A Survey on Image Processing based Techniques for Space Debris Detection

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Abstract—Space debris is the nonfunctional objects revolving in the outer earth orbit. The high-speed debris projecting to Kessler's syndrome is a threat to active satellites. Rigorous attempts are being made for the efficient detection of the debris for safeguarding existing functional satellites. Among them, image processing methods prove beneficial for the detection of space debris in orbit. The image captured from the satellite is in the form of visible images and thermal images. The survey is conducted on various image processing techniques for space debris detection based on ground-based tracking, satellite-based, simulation-based, and fusion-based detection. The features of debris detected by the various methods are thoroughly reviewed. The study enhances the importance of the fusion of the features of visible and thermal images provided with Deep Neural Networks (DNN). The fusion-based method provides an efficient solution to detect debris in both sunlit and non-sunlit areas from the satellite.

Keywords—space debris, visible image, thermal image, fusion, machine learning, deep neural networks.

I. INTRODUCTION

The frequent launch of satellites since Sputnik 1 in 1957 have increased the junk in space orbit. The major debris populated areas are the Low Earth Orbit (LEO) region which lies from 100 - 2000 km altitude from the earth's surface. In the past three decades, hundreds of satellites have been launched in space by many countries for scientific, environmental, and security purposes. Out of which some exploded due to one or another reason and are turned into debris. Most of the space-based debris surveillance program involves sensors for the debris detection. The high-resolution visible images and thermal images are obtained from visible sensors. The sensors detect visible images in sunlight regions whereas thermal images are obtained in non-sunlight regions. The space debris features like shape, size from visible image depends on the sun radiation and the observing sensor. This poses a major challenge for debris detection with visible images. The thermal image which is independent of solar radiation records the temperature profile of the object plays a vital role in space debris detection. However, infrared images lack identification of reflective properties of space debris such as size, shape, visible edges etc. The obtained thermal image relies on the fact that a hot surface emits more IR than a cool surface. All of the pixel values can then be transformed to temperature values, which can subsequently be represented as color codes. The fusion of visible and thermal images with application of image processing methods can be a preferable solution to obtain complementary and comprehensive information of space objects. The image processing methods for space debris detection still have their advantages over other debris detection methods. Because of their effective feature representation and excellent mapping capabilities, Deep Learning based image processing techniques give excellent performance in object detection. However, to handle the non-sunlit areas, thermal imaging in addition to optical imaging is proposed. Thus, the fusion of optical and thermal images, using Deep Learning, may outperform space debris identification. The major goal of the current work is to examine several strategies for detecting space debris and to comprehend thermal and visual image fusion using Deep learning. The paper is organized as: Section II explores various debris detection techniques based on ground based, satellite based, simulation based and fusion based debris detection, followed by a conclusion in section III.

II. RELATED WORK

Space organizations worldwide have explored various techniques to detect space debris. The survey broadly focuses on the approaches explored by various researchers to detect and address the space debris detection problem. The approaches for various image processing techniques for space debris detection includes ground-based platforms, satellite-based tracking, simulation setup based and image fusion based. The classification for the space debris detection techniques is shown in fig 1.

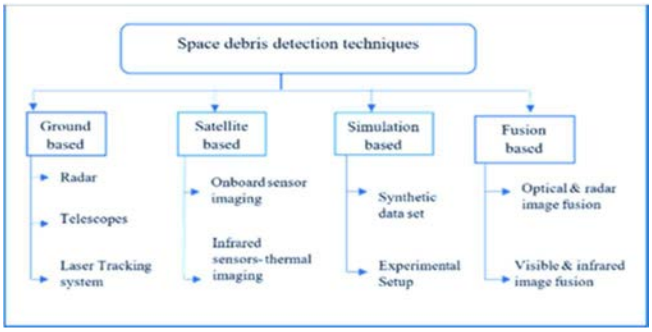

Fig. 1. Classification of various techniques for space debris detection.

1. *Ground based imaging methods for space debris detection-*

The ground-based imaging includes images of space debris captured from the earth surface. The imaging techniques for space debris detection using radar, telescopes and laser tracking system is presented in the survey below-

1.1 Radar imaging techniques-

The radar system incident the signal on the tracked target and receives the signal return in the form of echo. The intensity of the return echoes depends upon the parameter like size, shape material etc. of the target. The space debris detected using radar imaging is presented in the survey.

The Haystack Ultra-Wide Band Satellite Imaging Radar (HUSIR) [1] conducted experiments for calendar year 2019 are explored. In beam park mode, HUSIR radar transmits debris picture data in low Earth orbit (LEO). NASA's Size Estimation Model (SEM) is used to estimate debris Radar Cross Section (RCS) to size measurement. An object's characteristic length parameter is used by NASA's SEM. The typical length is the average of an object's three biggest

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dimensions measured along three orthogonal axes of a target. The identified debris is 5.5 mm in size. The height and sensitivity of the radar determine the detected size. The direct inclination for debris is not measured by radar in beam-park mode.

The Shadow Inverse Synthetic Aperture Radar (SISAR) system for space debris detection is proposed in [2]. The SISAR imaging is based on CubeSat, a nano-satellite passive radar. The Moving-End (ME) SISAR algorithm and k-NN classifier are used to analyze the radar signal that was received. The k-NN analyzes SNR and resolution from the received signal from debris. The algorithm model is based on Fresnel Kirchhoff diffraction formulae. The space debris is detected based on size, altitude and inclination angle. The debris in range of 15 mm to 2m length and receiver altitude ranging 400 kms to 600 kms are detected. The method improves system resolution for debris detection.

The 3-dimensional Inverse Synthetic Aperture Radar Imaging (3D-ISAR) imaging of space debris for mono-static radar systems is proposed in [3]. The 3D image of the moving target is obtained from the major axis dimension. The typical ISAR measures two dimensions as range resolution and cross resolution. However, 2-D ISAR imaging is inefficient to measure height of scatterers. The third dimension is height of scatter which is obtained by Modified Particle Swarm Optimization (MPSO) method combined with M-CLEAN technique. The image is scaled to get a 3D image with inverse radar transform method (IRT). The RCS feature is analyzed for space debris in LEO orbit. The method is inefficient for complex targets and small size debris.

The KAT-7 radar system in L band is analyzed in the paper [4]. The single input multiple output (SIMO) radar equation analysis is done for detection of debris detection. The images captured by the radar system include radio telescope receivers. There is a single transmitter and there are multiple receivers present in the SIMO radar that can measure the reflected signal from the target. The debris detection with SIMO radar equation analyzes radar cross section (RCS) and signal to noise ratio (SNR) of the debris. The RCS of detected debris is around 10. 5dBsm. The debris can be detected up to range of 800 km. The system can measure SNR of about 35dB and resolution of 0.6 m for tracked targets. The debris detected in the LEO orbit are in the range of size 2-10 cm. The method is unable to determine space debris at high range and resolution.

In the paper [5]radar imaging of space debris with in-space or ground-based radar is proposed. The image obtained from a radar image depends on the reflectivity of the tracked object. The imaging includes sunlit debris termed as Resident Space Objects (RSO). The pixel intensity of the object is used to detect RSO objects with the help of an envelope detector. If the pixel intensity is detected more than the set threshold of the envelope detector then an RSO object is present. The Constant False Alarm Rate (CFAR) threshold detector method is applied to RSO objects in case of noisy environments. The features of space debris detected are signal to noise ratio and the spatial resolution. The debris detected is in the range of diameter 1-10 cm in LEO orbit. The discussed framework overcomes low signal to noise ratio and range bandwidth measurement problems for small sized debris. The method to detect space debris, discussed in [6] is based on ISAR.

This technique involves 3D-image of rotating space debris around the major axis in a one interval. The back projection transform algorithm is proposed to analyze 3D-image of space debris. The algorithm integrates the sinusoidal curves and phase information of the moving target. The features analyzed are the pulse repetition frequency (PRF) and the resolution of tracked target. The debris tracked in Near Earth Orbit (NEO) are in the range of 10-100 cm size. The method is suitable for point scatters, continuous conductive targets, high spinning targets, and ground targets. The big and small sized debris are detected efficiently in shadowing and noisy environments. Table 1. Summarizes imaging techniques for radar-based for space debris detection.

Table I. Summary of Imaging techniques for space debris detection using radars.

Title	Approaches and Techniques used	Features detected	Remarks
Radar observations from the Haystack Ultrawideband Satellite Imaging Radar [1] (2021 ESA Conference)	The radar system to detect debris with size estimation model (SEM)	RCS, characteristic length.	Direct inclination is not measured
SISAR Imaging for Space Debris based on Nanosatellites [2] (2020 IET Research Journals)	The radar imaging is used to detect space debris with Moving End (ME) algorithm and k-NN classifier	SNR, size, altitude determination and inclination angle	The technique Improves the system resolution
A Method for 3-D ISAR Imaging of Space Debris [3] (2018 IEEE)	The 3-D image of space debris using ISAR radar with MPSO and M-clean technique	RCS analysis	Inefficient for complex targets and small size debris
SIMO radar design for small space debris detection in the LEO [4] (2015 IEEE)	The radar system analyze debris with SIMO radar equation	SNR, RCS	Limitation for detection of debris at higher range and resolution
Enabling Orbit Determination of Space Debris Using Narrowband Radar [5] (2015 IEEE)	RSO object is detected using constant false alarm rate detection method	SNR and spatial resolution	SNR and bandwidth problem is resolved
High-Resolution Three-Dimensional Imaging of Spinning Space Debris [6] (2009 IEEE)	3-D (ISAR) radar is used to analyze debris with back projection transform	Phase information, resolution	Inefficient for Dominant scatters and complex target

1.2 Optical imaging techniques with telescopes-

The optical imaging works on the principle of light characteristic of the target. The imaging techniques for space debris detection includes optical analysis features with telescopes. The approaches explored for space debris detection using optical imaging with telescope are discussed below-

An Adaptive Optics (AO) system is proposed in [7]. A 1.8 m telescope is used to take images with LASER ranging tracking for orbiting satellites and debris. An Electron Multiplying Charge Coupled Device (EMCCD) camera in a laser system is used for testing continuous single-photon images. The image features involve wavelength, albedo, and range accuracy detection. An AO system can resolve objects in space at around 800 km, with wavelengths ranging from 80 - 100 cm and size ranging from 40-50 cm.

The optical observations of debris in GEO orbit with Australian Remote Observatory (ARO) is discussed in [8]. ARO uses an 18 cm optical telescope to capture the image. It consists of a Charge-Coupled Device (CCD) having a camera covering 3.17-degree Field of View (FoV). The experiment is conducted in the geosynchronous orbit for 5-night data on 300 objects of magnitude 15. The uniform linear motion detection method is used to analyze telescopic CCD images for 18 images. The image feature depends on the target's shape, intensity and background noise. The signal from an orbital object is amplified and noise is reduced. Table2. summarizes imaging techniques for optical imaging with telescope for space debris detection.

Table II. Summary of imaging techniques with telescopes for space debris detection.

Title	Approaches and Techniques used	Features detected	Remarks
Adaptive optics for satellite imaging and space debris ranging [7] (2015 AMOS Conference)	AO system telescopes of 1.8m with EMCCD imaging	wavelength, albedo, range accuracy	Shape characteristics are not studied
Optical Observation, Image Processing and Detection of Space debris in Geosynchronous earth orbit [8] (2014 AMOS Conference)	CCD based optical to detect debris with uniform linear motion detection method	shape, intensity, background noise	signal from an orbital object is amplified & noise is reduced

1.3 Laser tracking techniques-

The laser tracking system is based on the laser beam to track the target. The imaging techniques use lasers and cameras in the infrared red region for tracking the space debris. The following survey includes space debris detected with laser tracking systems.

David A, Freiwald et al. [9] have proposed compact pulsed-laser and camera systems operating in the near infrared region. A diode pumped - crystal laser- is used to detect debris in the near infrared region. The Insulated Charge Coupled Device (ICCD) camera uses low laser energy with range gating technique to detect debris. The debris can be seen in the range of 1mm & 10cm. As the thermal camera is used to detect space objects, the system works better in non-sunlit areas. The unwanted backscatter from the target gets banished from entering the camera due to range gating technique.

An infrared laser tracking system with a visible light acquisition to track objects in range of 10cm is proposed in [10]. The Razor view project is carried out at the EOS center for tracking small debris objects using laser ranging techniques. The size of the object and orbit is tracked effectively. The table 3 summarizes imaging techniques for laser tracking of space debris detection.

Table III. Summary of imaging techniques for laser tracking of space debris detection.

Title	Approaches and Techniques used	Features detected	Remarks
Range-gated laser and ICCD camera system for on-orbit detection of small space debris [9] (2016 SPIE digital library)	A diode- pumped crystal laser and camera system	sharper images based on light intensity from laser	range gating technique is used to detect debris
The EOS Space Debris Tracking System [10] (2006 EOS Space Systems)	An infrared laser tracking system	Light intensity	Size and orbit accuracy is tracked accurately

All the above techniques make use of radars, telescopes, and laser tracking for space debris detection. These techniques track debris based on catalogued information. So real time debris tracking is not possible. The next phase of the survey includes satellite-based debris detection in which onboard sensors and payload cameras play an important role for real time tracking of debris.

2. Satellite based imaging methods for space debris detection-

The satellite imaging includes detection of debris from the spacecraft with various types of sensors and onboard camera. The following section discusses the satellite imaging techniques based on the onboard sensors and infrared sensors.

2.1 Satellite with onboard optical sensors for space debris detection-

Various approaches for sensor tracking of debris from the satellite in space are discussed below –

The on-board optical sensor to detect debris using an image processing-based technique is discussed in [11]. The camera records a picture facing debris in space in a set direction. The Lyapunov based control algorithm is proposed to detect stars and debris. The specific Kalman filter is designed to reduce noise in camera sensors. The Kalman filter's noise reduction reduces noise from 3 pixels to 0.84 pixels. The features detection involves streaks, angular velocity, attitude from stars, and debris detection. The debris movement is tracked when it comes into the scope of the camera. In the disengagement maneuver mode, the speed of the spacecraft is decelerated which helps in detecting streaks. The visible features of debris in space-based observations are efficiently tracked. The algorithm is unable to determine debris with multiple points of observation from an on-board camera.

Thillot et al. [12] proposed debris detection technique with optical sensors. In this paper active as well as passive sensors are reviewed to detect debris. The sensor characteristics depend on optical resolution and temporal parameters of debris. Active sensors allow it to detect debris for short-range and small debris with the drawback of required increased power. A passive visible sensor is based on optics with a large aperture. The classification of debris is done by estimating albedo surface product. The debris can be detected in the range of diameter less than 1 mm and from range of 10-100 mm. Table 4. summarizes imaging techniques for laser tracking for space debris detection.

Table IV. Summary of imaging techniques with onboard sensors for space debris detection.

Title	Approaches and Techniques used	Features detected	Remarks
Image-based attitude maneuvers for space debris tracking [11] (2018 Elsevier)	Onboard Optical sensors are used to detect debris with Lyapunov-based control algorithm, Kalman filter.	streaks, angular velocity, attitude	Unable to track Multiple point observation of debris
Micro-Satellite for space debris observation by optical sensor [12] (2017 International Conference on Space Optics)	active as well as passive sensors are used to detect debris	optical, resolution, temporal parameters	Passive sensor is more suitable for derris detection than active sensor

2.2 Satellite with infrared sensors and thermal imaging-

The satellite based thermal imaging includes infrared sensors which depend on the thermal profile of the object. The infrared image uses a temperature parameter for the detected target. The satellite imaging techniques for debris detection based on the infrared sensors with thermal imaging is presented-

The Longwave Infrared (LWIR) sensors with wavelength 18-14 micrometers to detect debris for Infrared-Active Debris

Removal Mission (IR-ADR) are analyzed in [13]. The images are captured from the LWIR sensor from the satellite. The proposed method detects temperature variation by combining thermal coatings, surface coating and external heat fluxes. The features detected are based on the temperature of the tracked target. The detected temperature is obtained from the difference of heat flux between net incoming and total radiated power. The heat fluxes for space debris are from sun and earth as there is no power dissipation or active cooling in space. Radiator coatings, paints and insulation blankets are surface coatings mostly used in different space applications. However, insulation coatings are highly emissive and vary in absorptivity. The temperature profile for debris in different orbit discussed in the paper as shown in table 5. The LWIR detectors give the best result for the debris with the temperature in the range of -90^0C and $+30^0$C in the LEO orbit. The model is suitable for detecting simple edge-based objects but fails for tumbling motion objects.

Table V. Temperature characteristics of space debris in different orbits.

Orbit	Characteristics	Infrared Detector Temperature Range
LEO-800km, non-elliptical	Constant temperature	-40°C to 30°C
LEO Eclipse orbit	Temperature variation depends on surface material, thermal inertia and α/ε properties	-90°C to 30°C

The long wave infrared sensors properties for space debris detection are proposed in [14]. The images are detected from the infrared sensor. Long-wave infrared sensors with 7–14 µm range are used to detect orbital debris with temperatures ranging from 100–4000C. The temperature analysis is done for unresolved imagery. The model is designed using STK SEET software for temperature analysis. The ratio of absorptivity ( ) to emissivity( ), cross-sectional area and tumbling rate are the features of detected debris. The algorithm used is Meyer Wavelet for near earth objects. A radiometric based approach is used to detect and characterize the space objects. The orientation, range, temperature and projection are extracted for each simulation for radiometric detection. The method is inefficient to detect the direction of tumble rate of debris.

The cooled infrared sensors to detect debris using thermal imaging is proposed in [15]. Even at altitudes above 500 km debris can be detected. The features detected are RCS, range and background noise. Thermal imaging data depends on mass and albedo property of debris. A small aperture system is used to view debris for satellite breakup events. The thermal characteristics of debris are easily verified above 500 km as it decays slowly. Table 6 summarizes satellite-based debris detection with infrared sensors and thermal imaging.

3. *Simulation based imaging technique-*

The simulation-based imaging techniques include synthetic data generation models and experimental set up based models designed for debris detection. The satellite imaging techniques for debris detection based on the simulation is presented-

The technique to gather high resolution images of rotating space objects from satellites in LEO is proposed in [16]. The high-resolution image is detected based on the angle and speed of the rotating object. The piece of fast-moving debris is detected in the model as a cluster of extremely small and highly reflecting objects. The high-resolution images, size of the synthetic aperture, rank-1 image and Kirchhoff migration technique are presented. The method efficiently analyses objects rotation speed and direction of its axes.

Table VI. Summary of debris detection with infrared sensors and thermal imaging.

Title	Approach and Techniques used	Features detected	Remarks
Thermal analysis of space debris for infrared-based active debris removal [13] (2017 Journal of Aerospace Engineering)	Infrared system to analyze temperature variations from surface coatings of debris	external heat fluxes, surface coating	Tumbling motion tracking is not analyzed
Debris characterization techniques via unresolved long-wave infrared imaging from a space-based platform [14] (2014 Journal of Applied Remote Sensing)	Long-wave infrared (LWIR) sensors for space debris with STK SEET software analysis and Meyer Wavelet algorithm	tumble rate, □/□ ratio, and RCS	Direction of tumbling rate of debris cannot be detected
Space debris characterization using thermal imaging systems [15] (2010 AMOS Proceedings)	Cooled infrared sensors to detect debris with thermal imaging.	RCS, mass, albedo, range, and background	Debris decay slow above 500km

An experimental setup to implement a robust Space Surveillance Tracking (SST) system is proposed in [17]. The synthetic image dataset is created using a 3D CAD tool with visible camera, thermal camera, robotic arm, and light source. SST is able to detect anomalies of non-catalogued while tracking and raising alarm to ground based operators. The satellite identification is done based on the three constraints i) to classify a satellite as a satellite object or debris ii) compare the attitude of satellites such as tumbling rate, pose variation satellite iii) The ratio of red, green, blue components is used to detect satellite or debris objects in obtained satellite images. For these explorations, various Machine Learning and Deep Learning algorithms are used. The Machine Learning algorithms used are Support Vector Machine (SVM), Multinomial SoftMax Regression (MSR) and Principal Component Analysis (PCA). Deep learning algorithm used is RESNET. SVM and MSR can handle a wide range of visual conditions based on position-sensitivity with respect to pixel values. The accuracy achieved by deep neural networks is 99.3%. All the methods are applicable for far range images only.

The optical image sequencing for background estimation for low SNR space debris with Feature Learning of Candidate Regions (FLCR) is proposed in [18]. It involves stars and debris detection with experimental hardware. The debris image considered is of small size with low reflectivity, sparse distribution, low energy with respect to background noise. The hot pixels from the observed image and flicker noise are removed first, from the acquired optical image sequences. The one-dimensional mean iteration method is proposed to remove non uniform background information. Further, the star objects are taken off which reduces the false alarm. The debris are detected using i) The motion features among multiple image sequences ii) Deep learning algorithms to classify objects based on spatial feature and iii) location of debris using weighted centroid localization. The low SNR space debris are detected with accuracy of 85.5% using the FLCR method.

The optical measurement of attitude estimation using photometric observation for Active Debris Removal (ADR) mission in [19]. The image is obtained from the light curve properties of debris. Light curves property uses brightness to detect the attitude of asteroids. The Machine Learning algorithm involves improving the accuracy, robustness, and calculation cost of imaging observation. Active debris removal involves estimation of shape, surface properties and attitude motion are needed to identify debris and monitor health of satellites. The 3DCG software with Convolutional Neural Network (CNN) algorithm is used to detect GEO objects based on shape, surface properties, and attitude. The CNN is applied to imaging observation for attitude estimation of GEO objects. The CNN algorithm gives better results than other methods.

The data pre-processing pipeline and analysis of optical observation of moving objects in space based on streak detection is proposed in [20]. The Streak detection framework as shown in fig.2 contains two main components: segmentation and classification. Segmentation involves low SNR information extraction from images. Classification includes characterization and efficiency of extracted data. The detection and astrometric reduction are done based on object trails, or streaks. The optical images from low altitude debris with high angular velocity have long and faint streaks. The algorithm involves single-image detection of streaks, Markov-chain Monte Carlo version and Streak-PCA classification method. The method requires 13 seconds for processing each image with a typical 2k x 2k resolution. The detection sensitivity is 90% for long streaks having length greater than 100 pixels and bright streaks with SNR=1. However, debris with a low SNR of 0.5, the sensitivity is reduced to 50%. Table 7. summarizes debris detection simulation-based debris analysis.

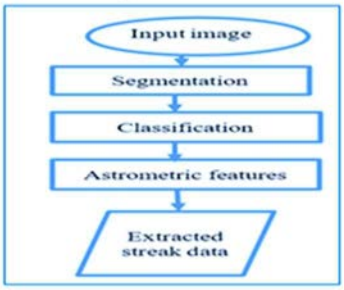

Fig. 2. Streak detection Framework.

4. Fusion based imaging technique for debris detection-

Fusion-based imaging techniques involve fusion of the various images detected by the system for detection of debris using visible and infrared properties. The classification of space debris detection based on robust fusion-based image detection are discussed in the following survey -

The fusion of images obtained from visible sensors and infrared images for detecting space debris is proposed in [21]. The visible and thermal images of debris are captured with sensors on the satellite. The method to process images used is a layered fusion technique based on Convolutional Sparse Representation (CSR) and Deep Convolutional Neural Network (DCNN). The feature selection is based on space debris, sun- illumination and observing sensors. The space debris data set is simulated based on a 3-d model design of the Apollo spacecraft. The visible images are obtained from 3dSmax tool and infrared image from Vega prime. The 100 images for each class with size of image 640*48 pixels are trained. The space debris recognition is done with an algorithm based on the Alex Net model. Data augmentation is applied to reduce the problem of overfitting due to a smaller number of image data. Testing is done based on a few assumptions such as batch size, weights, no of cycles. However, with insufficient images for data processing characteristics of rotation of debris, tumbling effect, distant from the sensors are not reviewed. The fused images are efficiently able to detect edges and textures features of space debris than the visible images. The accuracy achieved by DCNN is 99.68 % for visible images and 99.93% for fused images.

Table VII. Summary of debris detection with simulation-based debris analysis.

Title	Approach and Techniques used	Features detected	Remarks
Imaging space debris in high resolution [16] (2021 SIAM Journal)	The high-resolution debris imagining with Kirchhoff migration technique	High-resolution images, size of the synthetic aperture	Estimate of speed and direction axes of target.
Detection and Identification of On-orbit Objects using Machine learning [17] (2021 European Conference on Space Debris)	Experimental setup for debris detection with application of various ML and DL algorithms	Range, size	Accuracy of 99.3% is achieved with DNN, near range images resolution is not obtained
Space Debris Detection Using Feature Learning of Candidate Regions in Optical Image Sequences [18] (2020 IEEE)	Optical image sequencing with FLCR method.	Noise estimation, low SNR space debris with accuracy of 85.5%	FLCR method efficiently reduces the false alarms error induced by stars and noise.
Attitude Estimation of Space Objects Using Imaging Observations and Deep Learning [19] (2019 AMOS Conference)	Imaging observation with optical system, 3DCG software, CNN.	Shape, surface properties, attitude	CNN shows better performance
Streak detection and analysis pipeline for space-debris optical images [20] (2016 COSPAR Elsevier)	The single-image detections of streaks, with streak-PCA classification method.	streaks detection with astrometric features	For faint streaks sensitivity is reduce to 50%

The detailed emphasis on fusion strategy of rendered space objects dataset for visible and infrared images is proposed in [22]. The public dataset is created with 6 space environment objects and 4 debris. The method includes Convolutional Sparse Representation (CSR) based guided filtering and weighted average for the fusing the base layer of the image. The guided filter make use of local contrast measure as there is similarity in the neighborhood's pixel in space object image. The features tested are SNR, pose, background noise, spectrum and image range. The fusion efficiency can be improved.

The approach explored in [23] includes observation for combining image from radar and optical image for debris detection. The method to detect debris images include particle swarm optimization and dynamic characterization The features detected are spin parameter estimation and target's attitude. Based on the derived image projection geometry of the radar and optical observation, target dynamic parameters are studied. The algorithm overcomes continuous observation limitations and is suitable for most on orbit satellites.

Palmerini [24] have proposed combination of visible and thermal imaging for in-space operations. The image is captured with a thermal device with standard micro-bolometers. The device operates in the 8-14 micrometer band with a resolution of 160*220 pixels and limited focal length. The visible image is captured from micro camera device with resolution of 640*480 pixels. The techniques used to analyze images are Scale Invariant Feature Transform (SIFT) and Hough Transform. The features like distance to the target, different signatures in both visible and infrared bands, relative attitude(δ) are verified. The Extended Kalman Filter (EKF) is tested for fused images. The image analysis done only for planar surfaces; circular orbits is not considered. Table 8. summarizes fusion based debris detection techniques.

Table VIII. Summary of fusion-based debris detection techniques.

Title	Approach and Techniques used	Features detected	Remarks
Visible and Infrared Image Fusion for Space Debris Recognition with Convolutional Sparse Representation [21] (2020 IEEE Xplore)	The fusion of visible and infrared images for space debris detection using CSR method and Alex Net DNN model	edges and textures of image are verified	DCNN algorithm provides 99.93% accuracy for fused images
Visible and Infrared Image Fusion-Based Image Quality Enhancement with Applications to Space Debris On-Orbit Surveillance [22] [2022 International Journal of Aerospace Engineering]	The image fusion of public dataset visible and infrared images using CSR based guided filtering method with weighted average map.	SNR, pose, noise, spectrum for infrared image	Strong correlation of neighborhood pixels provides detailed image information
Optical-and-radar Image Fusion for Dynamic Estimation of Spin Satellites [23] (2019 IEEE)	The synchronization of optical and radar images with particle swarm optimization (PSO)	attitude and spin parameters of target are detected	The fusion method is of suitable for on orbit satellites
Combining Thermal and Visual Imaging in Spacecraft Proximity Operations [24] (2014 IEEE)	object detection from onboard satellite with Extended Kalman filtering (EKF)	distance to target, signatures in both visible and infrared bands, relative attitude(δ)	Combined images in circular orbits are not analyzed

The in-depth analysis of space debris detection methods has been carried out to understand the importance of fusion methods for detection of space debris from the satellite. The space debris features detection analysis concludes that the fusion of optical and thermal image features can prove beneficial for debris detection in sunlit or non-sunlit areas.

III. CONCLUSION

The paper provides detailed state-of-art for space debris detection based on various imaging-based techniques. The methods involve space debris detection using radars, tele-scopes, lasers with appropriate imaging methods. In order for continuous space surveillance tracking to avoid risk of debris collision, robust debris tracking mechanism is required. Thus, on board tracking with image features characteristic of debris is to be implemented. The visible and thermal images of debris provide features like size, shape and temperature for detecting debris. The traditional debris detection method is discussed to lead to the importance of fusion-based debris detection. The survey presented provides understanding of the importance of fusion of visible and thermal image with deep learning for space debris detection with payload cameras. The further research involves detection of high-speed space debris with controlled and uncontrolled features, combining features of optical image and thermal image feature using appropriate Deep learning model.

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