WHITE PAPER

Edge-Native Hyperspectral Intelligence and Advanced Time-Series Signal Processing for Space Domain Awareness

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Title: Edge-Native Hyperspectral Intelligence and Advanced Time-Series Signal Processing for Space Domain Awareness

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Executive Summary

AAMU proposes an edge-native artificial intelligence (AI) framework to transform Space Domain Awareness (SDA) and tactical threat monitoring. By integrating spectral compression with artificial intelligence and machine learning (AI/ML), our models enable real-time target detection, classification, and tracking directly on power-constrained orbital and atmospheric edge platforms. Our validated models resolve the physics-imposed bottlenecks of sensor data deluge, drastically minimizing storage, compute power, and downlink bandwidth requirements while accelerating actionable tactical timelines.

The Challenge: The Data and Compute Paradox at the Space Edge

Hyperspectral Imaging (HSI) captures continuous spectral fingerprints vital for precise material characterization. However, raw HSI data cubes generate massive data streams (e.g., ~9 GB/min for standard SWIR streams), which overwhelm modern space assets due to severe operational constraints:

- **Storage & Compute Limits:** Limited onboard mass memory and hardware compute budgets cannot support heavy full-band neural network pipelines.
- **Bandwidth Bottlenecks:** Downlinking massive raw data cubes over contested or highly restricted tactical networks introduces fatal transmission latency.
- **Signal Overlap:** Traditional distance-based clustering algorithms fail to isolate targets in spectrally dense or high-clutter environments.

Proven Technical Capabilities & Breakthroughs

AAMU-RISE possesses specialized academic and operational expertise to deliver lightweight, high-utility solutions across two core pillars:

1. Ultra-Low-Latency Spectral Compression & Edge Inference

Our published research establishes a mathematically optimized, four-stage pipeline for hyperspectral pixel classification and image segmentation:

- **Dimensionality Reduction:** Using unsupervised Principal Component Analysis (PCA) and supervised Linear Discriminant Analysis (LDA), our algorithms compress a 96-band Shortwave Infrared (SWIR) data cube down to just 3 to 5 synthetic components.
- **Information Preservation:** This 24× data reduction preserves 99.8% of total spectral variance, eliminating noise while maintaining pristine material characterization integrity.
- **Few-Shot Learning Mastery:** Deployed machine learning models (Logistic Regression and Multilayer Perceptron) achieve near-perfect accuracy (F1-scores > 0.999) using as few as 5 labeled training samples per class. This resolves the "curse of dimensionality" and enables rapid, automated edge adaptation to unknown objects.

2. High-Performance Time-Series and Signal Intelligence (SIGINT)

Beyond computer vision, AAMU-RISE maintains a mature portfolio in multi-dimensional signal processing applied to time-series data and acoustical waveforms:

- **Deep Architectural Performance:** We have developed deep 1D and 2D Convolutional Neural Networks (CNNs) that operate seamlessly on raw time-series data and time-frequency spectrograms.
- **Benchmark Superiority:** Engineered for tactical edge communications and out-of-context command verification, our models consistently outperform industry-standard transformer architectures, including OpenAI's Whisper-AI, while consuming significantly fewer computational resources.

USSF Operational Scenarios Addressed

Our dual capabilities map directly to the high-priority mission profiles defined by the Space Force:

Scenario 1: Looking Up (Ground and Air Platforms)

- **Orbital Debris Fingerprinting:** Tracking and characterizing Resident Space Objects (RSOs) down to single pixels. The system cross-references compressed spectral signatures against space-craft materials (alloys, silicates, insulation) to detect fragmentation or surface degradation.
- **Rotational & Stabilization Dynamics:** Exploiting micro-variations in time-series spectral reflections to diagnose the spin axis, stabilization mode, and operational status of dark or non-cooperative assets.

Scenario 2: Looking Down (Space and Stratospheric Platforms)

- **Missile, Warhead, and Decoy Separation:** Distinguishing threat warheads from thermally matched decoys or Mylar balloons by reading localized variations in material composition rather than basic geometric shapes.
- **Terrestrial Background Rejection:** Cutting through intense solar glare, cloud decks, and atmospheric scattering to unmask hidden high-value assets and active propellant signatures through optimized synthetic bands.