



Saudi Urban Passive Radar for LEO Debris Detection (SUPR-LEO)

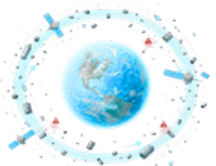
Haya Altamimi, Lyan Alkassim, Sara Aljarbou, Remas Alghamdi, Munirah Althawad, Amirah Alfunaytil, Farah Alghomlas, Arwa Alhassani,
Prince Bader AlFaisal ,Dr. Walid M. Dyab, Dr. Mourad S. Ibrahim

Department of Electrical Engineering, College of Engineering, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Introduction

The Low Earth Orbit (LEO) Space Debris Problem

The rapid growth of **LEO space debris** has become a major challenge for **space sustainability**. Thousands of objects travel at extremely high orbital velocities, increasing the risk of collisions with satellites. Conventional **space surveillance** radars require **high-power** transmitters and costly infrastructure, which serves as a disadvantage. **This project** investigates an **Urban Passive Radar for LEO surveillance (SUPRLEO)** that uses existing **DVB-T broadcast towers** as illuminators of opportunity while using radio telescopes as **passive bistatic receivers**. Instead of transmitting signals, the system analyzes **reflected DVB-T signals** from orbital objects to perform **passive detection and classification**.



The **bistatic Signal-to-Noise Ratio (SNR)** equation **evaluates** whether weak reflected DVB-T signals from LEO objects **can be detected** above the receiver noise floor:

$$SNR = \frac{P_t G_t G_r \lambda^2 \sigma_b}{(4\pi)^3 R_t^2 R_r^2 k T B F L} \cdot (T_{CPI} B)$$

This relationship combines **propagation loss**, **antenna gain**, **bistatic scattering**, **thermal noise**, and **coherent integration** into a **unified electromagnetic detection model**. **Higher SNR** values **improve target distinguishability** from clutter and interference, **enhancing** passive radar detection performance.

SNR Link Budget & Electromagnetic Relevance

Objective & Proposed Solution

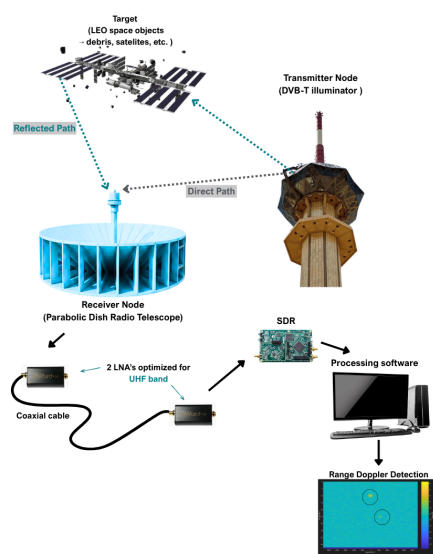
SUPR-LEO Motivation & Objectives

Proposed Solution: SUPR-LEO uses **DVB-T passive radar** and **low-cost** receivers for **real-time LEO object** detection and tracking. The system integrates **synchronized signal** processing and **AI-based analysis** for **scalable space surveillance**.

- **Develop** a **passive bistatic radar** framework for **LEO debris detection** using DVB-T signals.
- **Extract** and separate **reference** and **reflected signals** for accurate radar processing.
- **Suppress clutter** and direct-path interference using **adaptive filtering**.
- **Generate Range-Doppler** maps for target **localization** and **velocity** estimation.
- **Integrate AI** classification for **automated debris detection** and analysis.

Methodology

1 SUPR Radar System



Passive Bistatic Radar System:

- Passive bistatic radar using **DVB-T** transmitters as **illuminators** of opportunity.
- **Bistatic configuration:** Spatial separation between transmitter and receiver.
- **Antenna setup:**
 1. Reference channel: captures direct signal
 2. Surveillance channel: captures reflected signal
- Bistatic Range defined as:

$$R_b = R_t + R_r$$

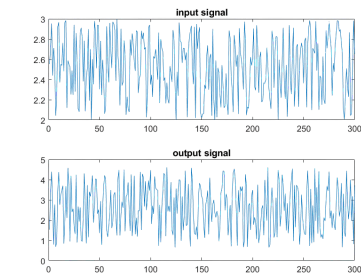
2 Signal Processing

Reference Extraction (LMS):

- **Least Mean Square:** Updates filter coefficients sample-by-sample, making it computationally efficient compared to block-based methods.
- **Adaptive filtering** isolates DVB-T direct-path signal.

Clutter Suppression (ECA):

- **Extensive Cancellation Algorithm:** Eigenvalue decomposition removes strong interference.



Cross-Ambiguity Function (CAF):

$$CAF(\tau, f_d) = \int s_{ref}(t) s_{surv}^*(t - \tau) e^{-j2\pi f_d t} dt$$

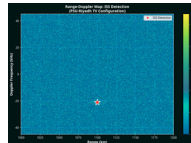
Cross Ambiguity Function: is a 2D signal processing tool used to calculate the Time Difference of Arrival and Frequency Difference of Arrival between two signals.

- Estimates **delay** → **range**
- Estimates **Doppler** → **velocity**

3 Target Detection

Range Doppler Processing:

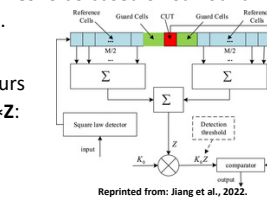
- CAF output forms Range-Doppler map
- Moving targets appear as distinct Doppler peaks.



CA-CFAR:

- A radar signal processing technique that **detects targets** by dynamically adjusting **detection thresholds** based on surrounding noise levels.

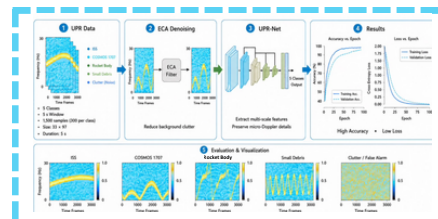
Detection occurs when: $Y \geq K_0 * Z$



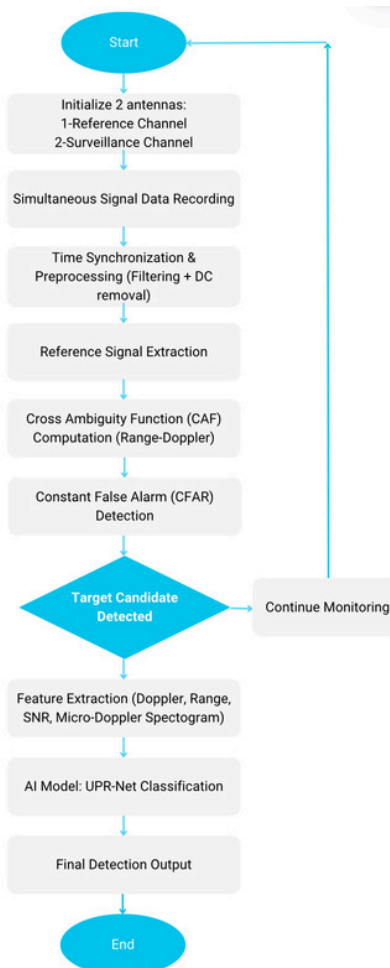
4 AI Classification

Micro-Doppler spectrograms are processed using **SUPR-Net** model which enables classification of debris vs. satellites.

→ Evaluation of accuracy with Confusion Matrix.



Processing Flow

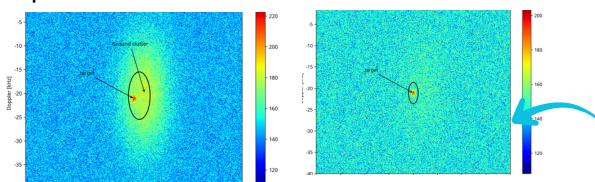


Results

Signal Response & Filtering

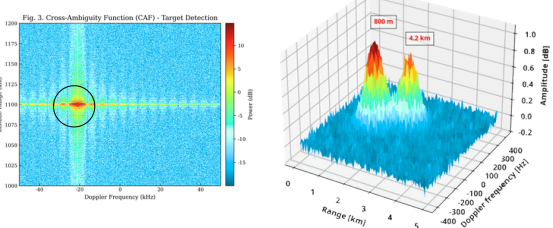
Simulated passive radar data was used to test the signal-processing chain **before full field deployment**. The target echo was modeled as a weak signal mixed with ground clutter, interference, and noise.

Filtering and clutter-suppression methods improved target isolation and increased the Signal-to-Clutter Ratio, **making weak LEO-like responses easier to detect** in the simulated data.

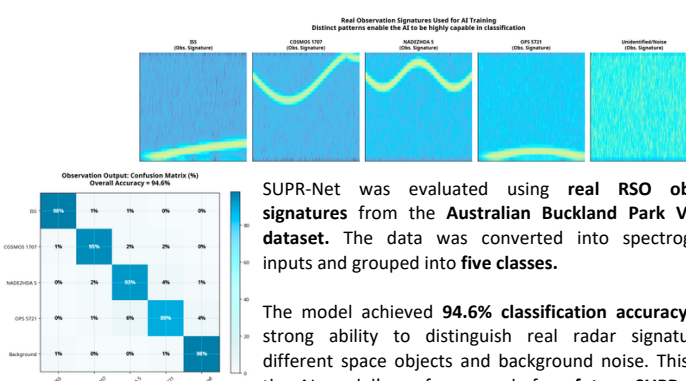


Range-Doppler Detection

The simulated reference and surveillance signals were processed using the **Cross-Ambiguity Function** to form Range-Doppler maps. Potential targets **appear as localized peaks in delay-Doppler space**.



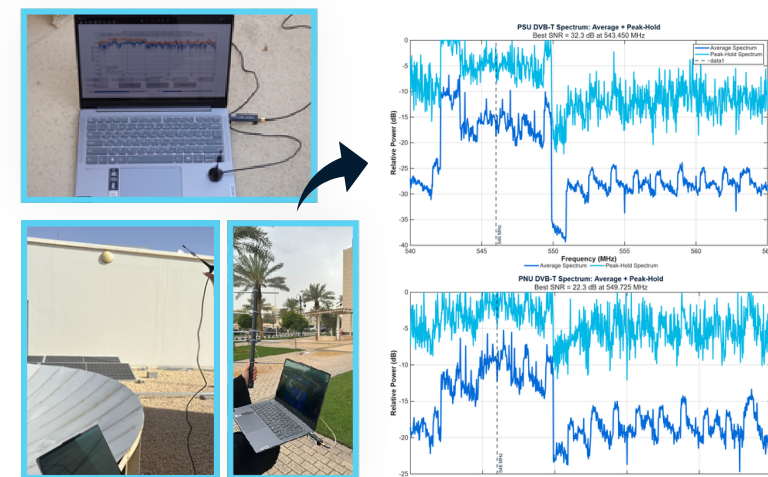
AI Model Performance



SUPR-Net was evaluated using **real RSO observation signatures** from the **Australian Buckland Park VHF Radar dataset**. The data was converted into spectrogram-style inputs and grouped into **five classes**.

The model achieved **94.6% classification accuracy**, showing strong ability to distinguish real radar signatures from different space objects and background noise. This validates the AI model's performance before **future SUPR-LEO field-data classification**.

Field Measurement Results



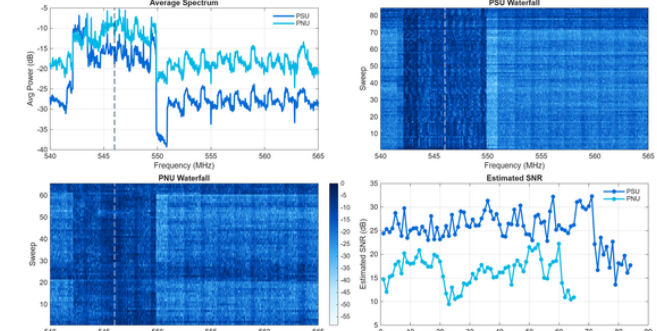
Initial field tests were conducted at **Princess Nourah University** and **Prince Sultan University** to validate real DVB-T reference-signal availability.

A **Yagi antenna**, **RTL-SDR**, and **customized DVB-T sweep code** were used to inspect the 540–565 MHz band. These measurements confirmed that usable DVB-T energy can be captured at both sites.

Real-World DVB-T Signal Data

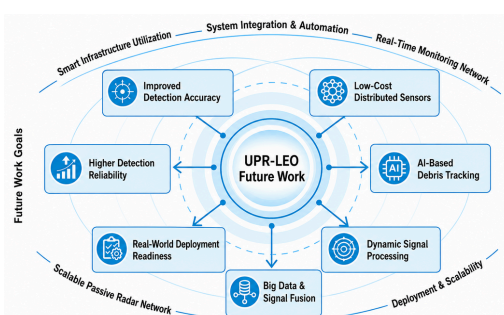
PSU showed stronger overall reception, with a best estimated SNR of **32.3 dB** near **543.45 MHz**. PNU also showed usable DVB-T reception, with a best estimated SNR of **22.3 dB** near **549.73 MHz**.

Real-World DVB-T Field Signal Validation: PSU vs PNU



Future work

Real World Deployment and System Extension



Our project is still under active development. Future work will focus on **designing dedicated UHF Yagi antennas** for reference and surveillance channels, extending **real-world recording duration** using improved processing hardware, and conducting **synchronized ISS/LEO observation campaigns**. These steps will allow SUPR-LEO to progress from reference-signal validation toward real reflected-signal detection and AI-assisted classification of space objects.

Conclusion

SUPR-LEO demonstrates the feasibility of using existing **DVB-T broadcast signals** as a foundation for **low-cost passive radar space surveillance**. By advancing low-cost and **energy-efficient space monitoring**, UPRLEO contributes to the development of a more **sustainable** and **safer space environment**.



Dashboard Module
(for desktop)



Real-World
Measurement



Simulated Data
Experiments



References

Acknowledgements :We sincerely thank **Prince Bader Al Faisal** for his support and encouragement of the SUPRLEO project. We also express our appreciation to **Dr. Yazan Allawi** for his valuable guidance and support throughout the project development process.

Our prototype



Prototype Description

The 3D model demonstrates the bistatic passive radar concept and the system's working principle.

- * Riyadh TV Tower: Acts as the transmitter (Illuminator of Opportunity) broadcasting DVB-T signals.
- * Radio Telescope: Acts as the passive receiver capturing reflected signals.
- * Satellites / Space Debris: Reflect the signals to enable detection and analysis.

The prototype explains how the transmitter and receiver are placed separately in a bistatic configuration to track space objects using existing broadcast signals.

Note: Please scan the QR code on the poster for more details and to explore the interactive dashboard.

