Venkataramaniah.

EMD can be used to separate nonstationary signal components even if their frequencies overlap in frequency domain. In the case of nonstationary signals whose frequency components intersect both in time and frequency domain, EMD fails to give desired results. In this study, we applied the FBT, FrFt and TF-based decomposition method for the separation of multi-component nonstationary signal whose components overlap in both time and/or frequency domain. The efficiency of the proposed method is compared with one of the traditional decomposition methods like EMD. The proposed method is applied to both simulated data and measured radar data. The quantitative analysis distinctly demonstrates that FB-TF method significantly improves the signal-to-clutter ratio compare to the EMD method. Results demonstrate that the proposed method could be used as potential tool for detecting and enhancing low observable maneuvering, accelerating air targets in the littoral environments. This part of the work is communicated as:

“A new signal decomposition approach for detecting maneuvering air target in sea clutter”,
P.Suresh, T. Thayaparan, K. Venkataramaniah.

In this study, we developed a new approach based on S-method in conjunction with the Viterbi algorithm to extract m-D features. The effectiveness of this approach in extracting m-D features is demonstrated through the application to indoor and outdoor experimental data sets such as rotating fan and human gait. The viterbi algorithm for the instantaneous frequency estimation is used to enhance the weak human m-D features in relatively high noise environments. As such, this study contributes additional experimental m-D data and analysis, which should help in developing a better picture of the human gait m-D research and its applications to indoor and outdoor imaging and automatic gait recognition systems. This part of the work is published as:

“Intelligent target recognition using micro-Doppler radar signatures”,
T. Thayaparan, L. Stankovic, Igor Djurovic, P. Suresh, K. Venkataramaniah.

For the first time, the S-method was introduced and applied for the extraction of m-D features from the experimental data sets like rotating
corner reflectors data and rotating antenna data. This method is also computationally simple, requiring only slight modifications to the existing Fourier transform based algorithm. This part of the work is published as:

"Analysis of micro-Doppler radar Signatures in SAR using S-method-based approach",
P.Suresh, T. Thayaparan, K. Venkataramaniah  
Proceedings of International Radar Symposium India, IRSI-2009, Bangalore, India.

The S-method has many advantages. However it is not without significant weaknesses. When the prominent scatterers within the target are very close to each other, the undesired cross-terms between scatterers or targets appear as a result of its mutual influence. In order to eliminate the interference terms between close scatters, we developed adaptive S-method based method for extracting m-D features. We used Otsu algorithm for calculating the threshold value in adaptive S-method. The efficiency of the adaptive S-method is confirmed by applying to experimental rotating corner reflectors data. This part of the work is published as:

"Micro-Doppler Analysis of Rotating Targets using Adaptive S-method",
P.Suresh, T. Thayaparan, K. Venkataramaniah  
Proceedings of International Radar Symposium India, IRSI-2011, India.

Gabor-Wigner transform was proposed for extracting m-D features from rotating targets. The method combines the advantages of short-time Fourier transform and Wigner Distribution in order to extract the m-D features of radar target returns. The effectiveness of the proposed method is compared quantitatively with short-time Fourier transform, Wigner-Ville distribution and S-method. By applying the proposed Gabor-Wigner transform to experimental data such as rotating corner reflectors and rotating antenna in SAR, the effectiveness of this analysis technique is confirmed. This part of the work is published as:

"Analysis of micro-Doppler Radar Signatures of Rotating Targets Using Gabor-Wigner Transform",
P.Suresh, T. Thayaparan, K. Venkataramaniah  
We developed a new method for estimation of the parameters of sinusoidally modulated signal. The proposed method is based on the inverse Radon transform and the concentration measures. Since the Radon transform of a two-dimensional signal containing a two-dimensional delta function is a sinusoidal pattern with amplitude corresponding to the distance of the point from the origin and the initial phase corresponding to the phase of the point position, then it is obvious that a sinusoidal pattern in the time-frequency plane will project to a two-dimensional delta in the inverse Radon transform. This is obviously an optimal transform for a two-dimensional sinusoidal pattern, since all signal energy from the time-frequency domain will be projected in a single point in the inverse Radon transform domain. The efficiency of inverse Radon transform in extracting m-D features has been demonstrated by applying to experimental radar data. Results from this study show that the proposed method provides reliable and robust estimation of the motion parameters. This part of the work is communicated as:

“Micro-Doppler parameter estimation using Inverse Radon Transform”

P. Suresh, T. Thayaparan, K. Venkataramaniah