

Moving Target Location in SAR Imagery using NSAR

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Abstract

One of the primary aims of Non-linear SAR (NSAR) is the detection and correct location of moving targets; a brief discussion on current methods is given. A further assessment and analysis of the performance of NSAR is then discussed. A brief summary of a flight trial (Trial 2) is presented, together with analyses of the data obtained. The practical velocity resolution appears to be determined by the target behaviour, rather than by system limitations

Keywords: Synthetic Aperture Radar, moving target detection

Introduction

This paper reports on some aspects of the third year of an on-going research study being undertaken by Sula Systems Ltd for the EMRS DTC under contract EMRS/DTC/4/66.

Previous analysis work [Ref. 1] has demonstrated that the combination of platform acceleration, together with NSAR processing, can potentially provide accurate estimates of the cross-range location and radial velocity of both stationary and moving targets.

In 2005/6 data from Flight Trial 1 were used to demonstrate that the NSAR technique could successfully produce high-quality imagery of a scene from an accelerating platform [Ref. 2].

Further work was required to demonstrate the moving target detection, location and velocity estimation. This year's programme therefore included a further trial, similar to Trial 1 but with a wider range of moving targets, both controlled and opportunistic. The data from this trial were then used extensively to investigate the feasibility of the NSAR technique for the accurate location and velocity estimation of moving targets.

The first section of this paper discusses

current methods of detecting and locating moving targets, one of the primary aims of NSAR. Further assessment and analysis of the performance of NSAR is then discussed, including some of the effects that could affect the location of moving targets. A brief summary of Trial 2 is presented, together with an analyses of the data obtained. Finally, conclusions and recommendations are given.

Detection & Location of Moving Targets

Synthetic aperture radar locates targets in azimuth from their Doppler offsets. Since Doppler is also caused by motion of the target along the synthetic boresight, some additional means is required to distinguish the effects of target motion from cross-range. Currently, this takes the form of an interleaved ground moving target indication (GMTI) mode. GMTI is typically implemented either as a form of displaced phase centre aperture (DPCA), or by using Doppler processing with an otherwise conventional radar.

The former uses adjacent antennas displaced by the distance travelled by the platform in a pulse repetition interval. With this arrangement, the receive antenna is always in the position the transmit antenna

was for each pulse, so that pulse cancellation can be used to eliminate stationary clutter. It is restricted to specialised sideways looking reconnaissance pods, and may require two or more individual antennas, hence is incompatible with most existing combat aircraft radar fits.

A forwards-looking radar is more likely to use Doppler processing, in which the component of aircraft velocity along the boresight is used to down-convert the Doppler to stationary. The target detection performance depends on antenna beamwidth and angle of regard, with very poor Minimum Detectable Velocity (MDV) performance at the limits, particularly with E-scanned antennas.

Both techniques use monopulse angle processing to locate targets in azimuth. This is limited in performance by the antenna beamwidth to fairly coarse cross-range resolutions, and also requires additional front-end hardware.

Correlation

The use of velocity vs. cross-range plots to characterise the ability of NSAR to discriminate between velocity and cross-range position was discussed in [Ref 1] and [Ref 2]. These are plots of the strength of correlation as a function of the velocity and cross-range hypotheses. An example of a theoretical correlation surface for a single point scatterer is shown in Figure 1. It shows the characteristic ‘bow-tie’ sidelobe shape, with the actual cross-range position and velocity given by the strong response at the bow-tie centre.

From the trial characteristics, the expected Point Spread Function (PSF) of the correlation surface leading edge diagonal is presented in Figure 2.

The cross range resolution is about 0.2m. Equivalently, observing the response peak from the velocity direction, the velocity resolution is given by:

$$\Delta v = -\frac{\Delta y}{R} U_{\max}$$

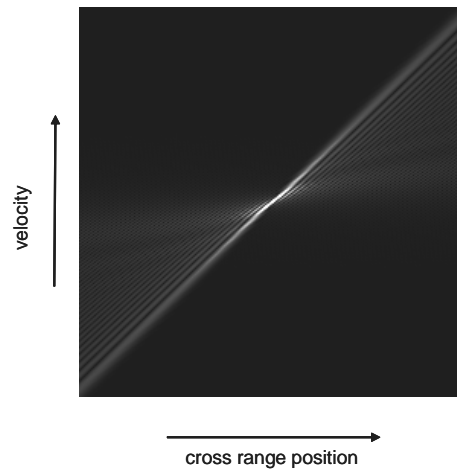


Figure 1: *Theoretical Correlation Surface Plot*

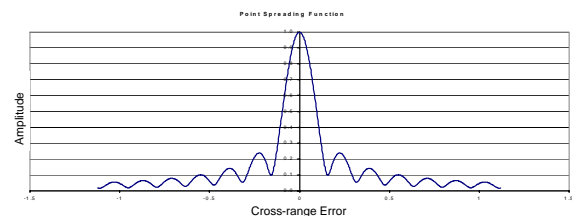


Figure 2: *Point Spread Function*

where R is the range from the synthetic aperture centre to the target scene centre, and U_{\max} is the maximum speed attained by the aircraft.

This yields a velocity resolution of 0.0013ms^{-1} .

When comparing the theoretical PSF to that produced by processing the trials data the following was observed:

- A peak response did not coincide with centre of the sidelobe pattern
- The response is lower, and lobe is broader than the theoretical response
- Neither the peak nor the sidelobe pattern corresponded to the expected scatterer location.

A number of issues were considered as possible causes, including non-uniformity of motion and tangential (cross-range) velocity.

Non-uniformity of Motion

Analysis indicates that the effect of a rapidly fluctuating scatterer radial velocity component would be to smear the scatterer image over the cross-range ambit associated with the displacement which a radial velocity equal to the fluctuation amplitude would cause.

Trial 2 used targets mounted on electric mobility scooters to reduce the variation in their velocities. However, it appears unlikely that their speed would be kept to within the 0.0013ms^{-1} bounds dictated by the nominal radial velocity resolution.

The effect of a sinusoidally varying radially velocity of only 0.002ms^{-1} amplitude is presented in Figure 3. The net effect is a pair of sidebands about the nominal scatterer cross range.

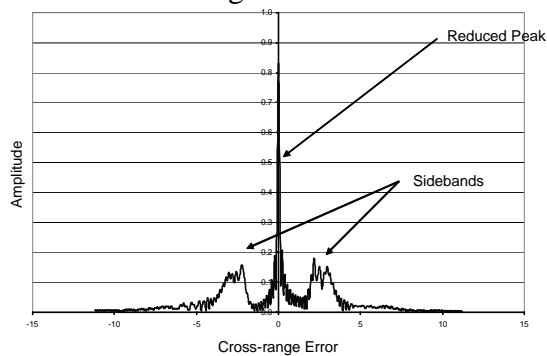


Figure 3: *Effect of Non-Uniform Motion*

This sensitivity to fluctuations in velocity is partially a consequence of the long integration times associated with the trials configuration, and is sufficient to explain the absence of narrow velocity peaks in the practical correlation plots. A shorter integration period, as would be used in practical applications, should broaden the main lobe, reducing the effects of sidebands, and rendering the scatterer location less ambiguous but at a lower resolution.

Further effects are expected from fluctuations in scatterer amplitude (scintillation).

Tangential Velocity

The two-dimensional correlation plot of cross range error vs. radial velocity error may be extended to a three dimensional volume by including the tangential velocity error.

Three orthogonal sections through the centre of the volume are presented in Figure 4.

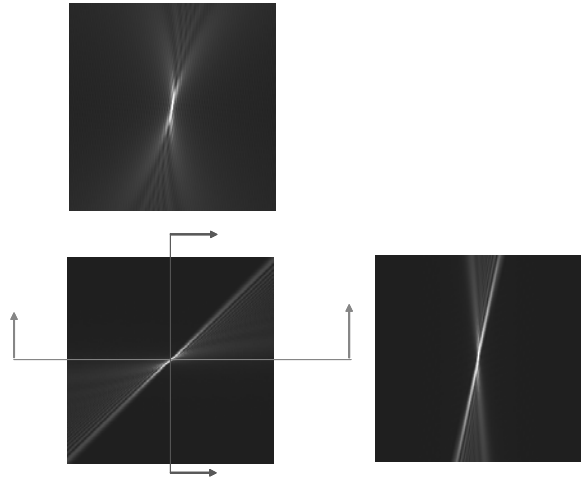


Figure 4: *Sections through the 3D Correlation Volume*

The ‘hottest’ point is at the centre of all three sections, implying that a unique solution exists at the zero error point. Conversely, displacement away from the maximum point in any direction must result in a reduction in amplitude and increase in width of the point spread function.

Using the trials values with a radial velocity error= 0.25ms^{-1} the expected errors are 19m in cross-range and 0.084ms^{-1} in tangential velocity.

Taking a section through the correlation volume at a tangential velocity offset results in the surface of Figure 5. Using the intersection of the edges of the sidelobes (the ‘bowtie’) to locate the peak produces an estimate which is offset from the true centre of the plot. However, the actual peaks are offset even further from the centre, and unlike the effects of scintillation, they do not appear equal in size, nor are they distributed evenly about the centre.

This is further illustrated by Figure 6 which shows the PSFs obtained from the numerical evaluation of the correlation integral for the 0.25ms^{-1} and 0.0ms^{-1} tangential velocity cases

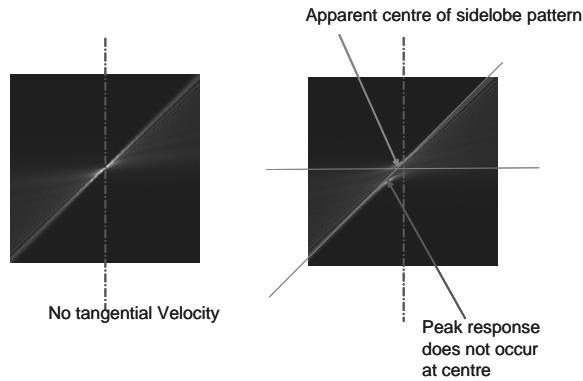


Figure 5: Cross section of the correlation volume at finite tangential velocity error

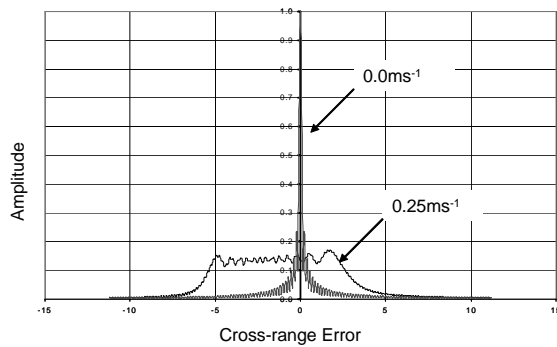


Figure 6: Effect of tangential velocity on PSF

Tangential velocity apparently introduces an asymmetry into the correlation surface such that the intersection of sidelobes fails to yield an accurate estimate of scatterer location and radial velocity. Removal of this asymmetry requires a search in the tangential, as well as in the radial velocity direction.

Flight Trial 2

Trial 2 used the SELEX Lightweight SAR flown on a Jetstream-31 aircraft operating from Cranfield, with the primary target set located within the perimeter of Cranfield airfield.

A flight plan similar to Trial 1 was adopted using linearly accelerating trajectories, either climbing or diving to achieve

maximum acceleration. Two controlled target sets were deployed (CT1 and CT2), as well as three targets of opportunity. CT1 included static targets which were set up on a disused taxi way at Cranfield. CT1 also included three moving targets. An example of a moving target is shown in Figure 7. Target CT2 consisted of a corner reflector and two marine reflectors mounted onto a truck as shown in Figure 8. During the experiment, the truck was travelling at 20mph in a North-West direction towards the village of Stilton.



Figure 7: A CT1 moving target



Figure 8: CT2 – moving truck

Figure 9 shows an image of CT1 at the beginning of one of the runs when the moving targets were still stationary. The starting positions of all CT1 moving targets can therefore be clearly identified.

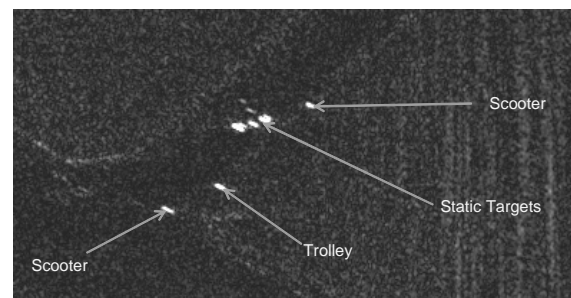


Figure 9: CT1 Moving Target Starting Positions

Figure 10 shows an image processed using a zero velocity assumption correlation from an accelerating platform. The moving targets appear both smeared and offset (as identified in the figure); this is consistent with predictions.

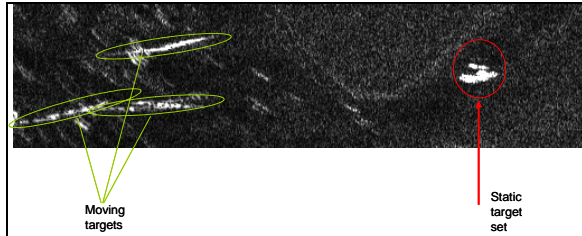


Figure 10: Image of CTI produced using zero-velocity assumption correlation

An example of a velocity vs. cross range plot is shown in Figure 11. This is produced for the range cell as highlighted in the zero velocity assumption correlation in Figure 12. Careful examination of Figure 11 puts the cross of the correlation surface in the position as marked on Figure 12 by the small-dashed line. However the moving target is known to have followed the path marked by the large-dashed line. Tangential velocity has been identified as a possible cause for this offset as discussed in the previous section.

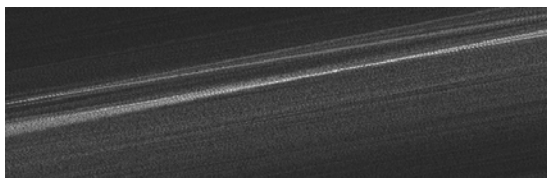


Figure 11: Correlation surface plot of the range cell as identified in Figure 12

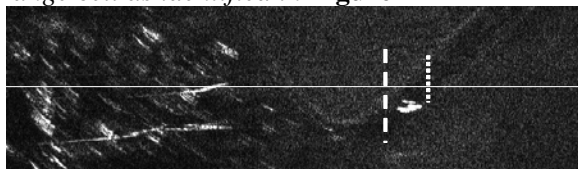


Figure 12: Zero velocity assumption correlation of CTI: showing the actual path of a moving target (small dashed) and the suggested cross range position (large dashed) given by the correlation surface in Figure 11

Conclusions and Recommendations

Conclusions

Considerable progress has been made in the assessment and analysis of the performance of NSAR. In particular we now have a much deeper understanding of the contributions to the NSAR correlation surface.

We have shown that locating moving targets by seeking correlation peaks at the nominal velocity resolution is not robust, as the peak response is broadened and could be offset.

However in analysing the causes of these effects we have identified that there are probably faster and more robust approaches available. Principally the distinctive sidelobe patterns of the velocity profile yield estimates of scatterer location and velocity which appear to be robust to the effects of amplitude modulation etc.

The practical velocity resolution appears to be determined by the target behaviour, rather than by system limitations such as the antenna beamwidth and sidelobe structure, which limit the MDV of conventional forms of airborne MTI radar. Overall, this year's work has further demonstrated that NSAR appears to offer significant benefits including its potential for detecting slow, low-RCS targets.

Recommendations for Further Work

This year's work has shown that effects of tangential velocity and variation in velocity need to be accounted for; therefore it is suggested to investigate these in more detail and to look at techniques for reducing their effects.

It is further recommended that NSAR's resolution and accuracy performance is investigated by

- Exploring the relationships between

image resolution/positional accuracy and platform motion, target motion, target RCS, integration time and PRI

- Assessing, for a given platform trajectory, what would be the typical positional accuracies and resolutions for different target types
- Identifying trajectory characteristics that would be beneficial and those that would be detrimental to the performance of NSAR against given target characteristics.

References

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