'Instrumentation and Techniques in Space Situational Awareness (SpaceAware)' Abstracts

Talks

On-Sky Performance of a Low-Cost, Scalable Wide-Field Optical Survey System for SSA Above LEO

Authors

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Abstract

We present the development and results of a low-cost, scalable, fully automated optical survey architecture for persistent monitoring of space objects above Low Earth Orbit via continuous wide-field observation. While LEO is already heavily monitored, surveillance in MEO and GEO remains sparse and tasking focused. These regimes are strategically critical and increasingly populated making persistent and scalable monitoring essential for long-term SSA.

Our prototype is therefore designed around survey-mode, built using commercial off-the-shelf hardware. Each node costs approximately 2500 GBP and provides a field of view of approximately 6 by 4 degrees, continuously observing all transiting objects. This results in persistent awareness at a fraction of the cost of traditional systems, while maintaining precision suitable for meaningful contributions to global SSA.

Operation is automated with weather sensing and real-time processing, using open-source tools including SExtractor and Astrometry.net for source detection and plate solving. Observations alternate between calibration and science exposures to maintain precise astrometric solutions, while star masking removes sidereal streaks, enabling extraction of non-stellar sources with real-time measurements of position and brightness.

Objects are identified using an adaptive nearest-neighbour approach matching TLEs to observations, using prior motion for better predictions. Unmatched sources are grouped into tracklets via a clustering and Hough Transform-based method. Uncertainties on positions reach sub-arcsecond levels in ideal conditions, equivalent to 100 to 200 meters at GEO, while those on separations between objects reach 0.1 arcseconds, equivalent to tens of metres at GEO. A single node detects 40 to 50 objects per night and identifies over 95 percent of catalogued GEO objects in view. Detection limits are approximately 1 to 2 meters in effective cross section, or 14th to 15th magnitude.

Repeated observations generate behavioural fingerprints via light curve analysis, enabling inference of rotation, structure, and anomalous behaviour. Multi-night observations then reveal changes in orbit or physical structure, enabling pattern-of-life analysis. The modular, low-cost design enables rapid scaling through distributed nodes. Multi-site observations

support parallax-based ranging and improved orbit determination, while multi-camera nodes increase sky coverage toward persistent GEO belt monitoring. Future extensions include multi-band observations for material and surface characterisation.

This system enables continuous wide-field surveying of higher orbital regimes, detection of anomalous behaviour, correction of inconsistent TLEs, tip-and-cueing of higher resolution assets, and pattern-of-life analysis. By complementing existing infrastructure and lowering barriers through open and reproducible design, it provides a pathway toward a more resilient and distributed global SSA capability.

Multi-site optical network with ML pipeline detects 1-10 cm debris in LEO. Triangulation from synchronized observatories enables sub-20m trajectory accuracy for ground-based laser ablation. Simulations validate single-pass Trace-Track-Tackle sequence.

Authors

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Abstract

Nearly three-quarters of the world's orbital asset is located in the Low Earth Orbit (LEO), sharing this volume of space with the major proportion of space debris. A significant fraction of this debris is within the size range of 1–10 cm, which is considered undetectable by conventional surveillance networks yet lethal to the operational satellites and human space missions. Active Debris Removal (ADR) through ground- based laser or orbital capture methods are currently the only viable means of clearing this debris field. This requires a very high level of precision in the acquired orbital elements of the debris, which is difficult to achieve using conventional single-point optical or radar detection and tracking methods. A concerted sequence of optical detection, tracing, and tracking of small space debris in LEO simultaneously from multiple sites, facilitated by machine learning algorithms, can achieve a much higher level of precision in orbital parameters through triangulation, enabling effective tackling of the debris. This paper presents a comprehensive system architecture for the detection, high-precision tracking, and active removal of this lethal, non-trackable debris population. The proposed solution, termed as the Trace, Track, and Tackle sequence, utilizes a synchronized, geographically distributed network of mobile optical observatories, based on a patented incremental detection refinement protocol. The system architecture integrates a multi-stage hardware configuration with a sophisticated, real-time machine learning pipeline. Initial wide-field detection is performed by a primary node, which employs a Real-Time Detection Transformer (RT-DETR) to identify faint debris streaks. Subsequently, multiple secondary nodes perform multi-view tracing, with a Hungarian algorithm solving the crucial data association problem to enable robust triangulation. The associated measurements are then fused by a Linear Kalman Filter to generate a high-precision Dynamic Trajectory Code (DTC). A tertiary node then uses this DTC to engage the target with a low-power laser, creating a Laser Illuminated Target (LIT) for final precision refinement and handoff to a kilowatt-class laser for de-orbiting. This integrated approach, executed within a single pass, will provide a scalable and cost-effective solution to the small-debris problem, with simulations indicating the potential to achieve the sub-20-meter trajectory accuracy required for effective ground-based laser ablation.

Demonstration of a Portable Low-Cost Optical Satellite Tracking Parallax System

Authors

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Abstract

With Earth's orbits becoming increasingly congested, the need for precise, cost-effective tracking of Resident Space Objects (RSOs) is critical. To address this, we present results from a portable, dual-telescope optical system that utilises parallax to derive precise 3D coordinates of RSOs.
Our architecture pairs the permanently installed University of Warwick's CLASP instrument on La Palma with a portable, sub £50,000 Commercial Off-The-Shelf (COTS) secondary unit. Building upon a short-baseline test in 2024, an extended-baseline observation campaign in August 2025 tracked over 250 unique objects across 110 and 140 km baselines between La Palma, El Hierro, and Tenerife. System calibration was validated using seven GPS satellites' precise positions, which in all instances, were within our measurement uncertainties.
By employing an optimised processing pipeline tailored for fast-moving targets, we extracted highly accurate Line-of-Sight (LOS) range and angle measurements. The extended baselines yielded range accuracy improvements of over two orders of magnitude compared to the 2024 2 km baseline, achieving sub-100 m errors at LEO and sub-10 km at GEO. Alongside astrometry, we extract photometric light curves to analyse RSO attitude dynamics, such as spin-rates of defunct rocket bodies.
These high-precision positional measurements have been used to perform orbital determination/refinement, providing ephemeris that exceed TLE (Two-Line Element) accuracy by up to 80". This advancement demonstrates the applicability of scalable, low-cost binocular optical networks to generate accurate ephemerides.

Understanding RSOs using multi-colour brightness maps

Authors

Paul Chote (1)

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Abstract

Upcoming instruments like the Digital Telescope will bring a step-change in observational capabilities of the GEO region: moving from tasked observations of individual objects to simultaneous monitoring of all accessible GEO objects at high cadence and high precision, in one, or potentially multiple, wavelength bands.
This talk will highlight key results from a unique precursor study that monitored a 10 degree strip of the GEO belt every clear night for a year using the STING instrument on La Palma. New techniques are introduced to analyse this rich four-colour dataset and infer structural and operational information about 14 active satellites within the field of view.

Multistatic Radar Observations of GEO Debris and Satellite Clusters with e-MERLIN/Jodrell Bank Radio Telescopes

Authors

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Abstract

We present recent developments in the use of radio telescopes as radar receivers for Space Situational Awareness (SSA). The 76-m Lovell telescope and e-MERLIN array is a unique instrument that allows us to achieve a sensitivity threshold capable of probing the population of small-scale debris in Geostationary Orbit (GEO) and beyond. With the Millstone Hill Radar (MIT Lincoln Laboratory) as a transmitter, we have conducted multiple observations of targets such as active satellites, tumbling rocket bodies and debris in MEO, GEO and graveyard orbits.

From observations of debris associated with Intelsat 33e, which anomolously exploded in October 2024, we have successfully detected and characterised a small piece of the debris which is ~65cm in length. We present the derived rotation rate and size estimation, demonstrating the capability of bistatic radar to resolve sub-meter debris at extreme ranges.

Also, previous observations have highlighted the difficulty of correlating targets in clusters with published TLEs. By implementing a scanning technique where we move the smaller beam of the Lovell telescope through the larger transmitted beam, we are able to observe the position of satellites in the plane of the sky to within the order of 0.001 degrees. These positions allow for the robust disambiguation of closely-spaced targets and provides a useful alternative to monopulse for single channel receivers.

These results highlight the capability of radio telescopes as receivers for multistatic radar, offering complementary capabilities to conventional SSA sensors. To progress this capability, we are also working towards combining observations from mutliple e-MERLIN outstations interferometrically.

An Ensemble Classical Machine Learning Approach to Characterisation of Low-Earth Orbit Satellites in EO/IR.

Authors

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Abstract

This talk presents a University of Warwick-Dstl collaboration on Satellite Characterisation for LEO (Low Earth Orbit), using a new dataset of LEO light curves collected from the Roque de los Muchachos observatory on La Palma in the Canary Islands, using the CLASP telescope owned and operated by the University of Warwick. CLASP comprises two co-mounted optical tubes, with an optical CMOS (Complementary Metal-Oxide-Semiconductor) sensor on one and a SWIR (Short-Wave Infra-Red) sensor on the other. This dataset consists of 1227 single-band optical light curves covering 901 different satellites (collected in 2024) and 3609 contemporaneous dual-band EO (electro-optical)/SWIR light curves covering 1459 different satellites (collected 2025/26), with more being added continuously. Analysis of the dataset was also undertaken using traditional machine learning techniques – in particular the use of an ensemble of decision trees on light curve features across the two wave bands for the purposes of classification, using Seradata labels as ground truth labels for the data. Finally, an analysis is presented regarding the relative performance gained using dual-band data over exclusively EO or SWIR data.

Space-based Inverse Synthetic Aperture Radar for High-Resolution Spacecraft Imaging

Authors

Gruffudd Jones (1), Lily Beesley (1), Marina Gashinova (1), Leah-Nani Alconcel (1)

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Abstract

Space Domain Awareness is achieved most commonly using passive and active surveillance and tracking observations from ground-based radar and optical sensors. While prolific, these systems are geographically limited, weather and illumination dependent, and crucially cannot usually provide images with sufficient resolution to perform detailed conditional monitoring or characterisation. Space-based sensors can alleviate these issues. This work discusses a space-based sub-THz frequency (300 GHz) inverse synthetic aperture radar (ISAR) sensing system, an active radar imaging method that can produce cm-scale images for ranges up to 100 km. These frequencies permit a high sensitivity to surface textures and small features, and can be utilised in space due to the lack of atmospheric attenuation, resulting in significantly lower propagation losses. We present the use of the Graphical Electromagnetic ISAR Simulator for sub-THz waves (GEIST), which enables the rapid generation of large volumes of high-resolution images to be used as training datasets for classification algorithms. This is essential for demonstrating the capability of the sensing system for future on-orbit deployment. Using GEIST, we detail the capability of this system for providing imagery of a number of space targets in different orbital regimes.

Chilbolton Observatory multi-modal observations of orbital objects

Authors

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Abstract

STFC's Chilbolton Observatory has been monitoring resident space objects, using visible imagers and radar systems, for more than 10 years. It currently undertakes SSA observations for NSpOC as part of their ongoing mission to maintain custody of UK-registered satellites. The combination of COATS (Chilbolton Optical Advanced Tracking System) and CASTR (Chilbolton Advanced Satellite Tracking Radar) has enabled radar tracking of un-cooperative targets by slaving the optical imager to the 25 m antenna. SWIR Imaging has demonstrated the potential for daytime imaging, including through thin clouds, while MWIR imaging developments will extend this and enable greater analysis capability through multi-spectral albedo/emission measurements. Meanwhile, the RF detection capability will soon be extended by an X-band imaging radar system and an advanced feed mechanism, again increasing the capability to both find and interrogate targets.

We will discuss the current state of the facility and its future direction, with key examples of all the different sensing modalities including the use of RF and optical (coherent and non-coherent) signals to analyse the attitude control of a Free Space Optical Communications satellite. We will describe the future roadmap for Chilbolton, including both standard operations and the development of new capabilities, including analysis of attitude and tumbling of objects, and the potential for the derivation of material and dynamics parameters from measurements.

Long-Term Evolution of the Rotation Periods of Inactive Resident Space Objects

Authors

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Abstract

To maintain Space Situational Awareness of the near-Earth space environment, the motion of resident space objects (RSOs) must be understood. While active RSOs typically have on-board mechanisms for determining their own motion parameters, the motion of inactive RSOs such as spent rocket bodies, defunct satellites, and debris fragments must be observed by external sensing systems.

This work presents the long-term rotational evolution of rocket bodies, using ground-based photometric observations from the Mini-MegaTORTORA (MMT) database. Rotation periods are derived from autocorrelation analysis of individual light curves spanning up to 11 years of observations. Rocket body types have been selected to identify differences in rotation evolution between objects with similar masses and geometries. Period evolution for multiple types of rocket upper stages are compared, including Atlas 2A, Ariane 5 and Long March. Correlations between orbit type and period evolution are identified. The results contribute to an improved understanding of rotational behaviour of inactive RSOs for space situational awareness applications and potential active debris removal missions.

Space Situational Awareness and astronomical observations: a two-way street

Authors

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Abstract

The dramatic increase in the number of artificial objects in low-Earth orbit is a concern for both tracking these objects and observing more distant astronomical objects. These efforts are highly complementary, however. Astronomy observations can help us learn about the orbits and physical properties of LEO objects. Simultaneously, improved characterisation of resident space objects via Space Situational Awareness (SSA) can help us avoid pointing telescopes towards bright LEO objects.

The International Astronomical Union's Centre for the Protection of the Dark and Quiet Sky (IAU CPS) brings together astronomers and the SSA community to jointly address these issues and to improve data sharing. Within SatHub, the CPS hub dedicated to observations, software, and data analysis, we have developed SatChecker, a satellite pass prediction tool that uses the most accurately available public orbital data. SatChecker can provide astronomers with predictions of when specific satellites will be visible, and also includes a Field of View service to predict all satellite passes for a given location, time, and observational field. We also host the Satellite Constellation Observation Repository (SCORE), which includes brightness measurements of satellites, but also allows for the cross-checking of observations with the predicted positions of satellites.

We are collaborating with colleagues at various companies connected to satellite operations and SSA activities to improve the available position accuracies and knowledge of satellite brightnesses. We welcome all interested parties to use and verify our open source software (please join CPS - https://cps.iau.org/). In this contribution, we will summarise the work done so far, the next steps, and the ways that others can contribute to this collaborative effort.

Implementing optimisation algorithms for satellite correlation

Authors

Kairavi Pandit (1)

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Abstract

3S Northumbria is working on deploying an observatory network to detect satellites, which will be used to create and maintain a catalogue with ephemeris and covariance data for RSOs.

I have been working on researching, selecting, and implementing optimisation algorithms that will be used to correlate the positional data of the streaks detected to satellites in the database. The software should update the catalogue after each detection accurately and autonomously. Using our in-house modelling tool, I have been simulating synthetic measurements and using open-source databases with orbital information to identify the optimal solution for each step.

Initial calculations are performed in the measurement domain, correlating projected positions with measurements to identify any matches and their correlation metrics. An optimal fitting algorithm is required to find the orbit with minimal differences between calculated positions and observations, and should account for uncertainties to find the best fit for the non-linear tracks. Where values are within the correlation threshold, orbital parameters are updated using an unscented Kalman filter.

New objects could be the result of launches, fragmentation events, spawning, or a manoeuvred satellite. Manoeuvre detection is a complex, multi-parameter problem, and I have been testing solutions for their detection by simulating and trying to detect different burns. Initial orbit determination also requires an appropriate solution to allow uncorrelated tracks to be correlated correctly with one another, and to be fitted to an orbit.

Posters

A Particle Filter Approach to Numerically Modelled Space-Debris Lightcurve Inversion

Authors

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Abstract

Properties of space debris such as attitude, geometry, and surface parameters may be determined via light curve data, in a process known as light curve inversion. Particle filters are a class of Monte Carlo algorithms which may be used for estimating hidden states of systems where only noisy measurements are available, and have been previously applied to light curve data. One such algorithm is being developed to be tested on synthetic light curve data, in order to recover the attitude and rotation of objects with known body parameters. An investigation into the effects of parameter changes, such as different object geometries, light curve lengths, and phase angles, has been performed to establish the efficacy of this approach for practical use in space situational awareness.

Brightness, Colour, and Polarisation for SSA: A Study of Gorizont-6

Authors

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Abstract

Characterising the attitude states of non-cooperative geosynchronous satellites remains a key challenge for space situational awareness, particularly where unresolved observations produce ambiguous light-curve interpretations. We present a coordinated optical campaign on the defunct GEO satellite Gorizont-6 combining simultaneous multi-colour photometry, long-baseline multi-site observations, and linear polarimetry. This multi-instrument approach was designed to test how complementary optical observables can improve rotation-state determination beyond what is possible with single-band photometry alone. Our analysis shows that simultaneous colour and polarimetric measurements help break degeneracies between the fundamental rotation period and its harmonics by linking specific light-curve features to distinct reflecting surfaces. Multi-epoch photometry further reveals a steadily increasing rotation period consistent with secular spin evolution (YORP), while paired glint events observed from Paranal and La Palma provide additional geometric constraints on the spin-axis orientation. Together, these results demonstrate that targeted combinations of wide-field photometry, polarimetry, and multi-site observing geometry can significantly improve the characterisation of defunct GEO objects.

Detectability of RSOs in the Near-Moon Environment: Optical and Short-wave Infrared

Authors

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Abstract

We present the results of a survey designed to quantify the detectability of RSOs in the near-Moon environment as a function of lunar conditions. We conduct the survey in two passbands, optical and short-wave infrared, and at a range of lunar illuminations (from 20 to 100%) and separations (from 2.5 to 15 deg from the lunar centre). We provide a method of determining sky brightness for any combination of values within these ranges and then convert this into target detectability. Detectability is considered in two regimes. Regime one considers a single frame and a moving target with relative motion, and regime two considers a target stationary within the frame and the combination of multiple frames. We find limiting magnitudes of 10 – 18 in G-band and 10 – 16 in J-band depending on the passband used and the chosen parameters. The results are provided as an adaptable tool, to be a method for informing efficient use of near-Moon/cislunar space for target observations.

SatLight: a high-fidelity light curve simulator for brightness mitigation

Authors

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Abstract

Photometric observations of resident space objects (RSOs) offer a means of characterising their physical properties, attitude, and rotational state. As the orbital population grows, the ability to interpret photometric signatures is increasingly important. Synthetic light curves support this by enabling characterisation of RSO geometry, surface materials, and attitude, and by producing labelled datasets for training machine learning models. These datasets can be generated faster than observational campaigns and under controlled conditions. However, existing light curve simulators are either not publicly available or rely on simplified models.

We present SatLight, an open-source Python package for synthetic light curve generation built on the Blender Python API. SatLight constructs a scene containing the RSO, solar and Earth illumination, and the observer geometry. It uses orthographic ray casting to replicate a distant observer and evaluates bidirectional reflectance distribution functions (BRDFs) at each surface point. A library of BRDFs for common spacecraft materials is included, with support for user-supplied definitions. Object geometries are imported via .obj and .stl formats. SatLight implements self-shadowing, and incorporates Earthshine via a discretised Earth albedo model.

SatLight provides a tool for light curve analysis including RSO fingerprint generation, failure analysis, and rotation state determination, as well as dataset generation for ML training. It also supports brightness mitigation analysis for satellite brightness impacts on astronomy.