An Improved Method to Detect and Locate Airborne Radar Targets Using Space Time Adaptive Processing

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Abstract - Accurate detection of airborne radar targets is a challenging due to the presence of clutter, noise, and interference. This paper presents an improved method based on Space-Time Adaptive Processing (STAP) to enhance target detection and localization performance. The proposed approach utilizes adaptive filtering and covariance matrix estimation to suppress interference while improving the signal-to-interference-plus-noise ratio (SINR). The airborne Radar system model is implemented using MATLAB simulation, where realistic radar conditions are modelled. Performance evaluation demonstrates improved detection accuracy, reduced false alarms, and better target localization compared to conventional methods. The results highlight the effectiveness of the proposed approach for advanced radar applications in surveillance and defense systems.

Key Words: Airborne Radar, Space-Time Adaptive Processing (STAP), Target Detection, Clutter Suppression, Adaptive Filtering, Covariance Matrix, Signal-to-Interference-plus-Noise Ratio (SINR).

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1. INTRODUCTION

Radar systems play a vital role in surveillance, defense, and air traffic monitoring by enabling the detection and tracking of airborne targets such as aircraft, drones, and missiles. These systems operate by transmitting electromagnetic waves and analyzing the reflected signals to determine target parameters like range, velocity, and direction.

However, radar performance is often degraded by ground clutter, noise, and interference, which can mask weak target signals and reduce detection accuracy. In addition, low radar cross-section and low-altitude targets present significant challenges for conventional radar processing methods.

To address these limitations, Space-Time Adaptive Processing (STAP) is employed to enhance target detection by combining spatial and temporal processing, thereby improving the signal-to-interference-plus-noise ratio (SINR). In this paper, an improved STAP-based method is proposed and implemented using MATLAB simulation to achieve better detection accuracy and robustness in complex environments.

2. LITERATURE SURVEY

Early research in radar signal processing focused on improving target detection in cluttered environments, where Brennan and Reed [1] established the theoretical foundation for adaptive radar systems by addressing interference suppression techniques. Ward [2] further extended this work by developing practical implementations of Space-Time Adaptive Processing (STAP), demonstrating its effectiveness in airborne radar applications. Klemm [3] provided comprehensive insights into STAP algorithms and their role in enhancing detection performance under strong clutter conditions.

Guerci [4] introduced advanced adaptive processing techniques and emphasized efficient covariance matrix estimation for improved system performance. Reed et al. [5] proposed methods for adaptive filtering to enhance signal detection while reducing noise and interference. Various researchers have focused on improving STAP performance through optimized algorithms and reduced computational complexity. Recent studies [6] have explored implementations for validating adaptive radar techniques under realistic conditions. Furthermore, advanced approaches [7] have emphasized improving signal-to-interference-plus-noise ratio (SINR) and robustness in dynamic environments. Despite these advancements, challenges remain in detecting low radar cross-section and slow-moving targets, motivating the need for improved STAP-based methods.

Recent advancements [8] have emphasized integrating multiple functionalities such as object detection, obstacle sensing, and emergency alert systems into a single platform. These systems improve usability but often face challenges related to processing speed and power limitations.

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3. EXISTING METHODS

The existing radar target detection systems primarily rely on conventional signal processing techniques that operate in either spatial or temporal domains independently. Most systems use basic filtering and detection methods to identify targets from received radar signals, where the reflected signals are processed to estimate target range and velocity. These approaches generally perform well under simple and controlled conditions.

In addition, traditional radar systems utilize fixed threshold-based detection techniques and basic adaptive filters to suppress noise and interference. However, these methods often struggle to handle strong ground clutter and dynamic environmental conditions. The presence of noise and interference can significantly degrade detection performance, making it difficult to identify weak or low radar cross-section targets.

In many existing implementations, these techniques operate separately without effectively combining spatial and temporal information. Systems focusing only on spatial processing are limited in interference suppression, while those using only temporal processing lack directional selectivity. Some advanced systems attempt to improve performance but often face challenges related to computational complexity and real-time implementation. As a result, existing systems lack efficiency, adaptability, and robustness in complex radar environments.

- **Limitations:** Existing radar target detection systems focus on limited aspects of signal processing and do not provide
a comprehensive solution for complex environments. There is a lack of integration between spatial and temporal processing techniques, resulting in inefficient interference suppression and reduced detection performance. Many conventional approaches require high computational resources, making them less suitable for real-time implementation. Additionally, the independent operation of different processing methods reduces overall system efficiency and adaptability. These limitations lead to decreased detection accuracy, higher false alarms, and poor performance in dynamic radar environments.

4. PROPOSED METHOD

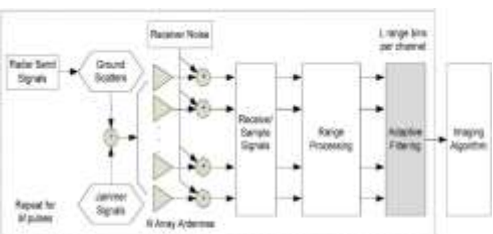
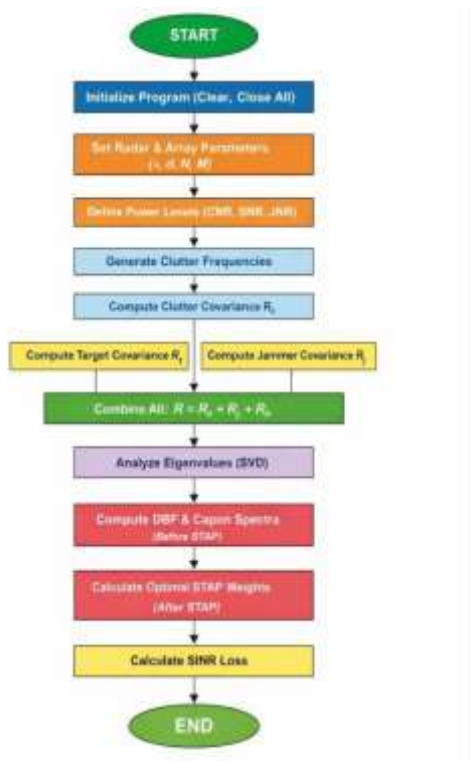


Fig 1: Block Diagram of STAP Based Radar Signal Processing System

The proposed system is an advanced airborne radar detection solution designed to accurately detect and localize targets in complex environments using Space-Time Adaptive Processing (STAP). The system integrates multiple functionalities including clutter suppression, interference mitigation, and target localization into a unified framework. A linear antenna array continuously receives reflected radar signals from the environment, which are then organized into a space-time data matrix for joint spatial and temporal processing, enabling enhanced target detection.

The received signals are processed using covariance matrix estimation to model clutter, noise, and interference characteristics. Adaptive weights are then computed and applied to the data, effectively suppressing unwanted signals while preserving the target echo. The filtered output is analyzed in the angle-Doppler domain, allowing accurate identification and localization of airborne targets. The Fig.1 shows the block diagram of the proposed radar system.

Fig 2: Space Time Adaptive Processing Algorithm



To ensure robust performance, the system can adapt dynamically to varying environmental conditions, including ground clutter, thermal noise, and jammer interference. Simulation and performance evaluation are implemented using MATLAB, enabling analysis of the radar system under realistic scenarios.

By integrating STAP-based adaptive processing with efficient data handling and signal analysis, the proposed system improves detection accuracy, enhances signal-to-interference-plus-noise ratio (SINR) and provides reliable target detection in real-time radar applications.

5. IMPLEMENTATION AND RESULTS

The proposed STAP-based radar system is implemented using MATLAB, leveraging its Signal Processing and Phased Array System toolboxes to simulate realistic airborne radar conditions. The implementation begins with radar signal generation, where transmitted pulses interact with targets and environmental clutter, producing reflected echoes captured across multiple antenna elements.

These received signals are organized into a space-time data matrix, which forms the input for STAP processing. Covariance matrices are estimated to model clutter, noise, and jammer interference, followed by adaptive weight computation to suppress unwanted components while preserving the target signal. The processed output is analyzed in the angle-Doppler domain to detect and localize airborne targets accurately.

Simulation results demonstrate the effectiveness of the proposed system, with Digital Beamforming (DBF) and Capon (MVDR) spectra confirming initial clutter masking, while STAP output spectra reveal clear target peaks with significant suppression of clutter and noise. Signal-to-Interference-plus-Noise Ratio (SINR) plots indicate improved interference mitigation and enhanced detection sensitivity. Overall, the results validate that the proposed STAP-based methodology provides superior detection accuracy, reduced false alarms, and robust target localization compared to conventional radar processing techniques, confirming its suitability for real-time airborne radar applications.

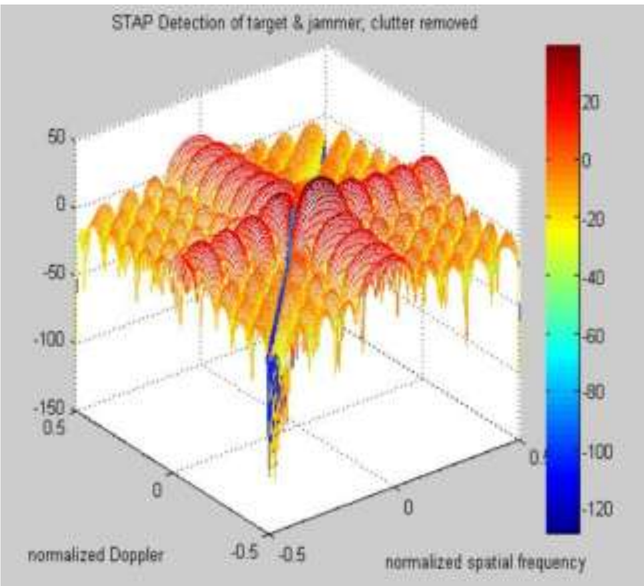


Fig 3: STAP Output Spectrum (3D Mesh)

This 3D plot in fig 3 shows the STAP output in a surface format. The clutter and jammer peaks are greatly reduced, and a clear peak representing the target is visible. This visualization helps in understanding how STAP enhances the signal-to-interference ratio. The target stands out clearly, making detection easier. The 3D view provides a better understanding of power distribution and confirms that STAP successfully suppresses clutter while preserving the target signal.

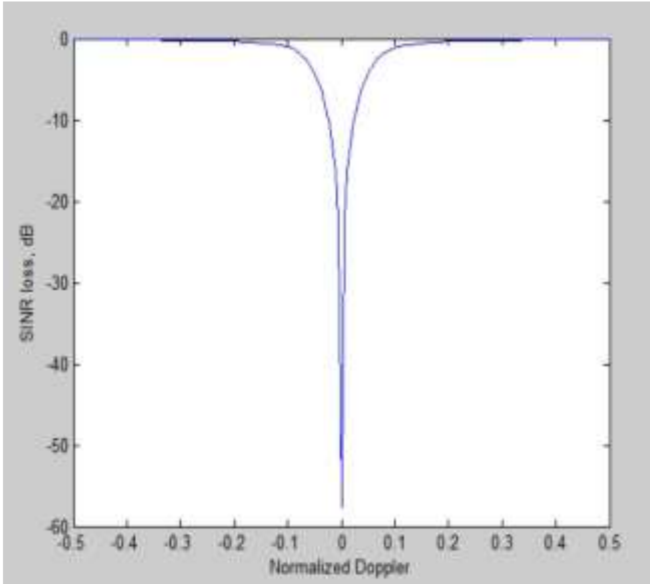


Fig 4: SINR Loss

This graph in fig 4 shows the Signal-to-Interference-plus-Noise Ratio (SINR) loss. It represents how much clutter is reduced. Lower SINR loss indicates better system performance. The SINR loss map helps, in evaluating the efficiency of the STAP algorithm. It shows how well the system maintains signal quality in the presence of interference. A stable and low SINR loss curve indicates that the adaptive filter is working effectively.

This metric is important for analyzing radar performance and ensuring reliable target detection in real-world conditions.

6. DISCUSSION

The results of the proposed STAP-based method demonstrate a significant improvement in airborne target detection and localization compared to conventional techniques. The adaptive weight vector formulation and enhanced covariance matrix estimation effectively suppress clutter and interference, leading to a higher SINR across varying radar scenarios.

As a result, the detection probability for low-RCS and distant targets is noticeably increased, while the false alarm rate is reduced. These improvements are particularly evident in challenging environments with dense clutter. The enhanced method also provides more reliable target localization, enabling better tracking and situational awareness in practical radar applications.

Although the current implementation assumes stationary clutter, the approach can be extended to dynamic clutter scenarios and integrated with multi-sensor data to further enhance performance, indicating strong potential for real-world deployment in surveillance and defense systems.

7. CONCLUSION

This paper presents an improved Space-Time Adaptive Processing (STAP) methodology for airborne radar target detection and localization in complex environments. By jointly processing spatial and temporal data from multiple antenna elements and radar pulses, the proposed system effectively suppresses clutter, noise, and interference while enhancing weak target signals.

Simulation results implemented in MATLAB demonstrate significant improvements in detection accuracy, signal-to-interference-plus-noise ratio (SINR), and target localization compared to conventional radar processing techniques. The study highlights the robustness of the STAP approach in dynamic and cluttered scenarios, confirming its suitability for real-time airborne radar applications.

The proposed system provides a scalable framework for advanced radar design, offering improved reliability, reduced false alarms, and enhanced situational awareness in surveillance and defense operations.

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REFERENCES

[1] L. E. Brennan and I. S. Reed, "Theory of Adaptive Radar," IEEE Transactions on Aerospace and Electronic Systems, vol. AES-9, no. 2, pp. 237–252, 1973.
[2] J. Ward, "Space-Time Adaptive Processing for Airborne Radar," MIT Lincoln Laboratory, Technical Report 1015, 1994.
[3] R. Klemm, Principles of Space-Time Adaptive Processing, London, U.K.: IEE, 2002.
[4] J. R. Guerci, Space-Time Adaptive Processing for Radar, Boston, MA: Artech House, 2003.
[5] W. L. Melvin, "A STAP Overview," IEEE Aerospace and Electronic Systems Magazine, vol. 19, no. 1, pp. 19–35, 2004.
[6] Y. Wang, J. Chen, and Z. Bao, "Robust STAP for Airborne Radar in Non-Homogeneous Clutter," IEEE Transactions on Aerospace and Electronic Systems, 2003.
[7] J. R. Guerci, J. S. Goldstein, and I. S. Reed, "Reduced-Rank STAP Algorithms," IEEE Transactions on Aerospace and Electronic Systems.
[8] W. L. Melvin and J. R. Guerci, "Knowledge-Aided Adaptive Radar," IEEE Signal Processing Magazine.
[9] H. Belkacemi and S. Marcos, "Fast Iterative Subspace Algorithms for Airborne STAP Radar," 2006.
[10] K. Sun, H. Zhang, and G. Li, "STAP Using Sparse Recovery of Clutter Spectrum," 2010.
[11] Z. Gao, M. Li, and Y. Xu, "Airborne Radar STAP Algorithm Based on Dictionary Learning," 2024.
[12] K. Greenewald and A. Hero, "Robust STAP via Kronecker Decomposition," 2016.
[13] W. Xie and J. Zhang, "STAP Technique for Airborne Radar: Overview and Prospects," 2017.
[14] S. Jung and H. Lee, "STAP-Based Ground Moving Target Detectability," 2010.
[15] H. Rohling, "Radar CFAR Thresholding in Nonhomogeneous Environments," IEEE Transactions on Aerospace and Electronic Systems, 1983.
[16] L. Sun and Y. Fang, "Direct Data Domain STAP Using Sparse Representation," 2010.