University Defence Research Centre (UDRC)
In Signal Processing

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[O07] Transmit Beamforming for Clutter Rejection in Forward-Looking Radars

PI: M. Sellathurai, Queen's University Belfast

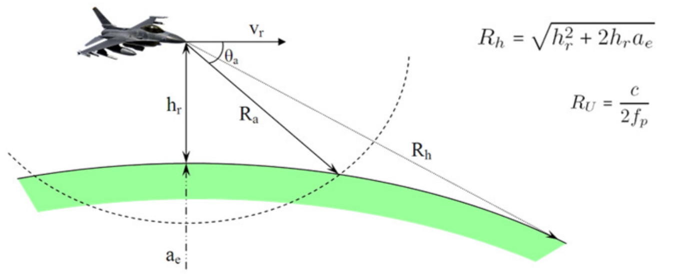
Researcher: D. Wilcox

Project Objectives

- **Apply novel signal processing techniques to mitigate degradation in FLR-STAP through:**
  - **Improved estimation of clutter covariance matrix**
  - **Reduced clutter competition in target detection and estimation**

Problems in FLR-STAP

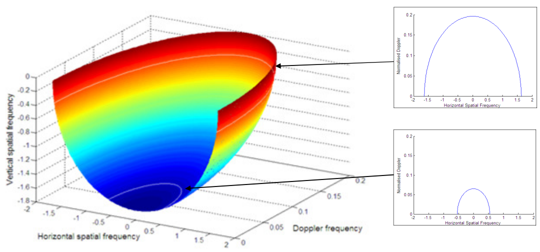
Look-down airborne radars illuminate significant amounts of ground clutter which interferes with the target signal and needs to be rejected



$$R_h = \sqrt{h_r^2 + 2h_r a_e}$$

$$R_U = \frac{c}{2f_p}$$

Clutter in forward-looking airborne radar forms an ellipsoid in the angle-angle-Doppler space



Clutter at different elevations (ranges) have different angle-Doppler characteristics

The clutter covariance matrix over the AESA elements and pulses is formed as

$$\boldsymbol{X}_c = \mathbb{E}\{\boldsymbol{r}_c\boldsymbol{r}_c^H\} \qquad \boldsymbol{r}_c = \sum_{i=1}^{N_r}\sum_{k=1}^{N_{AB}} \alpha_{i,k}\boldsymbol{v}(\theta_{i,k},\phi_{i,k},\bar{\omega}_{i,k})$$

The clutter can be rejected using the well-known MVDR solution (usually after some linear subspace transformation)

$$y = \boldsymbol{v}^H\boldsymbol{X}_c^{-1}\boldsymbol{x}$$

However, the interference covariance matrix is unknown in practice and must be estimated. The maximum likelihood estimate is:

$$\hat{\boldsymbol{X}}_c = \frac{1}{L}\sum_{l=1}^{L} r_c(l)r_c^H(l)$$

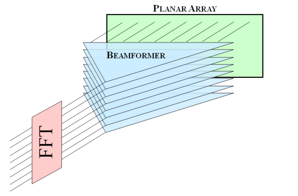
Due to the range dependence of the clutter samples, the clutter is not representative of that in the target bin which severely degrades performance. Also at higher PRFs multiple ambiguous ranges are included in STAP training data.

Adaptive Estimation of Clutter

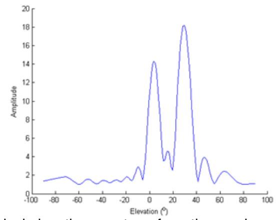
The ambiguous clutter angles can be calculated from the geometry of the radar scene:

$$\theta_a(i) = \sin^{-1}\left(\frac{a_e^2 - R_a(i)^2 - (h_r + a_e)^2}{2(h_r + a_e)R_a(i)}\right)$$

However, the ambiguous clutter directions may not be known exactly due to errors in the instrumentation, or lack or accurate ground elevation mapping. An alternative approach is to **estimate these angles** from previous CPIs



FFT-based ambiguous clutter estimation architecture
Beamformers provide computational and bias reduction
Zero padding can be used for additional smoothing



Typical elevation spectrum from the previous CPI data. The ambiguous range ring is clearly visible around 30º

Adaptive Beamforming Solution

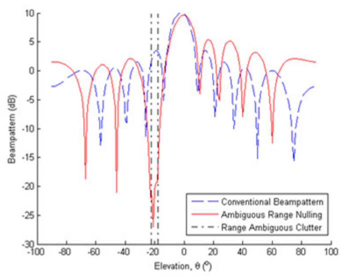
The problem of nulling the ambiguous ranges on transmit can be formulated as a **convex optimisation problem** as shown.

Other solutions are available, e.g. an MVDR formulation, but performance is reduced when they are subjected to transmit **weight normalisation**

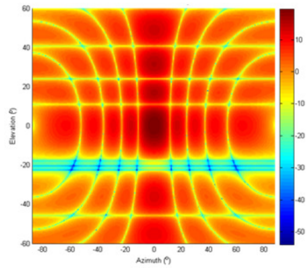
$$\begin{aligned} \min_{\boldsymbol{w}_V,\delta_1,\delta_2} \quad & [\mu_1 \ \ -\mu_2]\begin{bmatrix}\delta_1\\ \delta_2\end{bmatrix} \\ \text{s.t.} \quad & \|\boldsymbol{w}_V^H\boldsymbol{V}_V(\boldsymbol{\theta}_a)\|_2^2 \le \delta_1 \\ & \boldsymbol{w}_V^H\boldsymbol{v}_V(\theta_t) = \delta_2 \\ & \|w_V(i)\|_2^2 \le 1 \end{aligned}$$

$$\boldsymbol{V}_a(\boldsymbol{\theta}_a) = [\boldsymbol{v}_V(\theta_a(1)) \ \cdots \ \boldsymbol{v}_V(\theta_a(N_r))]$$

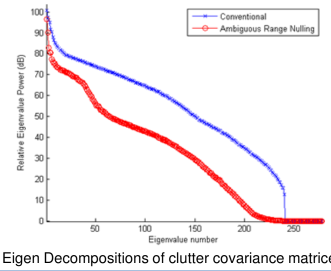
Simulation Results



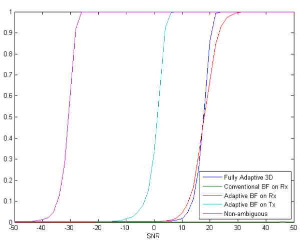
Elevation beampattern of conventional and adapted beampattern



2D Planar Array Pattern



Eigen Decompositions of clutter covariance matrices



Target Detection Performance

Conclusions

- **Transmit beamforming can be used to dramatically improve performance in FLR-STAP with ambiguous sidelobe clutter**
  - **The clutter estimation and beampattern optimisation procedures are readily extendable to the 2D case**
  - **Further investigation is required into robust beamforming techniques under assumptions of array errors**

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