The Application of Non-linear SAR to Combat Aircraft Radar

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Abstract

Non-linear Synthetic Aperture Radar (NSAR) uses a combination of platform acceleration and novel processing to deliver both high-resolution imagery from manoeuvring aircraft and the detection and accurate location of moving targets. This paper considers the application of NSAR to fast jets, it suggests the level of performance needed to provide an operationally useful capability and derives realistic trajectories to achieve this performance using both conventional SAR and NSAR techniques. A comparison of these techniques identifies the benefits given by NSAR.

Keywords: Synthetic Aperture Radar, moving target detection

Introduction

Non-linear Synthetic Aperture Radar (NSAR) uses a combination of platform acceleration and novel processing to deliver both high-resolution imagery from manoeuvring aircraft and the detection and accurate location of moving targets within the image.

Previous work (References 1 & 2) has demonstrated the feasibility of the NSAR concept through mathematical analysis, detailed modelling and a series of flight trials. The scope of this work was very broad, encompassing both forward-looking and sideways-looking radars on various trajectories. This year's effort has focused on the application of NSAR to a specific platform type: a fast jet such as the Tornado GR4 or Typhoon.

This paper considers the type of mission that these aircraft may fly in future, suggests the level of performance needed to provide an operationally useful capability and derives realistic trajectories to achieve this performance using both conventional SAR and NSAR techniques. A comparison of these techniques identifies the benefits given by NSAR.

Potential Fast Jet Missions

SAR (coupled with Ground Moving Target Indication (GMTI)), or NSAR may be used on a wide range of missions including: dedicated reconnaissance missions; the surveillance of specific areas whilst in transit to perform another task, for example during ingress or egress on an interdiction mission; seek and destroy missions to detect, recognise and then engage targets; and the observation of a designated target immediately before weapons release, for example to confirm the target identification or to ensure the risk of collateral damage is acceptable.

The mission which utilises both stationary target imaging and moving target detection/location is surveillance whilst in transit. Although this mission specifically considers the surveillance of a pre-determined area, similar considerations may be applied to the observation of a target of opportunity.

Pre-planned surveillance of an area whilst in transit is expected to mean only a single pass will be made by any individual aircraft. Different aircraft within a package may, however, coordinate their searches, for example to create a mosaic of images covering the entire area of interest.

The Minimum Detectable Velocity (MDV) of a GMTI system varies with the angle off the aircraft's nose: the smaller the angle, the lower the MDV. The effects of beam broadening mean that for the e-scan antenna in particular, useful GMTI performance is effectively limited to a sector of ±45° in azimuth. In order to maximise the likelihood of detecting moving targets, it is therefore assumed that the route would be planned such that the target area was on or close to the nose of the aircraft.

In order to generate (conventional) SAR imagery, an approximately straight and level trajectory is needed over the integration period. To minimise the integration period, it is assumed that the planned flight path would be as near as possible perpendicular to the line of sight (LOS) from radar to target. Although both the electronically-scanned (e-scan) and mechanically scanned (m-scan) antennas are assumed to be able to look up to 70° off the aircraft centreline, it is assumed that a practical limit of 60° would be used for planning purposes to allow some leeway for the effects of crosswinds or to respond to threats such as illumination by a weapon control radar.

One trajectory that meets the conflicting requirements of GMTI and SAR is illustrated in Figure 1 (not to scale). The initial approach directly towards the target area allows good GMTI performance; this is followed by a turn away followed by a straight and level SAR leg. Clearly, GMTI cannot begin until the radar has a LOS to the target; for a low level sortie, this unmasking range may be as little as 20km.

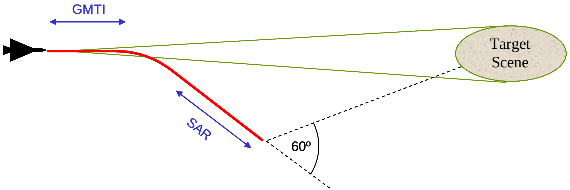

Figure 1: Example Trajectory – SAR/GMTI Surveillance in Transit

NSAR can use a similar flight path. For NSAR, the detection of moving targets and generation of high-resolution imagery take place simultaneously provided the platform accelerates over the synthetic aperture. The down-range and cross-range resolution of imagery produced by NSAR would be the same as that produced by a SAR trajectory having the same synthetic aperture width. SAR imaging can only begin once the aircraft has rolled out on its straight and level course, however, NSAR can image during the turn as well, as illustrated in Figure 2.

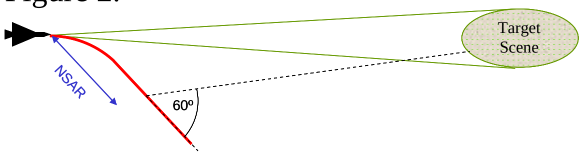

Figure 2: Example Trajectory – NSAR Surveillance in Transit

The NSAR technique allows the platform complete freedom to manoeuvre (for example in response to a threat) during the integration period so long as the radar can continue to illuminate the target. For a straight and level path NSAR would be entirely equivalent to (conventional) SAR, and so would be unable to detect moving targets; the greater the platform acceleration over the synthetic aperture, the better the ability to detect and accurately locate a moving target.

The benefits given by NSAR in this case are:

- NSAR allows the detection of moving targets and generation of imagery to be completed in less time than the equivalent GMTI followed by SAR. Alternatively, a larger area could be imaged by NSAR in the same observation period.
- NSAR affords greater freedom to manoeuvre, allowing any planned or unplanned manoeuvres as long as the radar can continue to illuminate the target area.

Candidate Mission

A candidate mission is described below for which the theoretical performance of conventional SAR/GMTI and the predicted (from analysis) NSAR performance are compared. The scenario for comparison is as follows:

- GMTI scanning on a large area picks up a potential target 20km away just off boresight
- The aircraft must then position itself so that the radar can target the area of interest and gain as much information about the area as possible

For a reasonable comparison the forward-range and cross-range resolutions of the imaging capability of each technique are made equal.

Theoretical GMTI Performance

The assumed geometry for the GMTI is given in Figure 3:

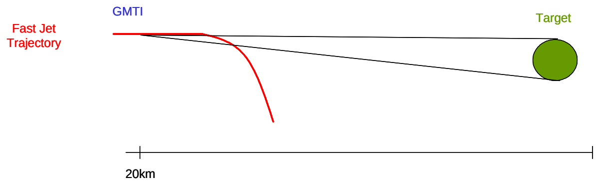

Figure 3: Candidate Mission – GMTI geometry

The minimum detectable velocity (MDV) of a target is shown in Table 1 for both e-scan and m-scan antenna types.

Angle off Aircraft Centreline (°)	MDV (E-Scan Radar) (ms^{-1})	MDV (M-Scan Radar) (ms^{-1})
0	0	0
10	2	2
20	5	4
30	7	6
40	10	8
50	15	10
60	23	12

Table 1: Typical MDV

Theoretical Conventional SAR Performance

Imaging with conventional techniques is possible with a forward-looking radar by using a high angle of regard. 60° angle of regard is the maximum assumed for this radar. For high resolution stretch processing is employed which restricts the forward range ambit to of the order of 750m with a range resolution of 1m. The assumed geometry for conventional imaging of the area of interest is shown in Figure 4.

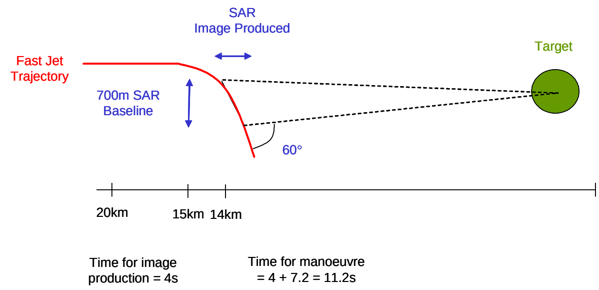

Figure 4: Candidate Mission – SAR geometry

The assumed cross-range resolution required for imaging is 0.3m, with a 14km range from the centre of the aperture to the centre of the target scene (allowing a suitable distance to decide to turn and then turn) the actual distance travelled is 866m. The performance of conventional SAR gives adequate imaging capabilities but provides no further information on any moving targets within the scene.

Potential NSAR Performance

As with the conventional SAR case the target scene is limited to 750m x 750m when using stretch processing. For comparison purposes it is assumed that the aircraft turns at the same time and in the same way as required for the conventional case, giving the geometry as in Figure 5.

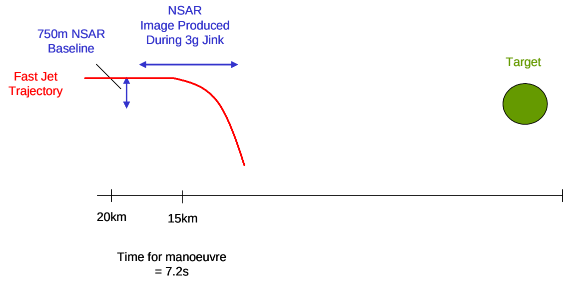

Figure 5: Candidate Mission – NSAR geometry

This gives the centre of the aperture at 15km from the area of interest. For a resolution of 0.3m a baseline of 750m would be sufficient using a maximum lateral acceleration of just over 3g.

Using NSAR the ability to resolve a target's velocity (velocity resolution) depends on the difference between the maximum and minimum platform velocities (projected into the aperture plane). This determines the potential separation of the moving scatterer from the stationary clutter, and hence the theoretical MDV.

Many different manoeuvres are possible for the NSAR technique to provide the similar performance.

Performance Comparison

A comparison of the theoretical performance of conventional imaging and moving target detection with the potential performance of NSAR is given in Table 2 and Table 3 respectively.

Parameter	SAR	NSAR
Range Resolution	1m	1m
Range Ambit	750m	750m
Range to target	14km	15km
Cross-range resolution	0.3m	0.3m
Effective aperture length	700m	750m
Time from start of manoeuvre to stop collecting data	11.2s	7.2s

Table 2: Imaging comparison

Parameter	GMTI	NSAR
Range Resolution	60m	1m
Range to target	20km	15km
Velocity Resolution	$0.375ms^{-1}$	$0.002ms^{-1}$
MDV	$1ms^{-1}$	$0.002ms^{-1}$
Azimuth accuracy as cross-range	40m	0.3m

Table 3: Velocity information comparison

Although the comparison shows that the imaging performance is very similar it must be remembered that it has been deliberately selected to be so, also NSAR offers significant potential benefit as it can collect the data in ~65% of the time of SAR.

There is a clear advantage in the velocity determination comparison especially in terms of range resolution and azimuth accuracy.

Many other manoeuvres are possible and greater rates of acceleration provide even better velocity discrimination.

Conclusions

Overall we have shown that the application of NSAR to forward looking radar on combat aircraft can provide significant improvements in capability.

Areas where NSAR could be used to improve the capabilities of modern combat aircraft radar, providing significant military benefit, have been found. A candidate mission to model the performance of NSAR has been defined.

The theoretical performance of NSAR and the more conventional methods, SAR/GMTI, were compared for both imaging of stationary targets and moving target detection/velocity determination. Using NSAR the data is acquired in ~65% of time required for conventional case.

Recommendations for Further Work

This year's work has shown that NSAR can provide significant benefits to a combat aircraft radar system. Further work is required to establish processing techniques which are both timely and robust to non-ideal moving targets.

References

1. Vigurs, G.J. and Wood, M.S., Non-Linear SAR Techniques, MSW/2692/PR111, Sula Systems Ltd (2005)
2. M L Jarrett, C Milner, G J Vigurs, M S Wood, Non-linear SAR Techniques, Final Report for 2005-06, FRP/PR126/043, March 2006.

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