

Robust radar detection of GMTI targets with STAP

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Abstract: Space-Time Adaptive Processing (STAP) is used in Ground Moving Target Indication (GMTI) to improve the detection of slow or small targets and targets in the presence of jamming. It is used in a number of airborne radar surveillance systems. In order for STAP to be robustly used as part of a practical military sensor it must deliver robust detection performance in all scenarios. In this study we have identified limitations of STAP in realistic scenarios which would affect target detection performance. To address these limitations we have implemented a Non-Homogeneity Detector in a conventional STAP algorithm and demonstrated enhanced target detection performance.

1. Introduction.

Ground Moving Target Indication (GMTI) radar is able to detect moving targets using short dwell times by distinguishing the weak radar signal of the moving target from the dominant returns due to the stationary ground. GMTI is employed by airborne surveillance assets for a wide variety of both conventional surveillance tasks and more recently to retrospectively track the source of Improvised Explosive Devices (IED) in Iraq [1].

The capability of a GMTI sensor is principally governed by the detection performance given by the Probability of Detection (PD). Other capabilities such as geolocation, recognition and tracking are then derived from the detection data. Detection of targets in GMTI can be difficult if they have a low Radar Cross Section (RCS), or if a jammer is active. A common solution to this problem is to use STAP to perform clutter cancellation performance, as demonstrated in [2]. However, in radar trials we have identified scenarios in which STAP does not have the desired effect and actually degrades the target detection probability. In this study we report significant enhancement in robust detection performance by making improvements to the STAP algorithm.

2. Limitations of existing STAP architectures.

STAP processing can be performed either before Fast Fourier Transform (FFT) (pre-Doppler) or after FFT (post-Doppler). A full description of the mathematics of STAP is beyond the scope of this paper, but it is described in detail by Klemm [3]. In summary, STAP attempts to minimise the received power subject to a constraint, by using a set of adaptive weights, adaptively derived from the data. The adaptive weight vector \underline{w} is given by:

$$\underline{w} = \frac{\mathbf{R}^{-1} \underline{c}}{\underline{c}^H \mathbf{R}^{-1} \underline{c}} f, \quad \text{Equation 1}$$

where \mathbf{R} is the covariance matrix \underline{c} is the constraint vector, and f is the constrained gain.

The weight vector is dependent upon the accuracy of the covariance estimate. The presence of a bright target in the data sample used to generate this estimate will lead to the weights being calculated inappropriately and STAP will not perform as expected. Examples of this behaviour are shown in Figure 1 and Figure 2.

From Figure 1 it is apparent that STAP is not forming the adaptive filter correctly, resulting in the null being formed at the wrong Doppler, when compared to the filters formed either side of the target (dashed lines in Figure 1). This failure is caused by the estimation of the covariance matrix in the region containing the target. The target signal is no longer weak and it significantly contributes to \mathbf{R} . The effect of this failure to form the filter correctly results in poor clutter cancellation performance around the targets, shown as dark patches in the clutter cancellation plot in Figure 2. In these regions, small and low RCS targets would not be detected.

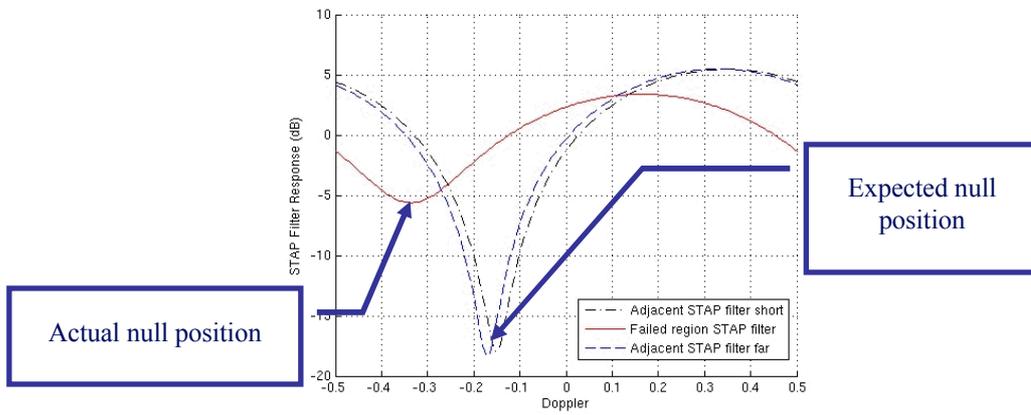


Figure 1 - Filter response for pre-Doppler STAP in the presence of bright targets, showing failure to form null correctly.

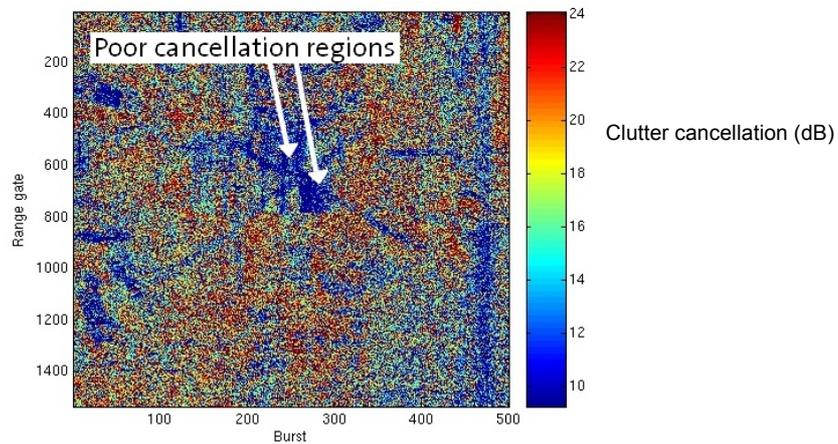


Figure 2 - Clutter cancellation map for pre-Doppler STAP, showing regions of failure around targets. The dark cross at the centre of the scene is due to low reflection from the runway at the trials site.

The post-Doppler STAP algorithm exhibits a very different behaviour in the presence of bright targets. The filter and clutter cancellation plots do not show the same limitations described above for pre-Doppler STAP. For post-Doppler STAP, adaptation is performed independently in each Doppler bin. STAP performance is only perturbed in the Doppler bin of the target. In particular, the moving target Signal-to-Clutter-and-Noise Ratio (SCNR) for the Doppler containing the targets is badly affected, as shown in Figure 3. This is caused by the STAP algorithm forming a null on the target rather than on the clutter, leading to the cancellation of the target signal.

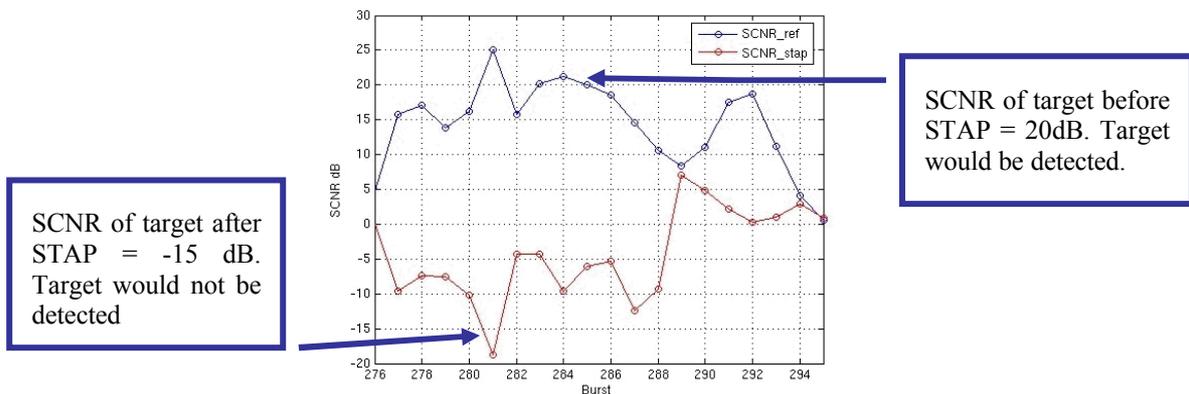


Figure 3 - Plot of SCNR for post-Doppler STAP, showing bursts containing a target without STAP (top) and after STAP (bottom), showing degradation due to STAP

In order for targets to be reliably detected, these limitations of poor clutter cancellation and target attenuation, for pre-Doppler and post-Doppler STAP respectively, must be removed or reduced. Although STAP currently appears to make the detection of targets more difficult, it is still required in order to detect targets in the presence of jamming and to detect small targets alongside much larger ones. A method is needed to make STAP more robust.

3. Non-Homogeneity detector

In order to improve the accuracy of the covariance estimate, it is necessary to identify and remove data samples that do not belong to ground clutter or jammers. In this study, this was accomplished using a Non-Homogeneity detector (NHD). The algorithm was derived from open literature [4] and inserted into the STAP algorithm as shown in Figure 4. The NHD uses the initial estimate of the covariance matrix to achieve a more consistent set of data by removing samples that are statistically unlikely to belong to background clutter. This subset of data is then used to form a robust covariance matrix which can then be applied to all of the data.

The assumption of the NHD algorithm is that the new robust covariance matrix better represents the clutter and jammer signals and is not contaminated by the spurious bright or moving target signals. As a result the final target SCNR will be improved as the clutter will be better cancelled and detection performance will be better.

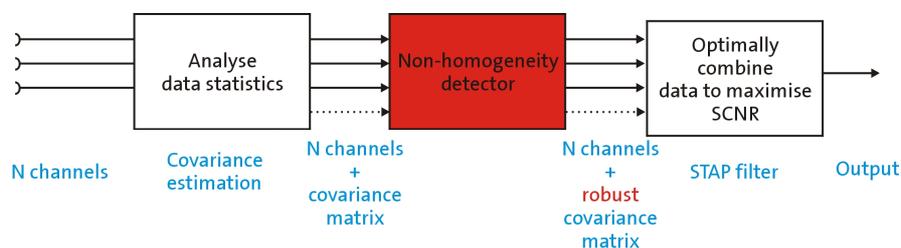


Figure 4 - Position of the NHD algorithm in the STAP algorithm

4. Implementation and evaluation of robust STAP

The NHD algorithm was implemented for both pre-Doppler and post-Doppler STAP using QinetiQ's GRAPE radar processing software suite. The improved robust STAP software modules were tested using trials data on a variety of vehicle targets.

Figure 5 shows the result of the introduction of the NHD on pre-Doppler STAP. Comparison with Figure 1 and Figure 2 shows that the adaptive null is now much closer to its expected location, both in terms of Doppler and depth. The clutter cancellation map shows that the dark regions around the targets have been significantly reduced in size, making detection of small targets in these regions much easier.

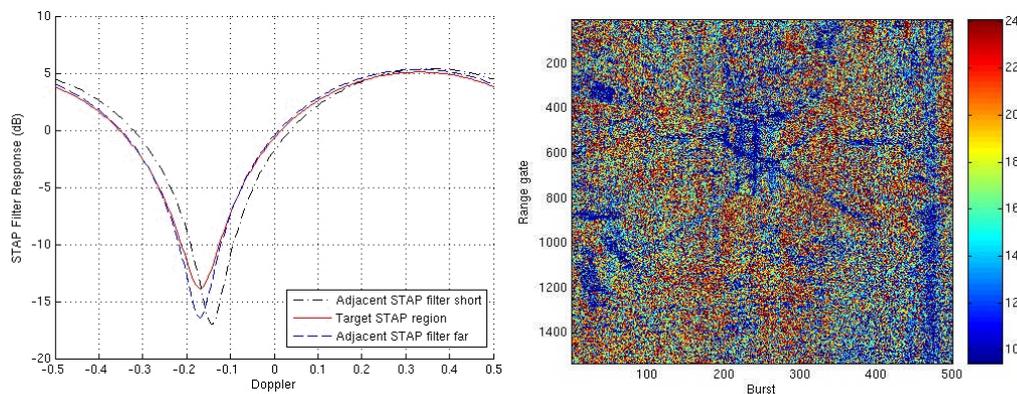


Figure 5 - Improved performance of pre-Doppler STAP following addition of NHD.

With post-Doppler STAP, the aim was to improve the SCNR of the target which had previously been badly affected by the STAP algorithm. Figure 6 shows the improvement after the addition of the NHD. The SCNR after STAP is now almost the same as it was before STAP, which at approximately 20 dB is sufficient for the target to be detected. This robust performance would facilitate the detection of other targets.

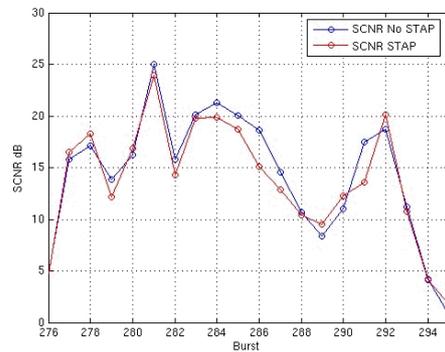


Figure 6 - SCNR plot for a region containing a target after pre-Doppler STAP

4. Conclusions

We have demonstrated that standard STAP algorithms may not be sufficiently robust in certain realistic scenarios to allow reliable detection of both small and large targets. Conventional STAP has been shown to fail when particularly bright targets, such as a large military vehicle, are present in a benign scene due to the effect of data from the target contributing to the covariance estimate. By automatically removing these non-homogeneities from the covariance estimate, the robustness of STAP can be greatly enhanced. This technique has been implemented for both pre-Doppler and post-Doppler STAP architectures and tested using real GMTI data. The results of these tests have shown a significant improvement in clutter cancellation performance for pre-Doppler STAP, and in SCNR for post-Doppler STAP. Both of these improvements lead directly to improved target detection performance.

Acknowledgements

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