Spatio-Temporal GNSS Interference Detection Using Multi-Receiver Monitoring

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Abstract

GNSS signals are vulnerable to jamming and electromagnetic interference, which may reduce positioning accuracy and system reliability. This project presents a multi-receiver interference detection approach based on C/No analysis. The Kalman Filter was applied for temporal signal monitoring, while the Nelder-Mead algorithm was used for threshold optimization. Simulation results showed improved detection accuracy and reduced false alarms compared with conventional single-receiver methods.

Introduction

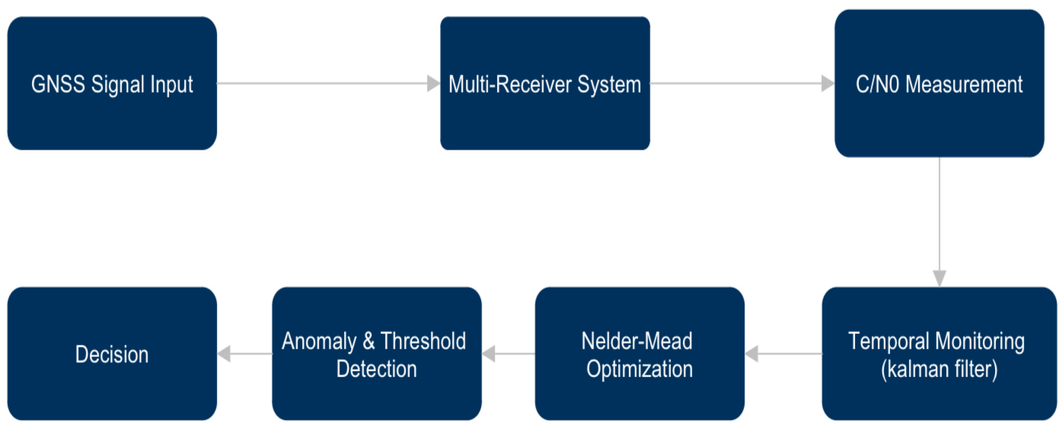
GNSS technologies are widely used in navigation and positioning applications. However, GNSS signals are weak and highly sensitive to electromagnetic interference and jamming attacks. These disturbances can degrade signal quality, increase positioning errors, and reduce system reliability, especially in noisy environments.

Conventional interference detection methods commonly rely on single-receiver monitoring and fixed threshold values, which may limit detection performance under varying signal conditions. To address these limitations, this project proposes a multi-receiver monitoring approach based on C/No analysis. Four virtual GNSS receivers were simulated in MATLAB to evaluate signal behavior under jamming conditions. Temporal signal variations were analyzed using the Kalman Filter, while the Nelder-Mead algorithm was applied for threshold optimization to improve detection performance and reduce false alarms.

Methodology

The system receives GNSS signals from multiple virtual receivers simulated in MATLAB. The C/NO values are continuously monitored and analyzed over time to detect possible interference events. First, the Kalman Filter smooths noisy measurements and predicts temporal signal behavior. Then, the Nelder-Mead optimization algorithm improves spatial signal analysis by optimizing receiver-based signal evaluation. Finally, the processed signals are compared against optimized thresholds to detect jamming events and generate warning alerts.

System Flow



The system analyzes changes in signal quality over time using:
$\Delta C/N0 = C/N0\,(t) - C/N0\,(t-1)$
Where $\Delta C/N0$ represents the variation in signal quality between consecutive time samples. Large negative changes may indicate possible jamming or interference.

Proposed Solution

The proposed system is built on two integrated layers: a Kalman Filter-based temporal prediction layer that smooths and stabilizes the C/N_0 measurements, and a Nelder-Mead optimization layer that adaptively selects the optimal detection threshold across multiple receivers. Together, these layers form a robust distributed framework capable of identifying abnormal signal behavior and detecting potential jamming events. The conceptual diagrams illustrate how the system processes the signal over time, optimizes the threshold spatially, and represents the interference pattern across receivers.

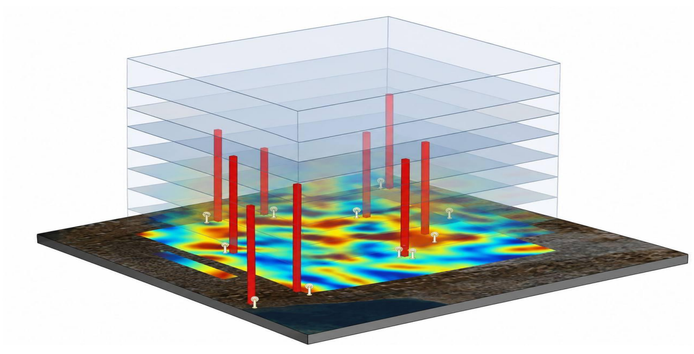


Figure a.3D spatio-Temporal conceptual Digram

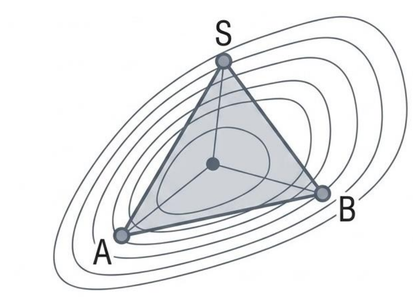


Figure b.Spatial Optimization Layer (Nelder-Mead Digram)

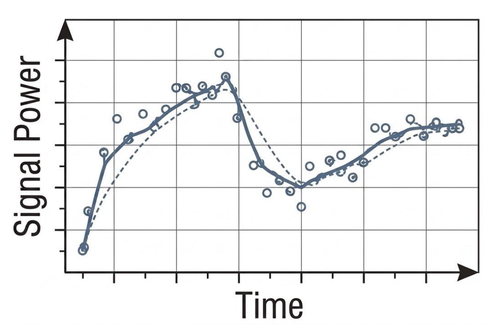


Figure c. Temporal Prediction Layer (kalman Filter)

Simulation Results

The proposed GNSS jamming-detection system integrates two core algorithms: a Kalman Filter for temporal smoothing of the C/N_0 measurements and a Nelder-Mead optimizer for adaptive threshold selection. The filtered time-series clearly highlights the jamming interval, while the optimized threshold ensures consistent detection across all receivers. The multi-receiver comparison demonstrates the variation in signal degradation, and the spatio-temporal surface plot visualizes how the interference propagates across receivers over time, providing a comprehensive view of the jamming event.

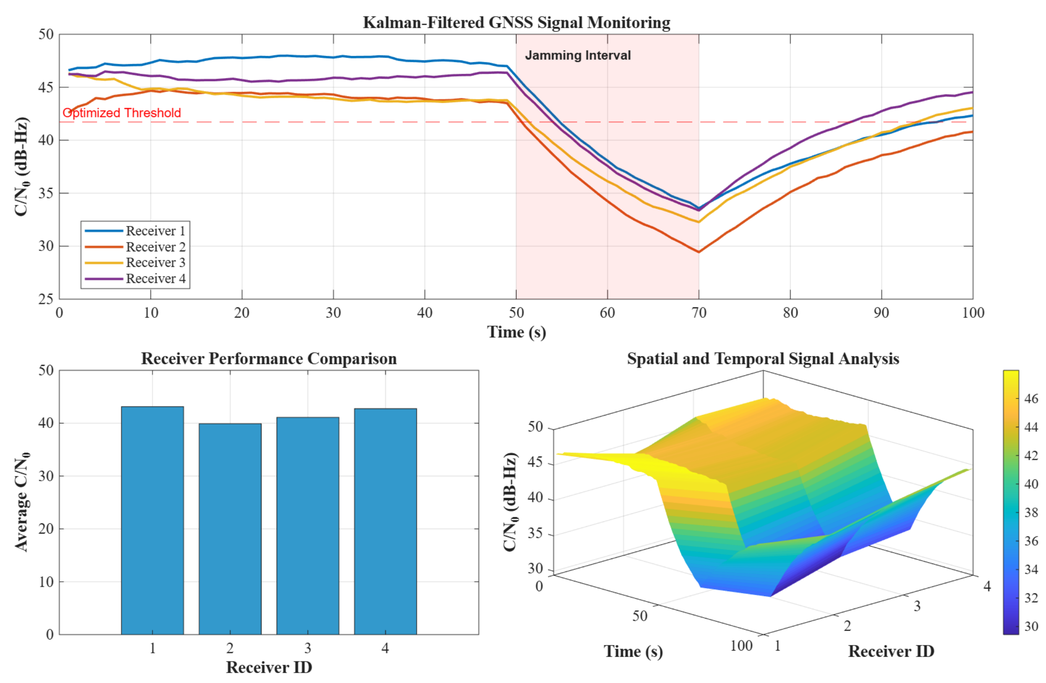


Figure 1. Simulation results showing (a) filtered C/N_0 time-series, (b) multi-receiver C/N_0 comparison, and (c) 3D spatio-temporal surface visualization of the jamming event.

Conclusions

This project successfully demonstrates a robust distributed framework for the proactive detection and localization of GNSS interference in aviation. Our findings confirm that integrating temporal analysis via Kalman Filtering with spatial cross-validation significantly enhances signal integrity, allowing for the detection of interference before a complete loss of navigation occurs. The primary contribution of this work lies in the development of a software-defined integration layer that utilizes low-cost multi-receiver networks to provide real-time source localization using the Nelder-Mead algorithm. Future directions focus on implementing machine learning models to automate the classification of diverse interference signatures and further refining the system's accuracy across varying flight altitudes and environmental conditions.

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References: