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Knowledge-Aided Sensor Signal Processing and Expert Reasoning

Raytheon

Enhanced Knowledge-Aided STAP for Airborne Radar Applications

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Outline

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- ***Factors Affecting Radar Performance***
- ***Limitations On STAP***
- ***Use of Prior Information to Overcome Performance Limitations***
- ***Planned Raytheon Effort***
- ***Example of Applying Prior Information: Use of Multiple Linear Directional Constraints***

Performance Limitations of Airborne Radar

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- ***Factors Affecting Airborne Radar Performance***
  - ***Non-homogeneous clutter***
  - ***Internal Clutter Motion***
  - ***High Sidelobes—Primarily Antenna, but also Doppler and Range***
  - ***Poor antenna calibration***
  - ***Main Lobe Clutter***
  - ***Jamming, Multipath***
- ***Space Time Adaptive Processing (STAP) Provides Significant Improvements***
  - ***Adaptive nulling of clutter and jamming overcomes sidelobe limitations***
  - ***Main lobe nulling Improves minimum detectable velocity, improves jammer immunity***
  - ***Mitigation of multipath reduces clutter***
- ***But practical effects also limit STAP performance***
  - ***Over-nulling due to large clutter in the training region***
  - ***Under-nulling due to large discretes***
  - ***Targets in training data***
  - ***Limited training set size***
  - ***Clutter motion, Broadened nulls in general***
  - ***High Range/Doppler sidelobes***
  - ***Poor antenna calibration***
  - ***Additional STAP Processing Loss in benign environment***

Shortfalls in the Practical Application of STAP

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- ***Loss of Sensitivity due to False Alarms and Clutter Breakthrough***
  - ***Under-nulled discretes***
  - ***Multipath***
  - ***Large sidelobe Targets***
- ***Detection and Discrimination of Slow Moving Targets from ground Clutter***
  - ***Unnecessarily wide nulls caused by over-nulling and long training regions***
  - ***Extraneous returns in the training region***
  - ***Range ambiguous ground clutter and Backlobe Effects***
  - ***Antenna Calibration Errors***
- ***Inadequate antenna calibration accuracy***
  - ***Degraded main beam nulling performance***
  - ***Higher error sidelobes***
  - ***Impaired Track Association and Handoff Accuracy***
- ***Finite Training Region***
  - ***"Non-stationary" Clutter Ridge (most pronounced in bistatics)***
  - ***Clutter returns too strong, too weak, contaminated by too many targets***
  - ***Processing Loss due to finite sample size***
- ***Jamming***

How Can A Priori Information and Signal Processing Help?

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- ***Loss of Sensitivity due to False Alarms and Clutter Breakthrough***
  - ***Determine existence of strong discretes and undernulling***
  - ***Multipath measurement methods***
  - ***Sidelobe discrimination methods***
- ***Detection and Discrimination of Slow Moving Targets from ground Clutter***
  - ***Excise excessively strong discretes and outliers from training region***
  - ***Compensate Angle/Doppler of training samples***
  - ***Design Waveform to minimize range ambiguous ground clutter***
  - ***Design antenna to allow backlobe ground clutter to be eliminated***
- ***Inadequate antenna calibration accuracy***
  - ***Calibrate using clutter or known target (in the presence of interference?)***
  - ***Measure array orientation***
  - ***Employ Internal channel calibration***
- ***Finite Training Region***
  - ***Use Known antenna and clutter characteristics to overcome "Non-stationarity"***
  - ***Use knowledge of clutter and targets to select training samples***
  - ***Improved Thresholding Methods based on Clutter Characteristics***
- ***Location and characteristics of interference and jammer(s)***

How Can A Priori Information Be Obtained?

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- ***Predict where strong returns will occur***
  - ***Use Knowledge of Platform motion and Antenna Characteristics to predict clutter location***
  - ***Use terrain (and cultural) data and clutter model***
  - ***Use prior measurements obtained for a particular region: days before, seconds before***
  - ***Use information from other sensors to determine where strong targets may be located***
- ***Use pre-processing to detect large targets and measure ground clutter***
  - ***Remove returns from training region and try again***
- ***Employ Sidelobe Discrimination Methods to Identify Sidelobe Breakthrough and Interference***
  - ***ACE (Adaptive Coherence Estimator) works well for single target/clutter breakthrough***
  - ***Adaptive Resolution of Mainlobe and Sidelobe Detections for multiple targets/clutter***
  - ***In range-Doppler cell (A.Jaffer J. Chen and T. Miller., IEEE Trans. AES October 2002)***
- ***Use external signal sources of known location to calibrate antenna***
  - ***Cal-on-clutter***
  - ***Known target locations***
  - ***In-band signal sources***

What are Limitations on Use of A Priori Information?

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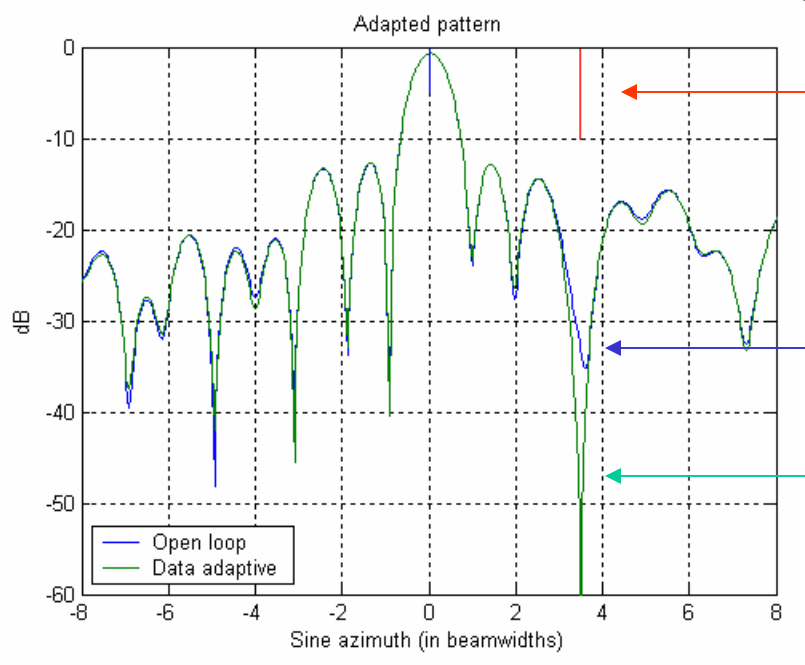
- ***Limits on Antenna calibration Accuracy***
  - ***Reduces effectiveness of Linear ("Open-loop") Constraints (see example below)***
  - ***Impairs ability to distinguish main lobe detections from sidelobe detections, assuming multiple signals are present***
  - ***Reduces effectiveness of angle-Doppler compensation methods for STAP***



Interference (jammer, clutter)

Open loop null depth is limited due to calibration inaccuracies

Data adaptive approach achieves deep nulling by implicitly using interference as calibration source

What are Limitations on Use of A Priori Information? - - - continued

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- ***A Priori data has Limited Resolution or Accuracy***
  - ***Resolution of Terrain Data***
  - ***Translating Terrain data to clutter characteristics***
  - ***INS errors***
  - ***Location of External Calibration Source***
- ***Information has Changed***
  - ***Location of External Calibration Source***
  - ***Different grazing angle or Frequency of Operation***
- ***Processing Load and processing Latency***
  - ***Pre-processing increases latency***
- ***Inadequate Training Samples After Excising Targets***
  - ***Dense target Environment***
  - ***Large Shadowed Regions***
  - ***Highly non-stationary angle/doppler***

Planned Raytheon Effort

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- ***Develop and Evaluate KASSPER Methods to Improve Airborne Radar and STAP Performance***
- ***Study Goals and Overall Approach***
  - ***Emphasis on evaluating previously developed methods***
  - ***Improve Training Data***
  - ***Identify and Correct False Alarms Caused by Clutter Breakthrough***
  - ***Identify and Correct False Sidelobe Detection***
  - ***Develop <u>robust</u> multiple constraints method for nulling a priori known interferences***
- ***Focus on A Priori Estimates of target and Clutter Environment***
  - ***Evaluate Various types of A Priori Information***
    - ***Terrain Data***
    - ***Ground Traffic***
    - ***Re-processing***
  - ***Incorporate into STAP Algorithms and Evaluate performance***
    - ***Evaluate primarily by Simulation***
    - ***Develop ability to evaluate performance using (existing) Airborne Radar Data***

Simultaneous cancellation of a priori known and other unknown interferences

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- ***Use multiple linear directional constraints on the weight vector for retaining nulls on a priori known clutter and jamming sources while simultaneously adapting to cancel unknown interferences***
- ***Best accomplished by decomposing into constraint subspace (for deterministic cancellation of known interferences) and orthogonal complement subspace (for adaptive cancellation of unknown interferences)***
- ***Apply reduced-rank generalized sidelobe canceller or multi-stage Weiner Decomposition methods incorporating these constraints***
- ***Investigate sensitivity of STAP performance using deterministic multiple constraints in presence of array calibration and temporal error sources***
- ***Modify and enlarge constraint subspace to render the deterministic cancellation of a priori known interferences relatively robust***

Site Specific Clutter Modeling

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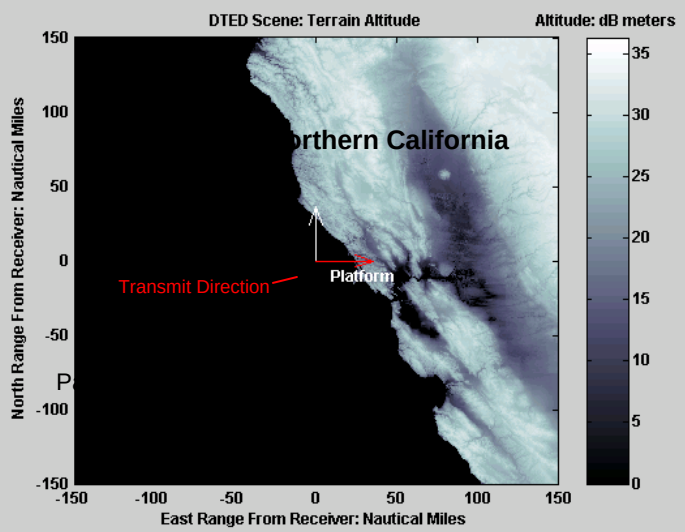

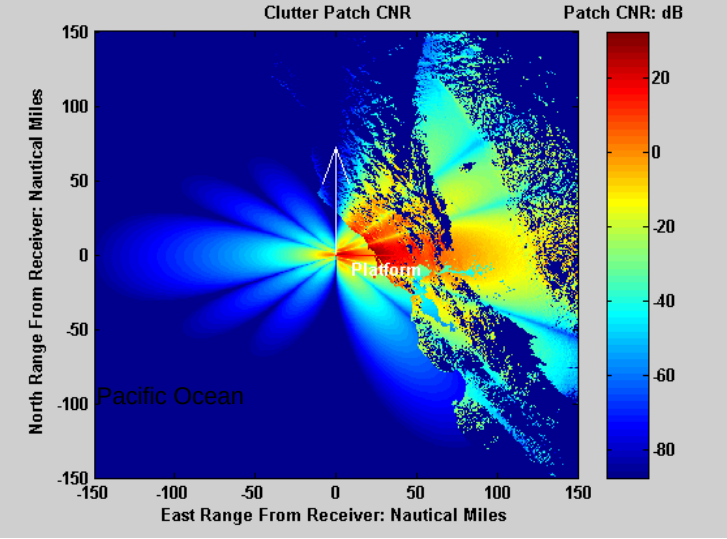

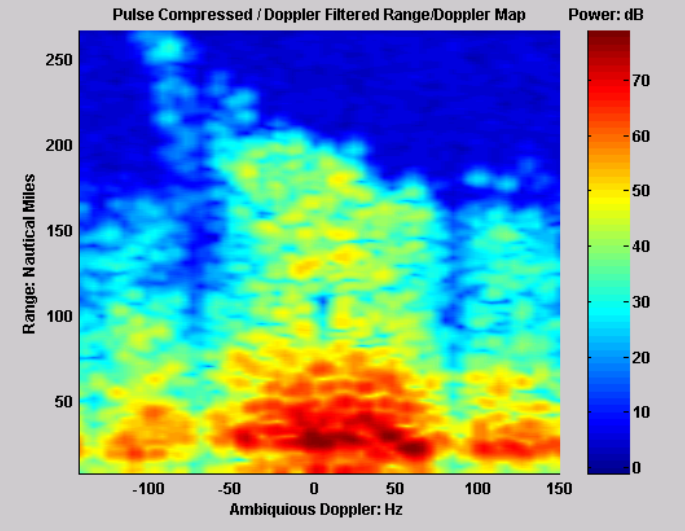

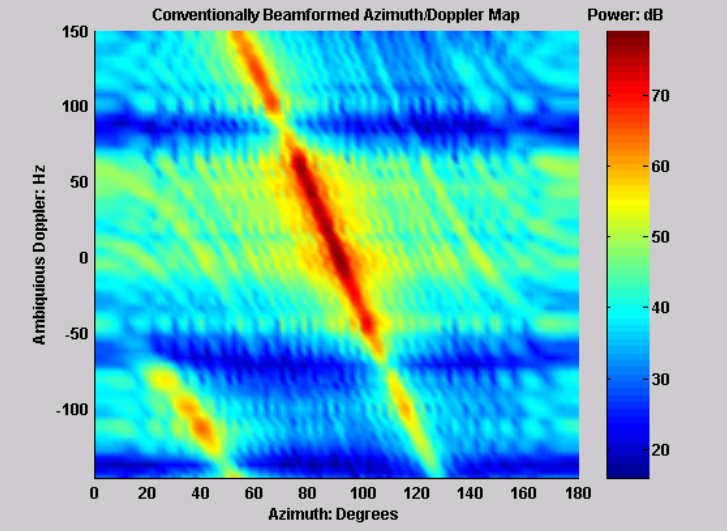

The use of DTED data provides a basis for modeling heterogeneous clutter environments

Some Ingredients...

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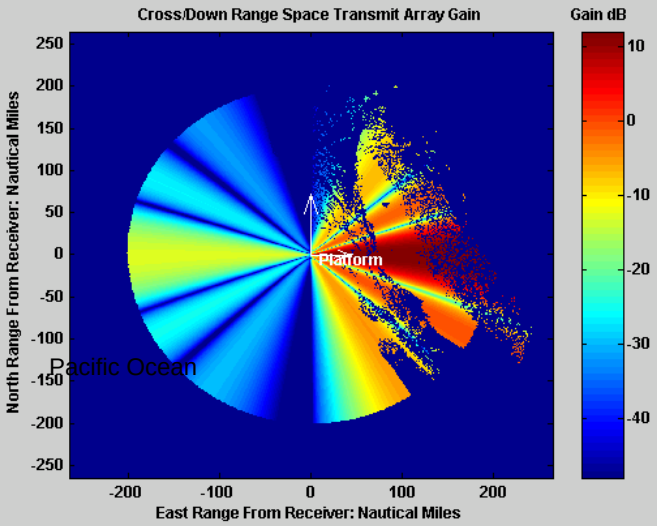

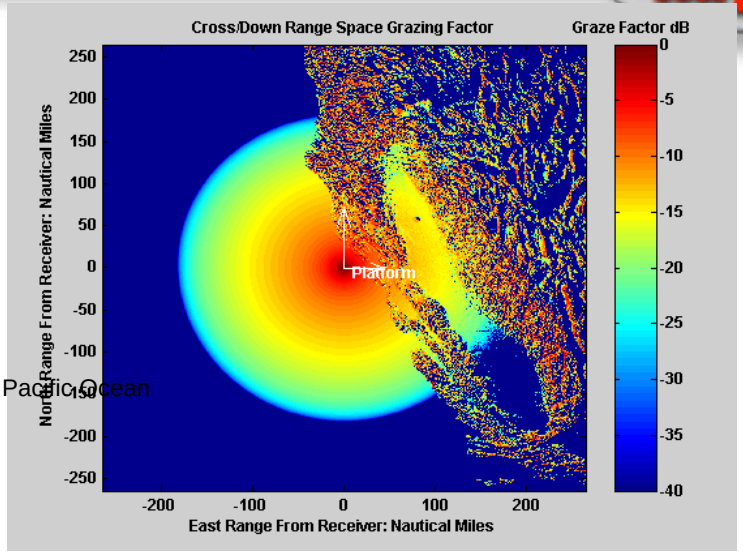

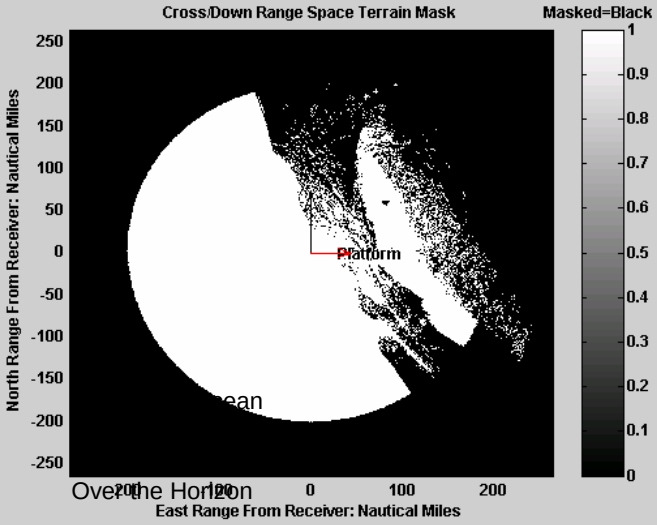

Radar Parameters	
Frequency	450 MHz
Peak Power	200 kW
Duty Factor	6 %
Instantaneous BW	4 MHz
Waveform Type	LFM
Num PRI	64
Num Receive Channels	32
Transmit Azimuth, Elevation Angle	90º,-5º
Platform Crab Angle	0º