# **Exhaustive Catalogue of Research Papers on Space Situational Awareness (SSA), Space‐Debris Tracking, Collision‐Risk Assessment, and Autonomous Conjunction Mitigation**

Space Situational Awareness (SSA) sits at the intersection of astrodynamics, sensing technologies, artificial intelligence (AI), and decision science. Over the last two decades, a rich scholarly corpus has emerged that attacks long-standing challenges—sensor fusion, initial orbit determination, collision‐probability estimation, maneuver optimisation, real-time visualisation, and increasingly, cislunar SSA.

Below is a structured, thematically organised compendium of key peer-reviewed journal articles, conference papers, theses, and high-impact technical reports that collectively map the current state of the art. Each entry is accompanied by a one-sentence contribution synopsis and is fully source-cited to facilitate rapid retrieval.

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## **Orbit Determination & Data Fusion**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 1 | “Radar Initial Orbit Determination Method from Angular Track and Doppler Shift Measurements” (2025) | Introduces IODAD algorithm combining admissible-region logic with Doppler constraints for monostatic & bistatic radars | 71 |
| 2 | “An Orbit Determination Method of Spacecraft Based on Distribution Regression” (2021) | Uses probability distribution regression and RKHS embedding to estimate orbits from sparse observations | 41 |
| 3 | “Orbit Determination Using a Decametric Line-of-Sight Radar” (2013) | Demonstrates real-time tracking of Hubble with HF radar; two-stage IOD refined via Levenberg–Marquardt | 65 |
| 4 | “A Software Suite for Orbit Determination in Space Surveillance and Tracking Applications” (2022) | Presents modular OD pipeline integrating UT-based covariance propagation for multi-sensor data | 50 |
| 5 | “Space Surveillance Tracking and Orbit Determination (SSTOD)” (2019) | Details end-to-end tool validated with OWL-Net optical and LeoLabs radar data | 56 |
| 6 | “Multisensor Data Fusion and Orbit Determination with Nonlinear Estimation for Space-Debris Radar” (2023) | Proposes DISSA software for fusing low-cost sensor networks using Bayesian filters | 16 |
| 7 | “IODAD: Initial Orbit Determination from Angular and Doppler Measurements” (2025) | Merges optical admissible-region theory with Doppler for short tracks, refined via batch filter | 71 |
| 8 | “Determination of Satellite Orbits from Radar Data” (NASA TN D-489, 1960) | Historic optimum method using differential corrections, still foundation for radar-based OD | 67 |
| 9 | “Orbit Determination for Space Surveillance” (MSc thesis, 2016) | Compares LS, EKF, and controlled LKF for distributed radar networks | 44 |
| 10 | “An Orbit Determination Software Suite for SST Applications” (CEAS 2024) | Extends previous suite with uncertainty-aware admissible-region correlation module | 59 |

## **Collision-Probability Modelling & Estimation**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 11 | “Computation of Collision Probabilities Based on Special Perturbations and High-Order Methods” (2017) | Uses Taylor expansion plus advanced Monte Carlo (Subset Simulation & Line Sampling) for LEO & GEO cases | 52 |
| 12 | “Fast-to-Compute Upper and Lower Bounds for Short-Term Collision Risk” (2025) | Re-derives Akella–Alfriend model; provides efficient error-function bounds 1.3× faster than Chan’s method | 55 |
| 13 | “Collision Risk Analysis for LEO Satellites with Confidential Orbital Data” (2011) | Differentiates short- vs long-encounter regimes; linearised motion with TCA fixing | 40 |
| 14 | “Gaussian Mixture Method to Propagate Orbital Uncertainty for Collision Probability” (2019) | Combines GM propagation with Chan’s integral for improved accuracy in complex covariance cases | 58 |
| 15 | “Space Debris Collision Probability Analysis for Proposed Global Broadband Constellations” (2018) | Quantifies collision likelihood under best & worst debris environments for mega-constellations | 46 |
| 16 | “Consequences of LEO Satellite Collisions—The Fragments” (2023) | Monte-Carlo analysis of catastrophic intra-constellation collisions and debris proliferation | 43 |

## **Collision-Avoidance Maneuver (CAM) Optimisation**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 17 | “Optimal Impulsive Collision Avoidance in Low Earth Orbit” (2015) | Provides fully analytical ∆V–miss distance relationship with eigenvalue formulation for fuel minimisation | 25 |
| 18 | “Analytical Solution to Quick-Response Collision Avoidance Maneuvers in LEO” (2016) | Semi-analytical finite-burn approach enabling sub-orbit reaction times | 9 |
| 19 | “Onboard Planning of Collision Avoidance Maneuvers Using Robust Optimisation” (2009) | Robust LP guarantees avoidance under bounded navigation uncertainty | 14 |
| 20 | “Collision Avoidance Maneuvers Optimisation in the Presence of Multiple Encounters” (2024) | Sequential convex programming + DA + GMM uncertainty; supports low-thrust CAMs | 68 |
| 21 | “Multi-Objective Multi-Perspective Optimisation of CAMs Using Differential Evolution” (2024) | Minimises fuel, collision risk, trajectory deviation & mission downtime simultaneously | 63 |
| 22 | “Spacecraft Autonomous Decision-Planning for Collision Avoidance” (2023) | Employs deep-recurrent Q-networks to train AI agent for autonomous CAM decision making | 22 |
| 23 | “Collision Avoidance Maneuver Optimisation” (MSc thesis, 2014) | Introduces eigen-analysis plus Chan probability for last-minute CAM design | 72 |

## **AI & Machine Learning for Large-Scale Conjunction Assessment**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 24 | “Artificial Intelligence for All-vs-All Conjunction Screening” (2022) | First proof-of-concept ensemble model filtering 170 million object pairs to sub-percent workload | 45 |
| 25 | “Benchmarking Deep-Learning Approaches for All-vs-All Conjunction Screening” (2023) | Compares CNNs, GNNs, and LSTMs on CNES BAS3E dataset; proposes dynamic learning-rate schedule | 48 |
| 26 | “Towards Graph-Based Machine Learning for Conjunction Assessment” (2022) | Frames orbit catalog as dynamic graph; uses GNNs to predict conjunction links | 42 |
| 27 | “AI for Satellite Collision Avoidance—Go/No-Go Decision-Making” (2023) | Evaluates LSTM and evidence theory for risk classification of CDMs | 26 |
| 28 | “Tracking an Untracked Space Debris After an Inelastic Collision Using Physics-Informed Neural Networks” (2024) | PINN estimates post-collision trajectory, mass & restitution from satellite deviation | 13 |
| 29 | “Enhanced YOLOv8-Based Method for Space-Debris Detection Using Cross-Scale Feature Fusion” (2025) | Introduces CARAFE-upsample & cross-scale fusion for high-noise astronomical images | 69 |
| 30 | “PINNMamba: Sub-Sequential Physics-Informed Learning with State-Space Models” (2025) | Reduces PINN error by 86% on PDE benchmarks—applicable to orbit propagation | 28 |
| 31 | “Onboard Artificial Intelligence for SSA with Low-SWaP GPUs” (2020) | Demonstrates real-time CNN classification of resident space objects on-board | 66 |

## **Imaging, Radar & Sensor-Level Innovations**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 32 | “Visible and Infrared Image Fusion-Based Image Quality Enhancement for Space-Debris Surveillance” (2022) | CSR-guided fusion improves SNR in dark-scene debris imagery | 6 |
| 33 | “Generation of Fused Visible and Thermal-Infrared Images for Debris Tracking” (2023) | Pixel-level fusion yields more informative composite frames for small-object detection | 36 |
| 34 | “Reflectance-Based Hyperspectral Imaging of Space Debris” (2021) | Proposes in-orbit hyperspectral HSI for material ‘fingerprinting’ of fragments | 73 |
| 35 | “Scanning and Observing—ESA Optical Survey Upgrades” (2021) | Reports next-generation survey telescopes targeting < 2-cm debris | 3 |
| 36 | “Technologies Available for Licensing: Space-Debris Imaging” (2024) | Summarises licensable sensor innovations for micro-debris detection | 50 |

## **Distributed Filtering & Networked SSA Architectures**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 37 | “Distributed Space-Debris Tracking with Consensus Labeled Random Finite-Set Filtering” (2018) | δ-GLMB filter over heterogeneous sensor network with time-varying topology | 18 |
| 38 | “How to Secure Distributed Filters under Sensor Attacks” (2022) | Saturation-based filter maintains bounded error despite falsified measurements | 33 |
| 39 | “Two-Phase Distributed Filtering for Uncertain Systems with Fading Measurements under Deception Attacks” (2020) | Designs RR-protocol-compatible estimator with explicit error-covariance bound | 29 |
| 40 | “Distributed Adaptive Signal Fusion (DASF) for Non-Smooth Optimisation in WSNs” (2024) | Extends DASF to sparsity-inducing norms, enabling energy-efficient sensor selection | 24 |

## **Cislunar & Deep-Space SSA Foresight**

| **#** | **Call for Papers / Review (Year)** | **Relevance** | **Citation** |
| --- | --- | --- | --- |
| 41 | “AI-Enabled Cislunar Space Situational Awareness” (2025) | Outlines research agenda for AI-powered sensing, tracking & autonomy beyond GEO | 70 |
| 42 | “Adaptive Physics-Informed System Modelling with Control for Nonlinear Structural Estimation” (2025) | Provides adaptive Kalman–PG algorithm suited to lunar-gateway structural monitoring | 37 |

## **Integrated 3-D Visualisation & Decision Support**

| **#** | **Research Paper (Year)** | **Key Contribution** | **Citation** |
| --- | --- | --- | --- |
| 43 | “Real-Time 3-D SSA Visualisation Inspired by Cesium & NASA Eyes” (2023) | Implements WebGL globe streaming 25 k objects at > 60 fps for operator consoles | 12 |
| 44 | “Thales Alenia Space Smart Collision-Avoidance Autonomy Suite” (2023) | Describes AI-supported decision engine integrated with mission-control VR interface | 30 |

## **Emerging Meta-Analyses, Reviews & Benchmark Suites**

| **#** | **Paper / Report (Year)** | **Focus** | **Citation** |
| --- | --- | --- | --- |
| 45 | “Space Debris and Space Situational Awareness Research Studies in ISRO” (2021) | Comprehensive national roadmap covering fragmentation modelling & SOPA automation | 7 |
| 46 | “Space Debris Tracking and Prediction Models: Comparative Review” (2024) | Benchmarks eight widely used models (SGP4, ORDEM, MASTER, etc.) | 8 |
| 47 | “Space Object Monitoring and SSA—Literature Review 2020-2025” (2025) | Collates ∼200 publications across sensing, analytics & policy | 1 |
| 48 | “Space Situational Awareness Global Market Report” (2025) | Market-focused, but summarises key academic breakthroughs driving commercialisation | 13 |
| 49 | “AI Impact Analysis on Space-Situational Awareness Industry” (2025) | Surveys AI contributions to detection, trajectory prediction & autonomous CAM | 60 |

# **Research Gaps & Opportunities to Address**

Despite the strong progress, several notable gaps remain open in the SSA, debris risk management, and autonomous mitigation research landscape. Your group can focus on these to make impactful contributions:

## **1. Improved Initial Orbit Determination Under Sparse & Noisy Conditions**

* Current admissible-region and distribution regression methods degrade sharply under limited short-arc data or combined radar+optical heterogeneous noise.
* **Opportunity:** Design robust, multimodal probabilistic IOD approaches integrating physics-informed deep learning to reduce uncertainty bounds faster.

## **2. Real-Time, Scalable All-vs-All Conjunction Screening**

* Existing AI/ML approaches have demonstrated filtering but require improvements on recall, false negatives, and adaptability to mega-constellation catalogs (10⁵+ objects).
* **Opportunity:** Explore dynamic graph-transformer models that incorporate temporal, environmental, and satellite health metadata for improved filtering precision.

## **3. Incorporating Maneuver Planning Uncertainty into CAM Optimisation**

* Most CAM solutions assume perfect execution. Real thruster uncertainty, maneuver timing jitter, and SOC attitude deviations likely elevate collision risk after CAMs.
* **Opportunity:** Develop RL or robust optimisation frameworks incorporating maneuver execution noise and fuel-flow stochasticity.

## **4. Multisensor Data Fusion With Fading & Adversarial Channels**

* Sensor networks experience variable delays, dropouts, and may be attacked or jammed in contested environments especially for cislunar SSA.
* **Opportunity:** Research saturation-based distributed filters with provable resilience against cyber-physical attacks.

## **5. Explainability & Operator Trust in Autonomous CAM Recommendations**

* Black-box AI models limit human trust and regulatory acceptance of autonomous CAM decision agents.
* **Opportunity:** Design explainable AI (XAI) layers with counterfactual reasoning and saliency maps specialized to orbital-encounter dynamics.

## **6. Realistic Material-Property-Based Debris Characterisation**

* Hyperspectral and radar imaging are promising but lack comprehensive spectral libraries and inverse models that predict debris evolution (e.g., fragmentation likelihood).
* **Opportunity:** Build high-fidelity spectral databases from ground testbeds and fit inverse radiative transfer models to orbit object detection data.

## **7. Extending SSA Capabilities to Cislunar & Deep Space Domains**

* Increasing activity around moon gateways, lunar relay constellations, and asteroid mining will stress near-Earth SSA systems limited to LEO/GEO.
* **Opportunity:** Develop physics-informed Kalman and PG filtering techniques adapted to weakly observable nonlinear lunar orbits.

## **8. Integrated Multi-Objective CAM Scheduling for Mega-Constellations**

* Multi-encounter conflicts and operational constraints (e.g., collision risk, margin, power limits, communication windows) complicate CAM decisions at scale.
* **Opportunity:** Design efficient multi-objective evolutionary and convex optimisation planners incorporating real-time constraint updates.

# **Summary**

This compendium reflects the rich multidisciplinarity underlying SSA and orbital safety research—from rigorous orbit estimation and physics-based collision risk models to scalable AI conjunction screening and multi-sensor fusion. The identified gaps and opportunities are intended as a research roadmap to position your team for high-impact contributions addressing the urgent commercial and security needs of space traffic management for current and future orbital domains.