Optimization of Radar Search Patterns for Three-Dimensional Phased-Array Radars

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Abstract:

Electronic Phased-Array Antennas offer new possibilities for Search Pattern Optimization over traditional rotating antennas, with the capability to perform bi-dimensional beam-forming and beam steering along both elevation and azimuth axes (Fig. 1). Modern Radars must perform multiple tasks simultaneously. Minimization of the search time-budget frees resources for other tasks: target tracking and identification, environment analysis and missile guidance among others...

Design of Radar Search Pattern, or Radar Covers, can be viewed as an optimization problem: minimization of the search time-budget under detection constraints for given detection range, detection probability and constant false-alarm rate. This problem is closely related to combinatorial spatial problems, such as the Set Cover problem, and can be solved using similar approaches based on Integer Programming.

The Radar total radiation beam pattern (1) is controlled by the phase and amplitude of the radiating elements on the Phased-Array Antenna . From this pattern, the Radar detection range (2) can be computed [2]. Informally, wider beams decreases detection range. Design of a feasible radiation pattern from an ideal pattern is a difficult inverse problem.

$$g(az, el) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} A_{k,l}\, e^{\phi_{k,l}}\, e^{j2\pi(\cos(el)\sin(az)x_l + \sin(el)y_k)} \tag{1}$$

with $\{A_{k,l},\ \phi_{k,l}\}$ the array phase-amplitude law and $(x_l,\ y_k)$ the radiating elements positions.

$$R^4(az, el) \propto \eta_w(az, el) \cdot g(az, el) \cdot L_s(az, el)^{-2} \tag{2}$$

with η_w the signal efficiency in the current environment (chosen from a database of available signals) and L_s anisotropic scanned losses.

The optimization problem is difficult to solve in a straightforward manner because of mixed variables (continuous for the array phase-amplitude law, discrete for the signal selection and the number of beams) and non-convex functions (radiation pattern, detection range). A more sensitive approach is to break down and approximate the problem as several successive sub-problems:

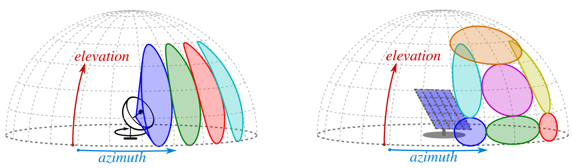

Figure 1: Rotating radar (left) and Electronic Phased-Array radar (right)

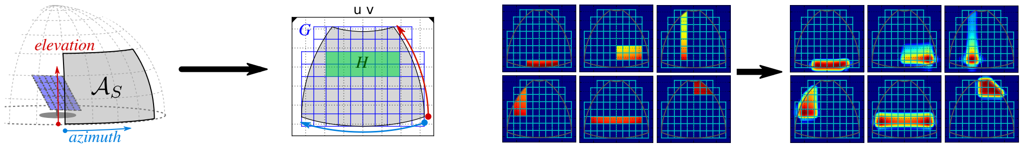

Figure 2: Discrete grid (left) and Pattern synthesis (right)

- **Discretization**: The surveillance space is approximated by a grid. On this grid, the detection is checked cell-by-cell (Figure 2).
- **Pattern synthesis**: For each sub-rectangle on the grid, a feasible pattern is synthesised from the ideal detection pattern, using a synthesis sampling method (Figure 2).
- **Optimisation**: On the discrete grid, the radar cover can be reduced to a Set Cover problem, and formulated as an Integer Program :

$$\begin{array}{rl} \min & \mathbf{T}^T.\mathbf{x} \\ s.t. & \mathbf{A}\cdot\mathbf{x} \geq \mathbf{1} \\ & \mathbf{x} \in \{0,1\}^p \end{array} \tag{3}$$

  with $\mathbf{T}$ the radar beam duration, $\mathbf{A}$ a matrix representing the beam covers on the discrete grid, and $\mathbf{x}$ the beam selection variables. This problem can be solved by a Branch&Bound method using linear relaxation [1].

Our approximation method procedure offers a solid framework with several advantages:

- Independance of each step: the discrete grid, pattern synthesis method et optimization algorithm can each be modified individually without impacting the rest of the framework.
- Integer Program formulation flexibility: each cell correspond to a detection constraint. Environmental characteristics (clutter, terrain masks) and objective parameters (range, update rate, false alarm tolerance, etc.) can be defined locally to each cell.
- Beam pre-selection: optimization is done by selection of beamshape in a candidates database, allowing pre-selection on certain criteria (range resolution, first eclipse distance).
- Scalability: computational cost of the solution can be controlled by the discrete grid resolution. Branch&Bound is suitable for producing "just-in-time" solutions in real-time applications, as the method keeps track during computation of the best solution(s) found so far.

Among our future objectives, several research leads could offer improvement of the method: optimization of the discrete grid itself could improve solution quality while decreasing computational cost. A probabilistic formulation is also possible: instead of ensuring that detection is achieved with given probability for at least one beam, compute the detection probability for each beam, and ensure a minimum probability that at least one beam achieve detection. This formulation could thus make use of overlays between beams.

References

[1] Michele Conforti, Gerard Cornuejols, and Giacomo Zambelli. *Integer Programming*. Springer Publishing Company, Incorporated, 2014.

[2] M. Skolnik. *Radar Handbook, Third Edition*. Electronics electrical engineering. McGraw-Hill Education, 2008.

Short biography – Yanis BRIHECHE received his engineering degree from SUPELEC in 2014 and a MSc in Signal Processing from the Technical University of Madrid in 2014. He is currently preparing his PhD thesis on Radar Search Pattern Optimization in a joint project (CIFRE-DGA) between THALES AIR SYSTEMS and Centrale Nantes, with funding from DGA (*Direction Générale de l'Armement*).