SAR Imaging for Multiple Target Tracking

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ABSTRACT

In this thesis, we study the new imaging theory developed that incorporates target motion during data collection for the imaging process. The subject of radar imaging from scattered waves is explored and incorporated into the new imaging approach. A simulation model using MATLAB is developed to simulate the imaging algorithm and also to validate the performance. It is shown that the new imaging scheme is well behaved and is linear shift invariant when the data are ideal. It is also shown that the geometry of the transmitters and receivers affects the behavior of the imaging system.

I. INTRODUCTION

A. RADAR IMAGING

Radar is a system that uses electromagnetic waves for detecting, locating, and identifying reflecting objects over long distances in both adverse and good weather conditions. Unlike optical systems, radar systems are generally not affected by atmospheric attenuation because of the wavelengths used. However, in imaging, the resolution of the image is dependent on the signal wavelength. Many radar imaging techniques have been developed since the 1950s to improve the resolution of radar-based imaging systems. Examples of such techniques are Synthetic Aperture Radar (SAR) and the Inverse Synthetic Aperture Radar (ISAR), which have the ability to produce imagery with high resolution.

B. IMAGING TECHNIQUES TO CREATE ARTIFACT FREE IMAGERY

The main goal in radar-based imaging techniques is to create an artifact free image. The start stop approximation is common to all existing imaging techniques and this is central to the thesis and holds a fundamental difference between the new imaging scheme developed in and current techniques.

1. The Born Approximation

In the standard radar scattering model, an object is assumed to be composed of a collection of simple point scatterers. When considering multiple scattering (in which the scatterers are allowed to interact) analysis becomes too unwieldy. Hence the “weak 2 scatterer” or Born approximation is used instead

2. Bandwidth Limited Radar Systems

Although, ideally, an infinite bandwidth is desired, all practical systems are bandwidth-limited, and this fact affects image resolution. In addition, the signal information measured from practical systems is not noise-free, as it is always corrupted by unwanted signals, and this also causes unwanted image artifacts.

3. The “Start-Stop” Approximation

Most modern radar systems use a train of pulses together with coherent integration for the detection of a target and for an estimation of the target’s velocity.

These types of waveforms typically allow the use of the start-stop approximation, which assumes the target is stationary during the measurement process. In order to achieve better signal-to-noise ratio (SNR) in the measurements, coherent integration is required.

C. MOTIVATION: IMAGING MOVING TARGETS

Many imaging techniques have been developed to image moving targets. For example the Space-Time Adaptive Processing (STAP) (which is a signal processing technique) uses multiple-element antenna arrays coupled with real-aperture imaging techniques to produce ground moving target indicator (GMTI) images. The technique described in uses SAR (designed to image stationary scenes) together with GMTI processing for detecting slow-moving surface targets that exhibit start-stop like maneuvers.

D. OBJECTIVE

The objective of this thesis is to study a linearized imaging theory, developed by professors Cheney and Borden, for imaging a scene with moving targets. The physics behind it and the approach to address image artifacts associated with targets moving in an unknown fashion will be discussed. On a moving point scatterer via MATLAB simulation.

I. IMAGING THEORY

A. RADAR SYSTEMS

Radar systems use electromagnetic waves to detect the presence of a target in an area of interest. These systems send out a signal, which could be a pulse or a series of pulses (known as pulse train), and this signal interacts with a target and is reflected back to the radar. From the reflected signal, the two measurements that can be obtained are the round trip time delay of the transmitted signal and the target radial velocity. The range of the target is determine by measuring the round trip time delay, τ , where Range, $R = c\tau / 2$.

B. SCATTERING OF ELECTROMAGNETIC WAVES

Radar information is based on the reflected electromagnetic waves. Understanding the behavior and properties of such waves provides important information about the target. Assuming the waveform generator produces a time varying waveform s(t) and is mixed with the carrier wave of frequency w_0 to produce $f(t) = s(t)\cos(w_0 t)$, the transmitted field is

$$\tilde{E}_{inc}(x,t) = \tilde{E}_0^{inc} f(t - x/c)$$

Substituting, $u = t + R(t)/c$, we can solve for t in terms of u (at boundary condition):

$$t = \frac{u - R/c}{1 + v/c}$$

And so the scattered field can be expressed as:

$$\tilde{E}_{scatt}\, g(t + R(t)/c) = -\tilde{E}_{inc}\, f\left[\alpha(t + x/c - R/c) - R/c\right]$$

C. CORRELATION RECEPTION

Although we can easily increase the signal to noise ratio (SNR) by doing coherent pulse integration, there are limitations. For example, the increase of pulse repetition frequency will also decrease the maximum unambiguous range. The target usually moves during data collection, which results in the phase of the scattered field being altered. Pulse integration is also limited by the ability of the local oscillator to remain coherent over the interval in which the pulses are transmitted.

D. ONE-DIMENSIONAL (HIGH RANGE RESOLUTION) IMAGING

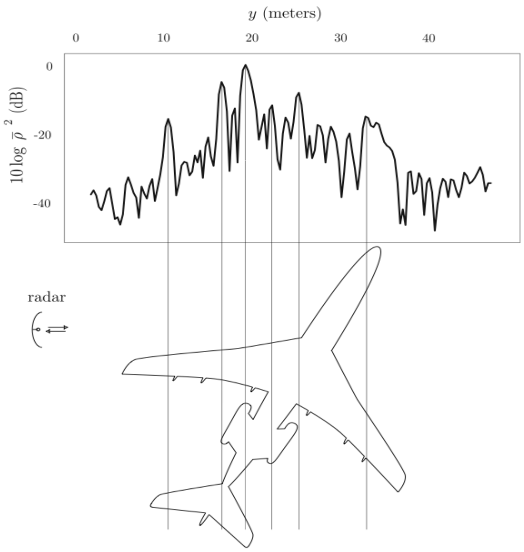


Figure 1. Example of a range profile from a B-727 jetliner.

However, range profiles can be difficult to be used for target classification, since all scatterers located at the same distance from the radar will reflect the signal back with the same time-delay. As a result, the range profile will not be able to distinguish the cross range structure.

E. TWO-DIMENSIONAL IMAGING

A simple concept based on "triangulation" can be used to determine the cross range target structure while still using an HRR radar system. Figure 2. Illustrates this approach, which relies on range profiles collected from different target orientations and correlated to form a two-dimensional image.

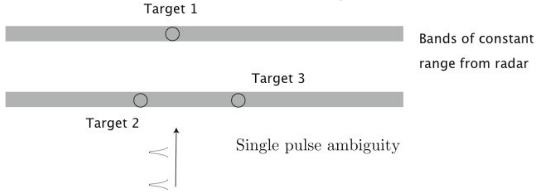


Figure 2. Ambiguous scenario from a single radar pulse

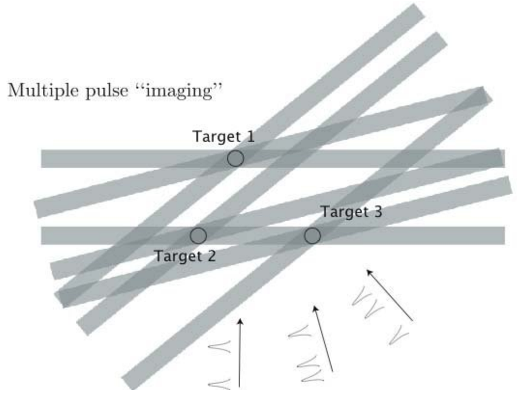


Figure 3. Cross-range information obtained from range profiles

There are 2 different schemes used to collect data from different target aspects. In one, the radar moves while the target remains stationary. This data collection process occurs over a synthetic aperture and hence is called "synthetic aperture radar" (SAR). In the other, the target rotates while the radar is stationary and staring at the target. This data collection process is called "inverse synthetic aperture radar" (ISAR).

F. RADAR IMAGING—AN INVERSE PROBLEM

Normal radar can be approximated as a linear measurement system, which is also shift invariant. Radar imaging would not be possible if the time-delayed scattering signal looked different for different time delays. Hence, a radar imaging system can be expressed by the functional operator or "kernel" κ that describes how the measurement system works $m = \kappa f$

1. Well-Posed and Ill-Posed Problems

Radar systems, which are typically band-limited, do not allow a unique solution to the inverse problem. This is due to the fact they yield finite measurement data, which are noisy as well. $f = \kappa^{-1} m$

2. Data Reconstruction Regularization

For limiting the effect of noise, both truncation filters and Tikhonov regularization are powerful and useful methods. However, none offers a method to choose the "best" threshold value α. With too large α, the ability to accurately estimate the object will be affected, and too smallα will not control the noise effectively.

III. IMAGING AND THE MOVING TARGET DATA MODEL

A. LINEARIZED DATA MODEL

The scattering model used to describe non moving targets is based on a scattered field using Born approximation and is

$$\Psi_{scatt}(x,t)=\iiint_{n} g(x',x;t',t)\rho(x')\psi_{inc}(x',t')d^3x'$$

Where;

$$g(x',x;t',t)=\frac{\delta(t-t'-|x'-x|/c)}{4\pi|x'-x|}$$

B. FURTHER SIMPLIFYING APPROXIMATIONS

1. The Slow-Mover Approximation

Inserting this approximation into the result for ψ *scatt* (*y*, z, *t*) and simplifying yields

$$\psi_{scatt}(y,z,t)=\iint\frac{s_y\left(\alpha_{x,v}\left[t-R_{x,z}(0)/c\right]-R_{x,y}(0)/c+T_y\right)}{(4\pi)^2R_{x,z}(0)R_{x,y}(0)}\rho_v(x)d^3vd^3x$$

Where

$$\alpha_{x,v}\equiv\frac{1-\hat{R}_{x,y}(0)\cdot v/c}{1+\hat{R}_{x,z}(0)\cdot v/c}$$

2. The Slow-Mover and Narrow-Band Approximation

The second time derivatives of (*y s t)* are dominated by the *e*− *i*ω *y t* factor, and by implementing the slowly varying and narrow-band approximation, we obtain,

$$\psi_{scatt}(y,z,t)=-\iint\frac{\omega_y^2e^{i\varphi_{x,v}}e^{-i\omega_y\alpha_{x,v}t}}{(4\pi)^2R_{x,z}(0)R_{x,y}(0)}$$
$$\times\tilde{s}_y\left(t+T_y-(R_{x,z}(0)+R_{x,y}(0))/c\right)\rho_v(x)d^3vd^3x$$

Where

$$\varphi_{x,v}\equiv\omega_y^2\left[R_{x,y}(0)-cT_y+\alpha_{x,v}R_{x,z}(0)\right]/c$$

3.The Slow-Mover, Narrow-Band and Far-Field Approximation

Substituting the expansions into previous approximations Equation (3.17) then yields

$$\psi_{scatt}(y,z,t)\approx\frac{-\omega_y^2}{(4\pi)^2|z||y|}\iint e^{i\varphi_{x,v}}e^{-i\omega_y\alpha_{x,v}t}$$
$$\times\tilde{s}_y\left(t+T_y-(|z|-\hat{z}\cdot x+|y|-\hat{y}\cdot x)/c\right)\rho_v(x)d^3vd^3x$$

Where;

$$\varphi_{x,v}\equiv\omega_y\left[|y|-\hat{y}\cdot x-cT_y+\alpha_v(|z|-\hat{z}\cdot x)\right]/c$$

IV. OUTPUT

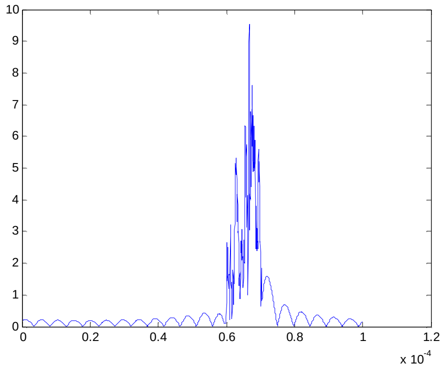


Fig1:Scattering Data of Linear Array Configuration

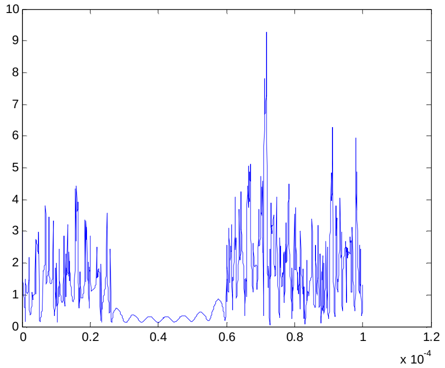
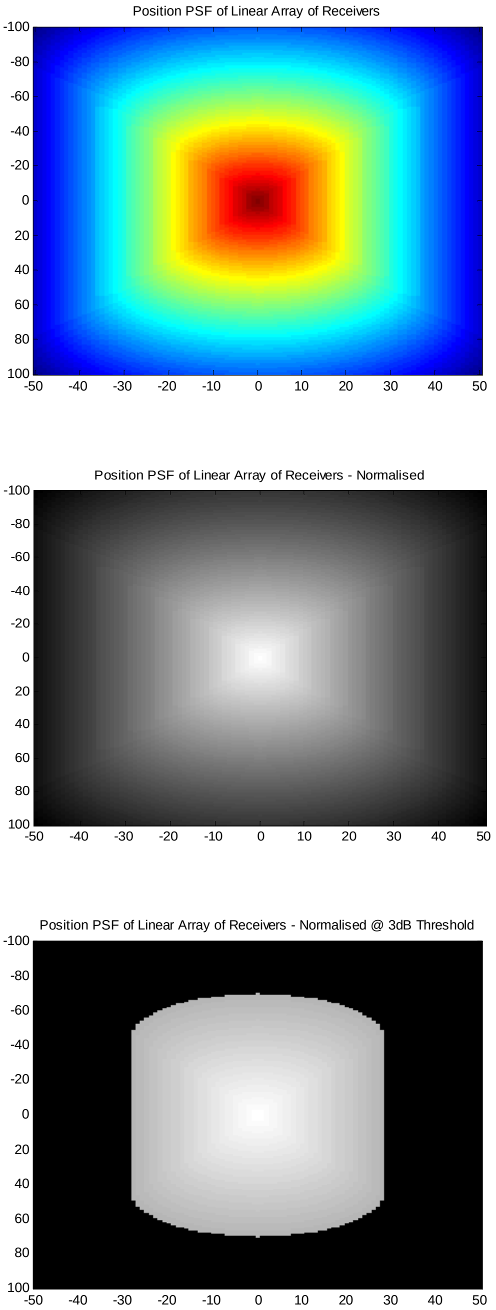


Fig2: Scattering Data of Circular Array Configuration


Position PSF of Linear Array of Receivers

Position PSF of Linear Array of Receivers - Normalised

Position PSF of Linear Array of Receivers - Normalised @ 3dB Threshold

Fig3: Position PSF of Linear Array Configuration Using Rectangular Pulse

CONCLUSIONS AND RECOMMENDATIONS

This thesis analyzes the new imaging approach developed by Cheney and Borden that can accommodate target motion during the imaging process. The simulation results, obtained by using MATLAB, showed that the new imaging scheme is well behaved. It is able to localize the target in position and velocity. In addition, the geometry of the transmitters, receivers, and waveforms utilized affect the behavior of the imaging system. This thesis used single pulse radar waveforms, but in reality, fielded radar systems typically utilize long coded pulse trains. In addition, multistatic radar systems may not be restricted to one transmitter. In this case, the imaging scheme has to be adjusted to incorporate more realistic radar waveforms and optimized for the transmitter/receiver geometries for implementation of the imaging algorithm. These will be used to support the development of the eventual imaging algorithm. Finally, real world target data can then be applied to the developed imaging algorithm to assess its performance.

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