1. <https://www.jpl.nasa.gov/nmp/st6/TECHNOLOGY/star_camera.html>
   1. Star trackers, also known as star sensors or star cameras, are vital devices for spacecraft navigation, providing precise attitude determination by using the fixed positions of distant stars. Since spacecraft cannot rely on terrestrial navigation methods like GPS, star trackers capture images of star patterns and compare them to a preloaded star catalog to calculate the spacecraft’s orientation relative to a fixed reference frame. This continuous process is essential for maintaining alignment needed for communication, power generation, and scientific instrument accuracy. Modern star trackers use advanced optical sensors like charge-coupled devices (CCDs) or active pixel sensors (APS), with APS offering benefits such as lower power consumption and improved durability against space radiation. Wide-field-of-view (WFOV) star trackers capture larger sky areas, enhancing star identification speed. Star trackers typically work with other systems like gyroscopes and Sun sensors to ensure comprehensive and continuous attitude control. Despite their accuracy—often within a few arcseconds—star trackers face challenges such as interference from bright objects like the Sun or Earth, space radiation effects, and motion-induced image blurring. However, advancements in sensor technology, such as machine learning algorithms and APS integration, improve their performance under these conditions. Miniaturization has also enabled their use on small satellites like CubeSats without compromising accuracy. Star trackers are essential across various missions, from Earth observation and planetary exploration to human spaceflight and scientific research. As technology continues to evolve, star trackers will remain crucial for maintaining precise orientation, supporting complex missions, and enabling deeper exploration into the solar system and beyond.
2. <https://solar-mems.com/blog-news/star-trackers-the-heart-of-satellite-stabilization-and-control/#:~:text=A%20Star%20Tracker%20is%20an,%2C%20Earth%20observation%2C%20and%20communication>.
   1. Star trackers are essential optical devices used in satellites to determine their orientation relative to the stars, playing a key role in the Attitude Determination and Control System (ADCS). These devices capture images of the star field using sensitive cameras equipped with CCD or CMOS sensors. Advanced algorithms identify stars by comparing the captured images to an onboard star catalog. By analyzing the positions of the stars, star trackers calculate the satellite’s exact orientation and relay this data to the satellite’s control system, allowing it to maintain or adjust its position. This precise orientation is critical for scientific missions, Earth observation, and communication satellites, where accurate pointing is required. Star trackers provide exceptional angular precision—down to a few arcseconds—offering greater accuracy than other methods like sun sensors or magnetometers. They also enhance satellite autonomy by reducing the need for ground intervention, which is especially beneficial for deep-space missions. However, star trackers face challenges, such as susceptibility to space radiation and interference from bright celestial bodies like the Sun. Advances in sensor technology and artificial intelligence are improving their resilience and performance, allowing for faster and more efficient star identification. As technology continues to evolve, star trackers will remain vital for ensuring the success of modern and future space missions.
3. <https://sites.psu.edu/takugoamy/aeroastro-work/the-design-and-operational-principle-of-star-trackers/>
   1. Star trackers are crucial for spacecraft navigation, providing precise orientation by using distant stars as fixed reference points. In space, where conventional cues like gravity or the horizon are absent, spacecraft must rely on celestial bodies for guidance. While the Earth, Moon, and Sun can serve as references, spacecraft operating outside Earth's sphere of influence or requiring higher pointing accuracy need more consistent markers. Star trackers address this need by capturing images of stars and comparing them to an onboard star catalog. The tracker records the direction in which the image is taken and cross-references it against known star positions to determine the spacecraft's orientation. This orientation data is sent to the spacecraft’s attitude control system, allowing for real-time adjustments. The system works continuously, ensuring rapid updates that minimize discrepancies between the current position and the star-tracked orientation. Star trackers are now a standard component on most modern spacecraft due to their reliability and precision. A typical star tracker consists of several key components: a stray light shield, an optical system, an image definition device, a detector, and supporting electronics. The stray light shield blocks unwanted light from the Sun, Earth, and Moon, preventing interference with the detection of faint stars. The optical system focuses incoming starlight and filters specific wavelengths to improve image clarity. The image definition device restricts the field of view, ensuring that the detector only captures the necessary portion of the image. The detector converts the optical image into an electrical signal, using either an analog image dissector tube or a charge-coupled device (CCD) to process star patterns. Finally, the electronics amplify and filter the signal, removing noise and sending refined data to the spacecraft's computer. There are three main types of star trackers: star scanners, gimbaled star trackers, and fixed-head star trackers. Star scanners use a slit aperture on spinning spacecraft to scan the star field, with accuracy depending on the slit size and spin stability. Gimbaled star trackers, mounted on movable platforms, offer a wider field of view and are used on spacecraft requiring complex maneuvers, though their mechanical parts limit their lifespan. Fixed-head star trackers use a photosensitive array to electronically scan star patterns, offering high sensitivity without moving parts but being vulnerable to radiation and magnetic interference. As space exploration advances, star tracker technology continues to evolve, enhancing accuracy and durability for future missions.
4. Spratling IV, B. B., & Mortari, D. (2009). A survey on star identification algorithms. *Algorithms*, *2*(1), 93-107.
   1. The paper provides an in-depth examination of star identification algorithms, which are vital for spacecraft attitude determination. It begins by tracing the historical development of these algorithms, starting with the first CCD-based star tracker introduced in 1976. The authors discuss the inherent challenges in accurately matching observed inter-star angles and the necessity for efficient computational methods to process large datasets. Notable contributions from researchers like David Anderson and Liebe are highlighted, with Anderson's work focusing on enhancing matrix multiplication efficiency through permutation matrices and array processors, while Liebe's approach connected feature selection to database search time, allowing for a more streamlined identification process. The paper categorizes the algorithms into several types based on their operational requirements. Lost-in-space algorithms operate without any prior attitude information, while recursive algorithms can utilize some prior estimates to improve identification accuracy. The authors emphasize the significance of independent pattern features derived from inter-star angles, noting that while a star pattern can yield numerous inter-star angles, only a limited number are truly independent due to their interdependencies. The discussion also includes the role of star magnitude information, which can provide additional independent features, although it may introduce some inaccuracies in the identification process. Furthermore, the paper delves into the practical applications of these algorithms beyond mere attitude determination, extending to areas such as star gyros, space surveillance, and navigation systems. The authors highlight the ongoing advancements in algorithm performance, particularly in terms of speed and robustness, which are crucial for real-time processing in dynamic environments. They conclude by emphasizing the importance of continuous research and development in star identification algorithms to address emerging challenges and improve the reliability of spacecraft navigation and control systems in increasingly complex operational scenarios.
5. Ho, K. (2012). A survey of algorithms for star identification with low-cost star trackers. *Acta Astronautica*, *73*, 156-163.
   1. The paper focuses on the development of algorithms for lost-in-space star identification, specifically designed for small satellites like Nano-JASMINE. It highlights the significance of accurate star identification for maintaining attitude stability, which is crucial for high-level missions. The study emphasizes that small satellites can leverage advanced technologies traditionally reserved for larger satellites, thereby enhancing their operational capabilities and mission success rates. The proposed algorithms consist of two main phases: feature extraction and catalogue search. In the feature extraction phase, the paper suggests using extended and combined images to improve the identification of star features. The catalogue search phase employs a Group Catalogue approach, which is shown to be the most efficient method for matching extracted features with known star positions. The algorithms are tested through simulations, demonstrating their robustness against various errors that may occur during the identification process. Furthermore, the paper discusses the implications of these algorithms for the design of star trackers in small satellites. By allowing for "unequal" star trackers, the proposed system enables a more cost-effective approach to satellite design without compromising performance. The results indicate a significant improvement in the success rate of star identification, which is essential for the precise attitude control required in missions like those of Nano-JASMINE, ultimately contributing to the advancement of small satellite technology in the aerospace industry.
6. Hashemi, M., Mashhadi, K. M., & Fiuzy, M. (2019). Modification and hardware implementation of star tracker algorithms. *SN Applied Sciences*, *1*(12), 1524.
   1. The paper discusses the development and evaluation of algorithms for star trackers, which are essential for determining the attitude of satellites. It outlines a semi-physical testing approach where images of the night sky are captured under various orientations, allowing for the comparison of calculated attitudes against known correct values. The study emphasizes the importance of accurately identifying stars and calculating their positions to improve the reliability of attitude determination. A significant focus of the research is on modifying the k-vector searching technique to enhance the efficiency of star identification. By arranging the database of star positions and employing a fitted quadratic curve for searching, the authors achieved a threefold reduction in the searching range, resulting in a 14 times faster algorithm execution time. This optimization is crucial for real-time applications in satellite navigation, where quick and accurate processing is necessary. The paper also highlights the use of the Hipparchus catalog for star identification, which was filtered to improve processing speed and reduce data load. The results indicate that selecting brighter stars significantly impacts the accuracy of attitude determination, leading to the conclusion that adaptive approaches in centroiding can enhance performance. Overall, the research contributes valuable insights into improving star tracker algorithms, which are vital for the successful operation of satellites in orbit.
7. Liu, M., Wang, H., Yi, H., Xue, Y., Wen, D., Wang, F., ... & Pan, Y. (2022). Space debris detection and positioning technology based on multiple star trackers. *Applied Sciences*, *12*(7), 3593.
   1. The document discusses a method for detecting moving targets using temporal information frames, which are created by analyzing a sequence of images. In this approach, moving targets are identified as connected domains within the temporal information frame, where data points share the same time markers. The process begins with the removal of "stars," which represent different temporal information clusters, allowing for a clearer focus on the moving targets' time and position information, essential for accurate target detection. After stellar removal, the algorithm assesses the trajectory of the moving targets by evaluating the angles between consecutive points (P2, P3, and P4). If the angle between these points is less than a predefined threshold (Angleth), they are confirmed as part of a true trajectory; otherwise, they are classified as a false trajectory. This step is crucial for ensuring that only valid movements are tracked, which enhances the reliability of the detection process.To estimate the velocity of the moving target, the mean distance between specific points (D23 and D34) is calculated, providing a basis for predicting future positions (P1e and P5e). A tracking window is then established around these estimated positions to monitor the target's movement. The method assumes that the data samples from the image sequence are independent Gaussian random variables, and the noise is treated as Gaussian white noise, which simplifies the analysis and enhances the accuracy of the target detection process.
8. Burroni, T., Servidia, P., Thangavel, K., & Sabatini, R. (2024). Constellation of Formations for Space Domain Awareness using Star Tracker/GNSS Integration. In *IAA Latin American Congress on Small Satellites, Technologies and Applications, Salta, Argentina, November 4th to 9th*.
   1. The conference paper titled "Constellation of Formations for Space Domain Awareness using Star Tracker/GNSS Integration" discusses the enhancement of Space Domain Awareness (SDA) through the utilization of advanced tracking methodologies for Resident Space Objects (RSOs). The authors, Tomás Burroni and Kathiravan Thangavel, propose a framework that integrates star trackers with Global Navigation Satellite Systems (GNSS) to improve the tracking capabilities within distributed satellite systems (DSatS). The paper emphasizes the significance of autonomy in the operations of spacecraft, aiming to optimize the duration for observing RSOs to yield better data and insights. The document outlines a model for organizing satellite formations within a constellation, consisting of multiple formations, each with a leader and several followers. This structure allows for efficient tracking and monitoring of RSOs, as described by the formation parameters, which include the number of satellites in each formation and their spatial arrangement. The paper illustrates how the constellation and its respective formations can be strategically designed to maximize the observational capabilities and minimize risks associated with tracking in Low Earth Orbit (LEO) environments. Furthermore, the paper contributes to the discourse on the operational aspects of autonomous satellite systems, highlighting the need for trusted operations in complex space environments. It references previous works related to autonomous operations and machine learning applications in satellite systems, indicating a broader context of research and development in this field. The findings are positioned to influence future advancements in satellite technology and operations, particularly in enhancing surveillance and tracking of space objects.
9. Thangavel, K., Burroni, T., Servidia, P., Spiller, D., & Sabatini, R. (2025). Enhancing Space Domain Awareness Using Star Trackers in Satellite Formations. *IEEE Transactions on Aerospace and Electronic Systems*.
   1. The document discusses advancements in Space Domain Awareness (SDA), focusing on the monitoring and tracking of Resident Space Objects (RSOs) such as satellites and space debris. It emphasizes the importance of precise detection and identification of these objects to ensure a secure and sustainable space environment, which is critical for future space missions. The authors propose a novel algorithm that integrates data from multiple satellites within a formation, utilizing star trackers and Global Navigation Satellite System (GNSS) receivers. This integration allows for real-time determination of the orbital parameters of RSOs, enhancing the accuracy of their tracking and identification. The proposed methodology leverages the concept of satellite formations, where multiple satellites observe the same RSO simultaneously. This multistatic acquisition approach enables the use of parallax effects to improve positional estimates of the RSO. By having satellites in close proximity, the observations can be more coherent, leading to better accuracy in orbit determination. The document highlights the benefits of using star trackers, which rely on star patterns for attitude determination, and discusses how this technology can be enhanced by incorporating additional information from brighter objects, such as planets, to improve RSO detection. The authors also differentiate their approach from previous methodologies, noting that their algorithm does not rely on certain assumptions about motion and provides a simpler closed-form solution. Simulation results presented in the document indicate that the proposed algorithm can significantly enhance the precision of RSO orbit determination compared to traditional methods. The authors argue that this approach not only benefits Earth Observation (EO) missions but also plays a crucial role in enhancing Space Traffic Management and Space Situational Awareness. By improving the ability to track and predict the behavior of RSOs, the research contributes to the broader goal of maintaining a safe operational environment in space, particularly as the number of satellites and debris in orbit continues to grow. Overall, the document underscores the potential of advanced satellite systems and algorithms in addressing the challenges of space debris and traffic management.
10. Qashoa, R., Suthakar, V., Chianelli, G., Kunalakantha, P., & Lee, R. S. (2024). Technology Demonstration of Space Situational Awareness (SSA) Mission on Stratospheric Balloon Platform. *Remote Sensing*, *16*(5), 749.
    1. The study presented in the document focuses on advancing Space Situational Awareness (SSA) through the development and testing of a dual-purpose star tracker system, which was launched on a stratospheric balloon platform. SSA is critical in the context of increasing numbers of resident space objects (RSOs) in Earth's orbit, as it involves the detection, tracking, identification, and characterization of these objects to mitigate collision risks. The research team, affiliated with York University, aimed to leverage existing star tracker technology, which has traditionally been used for attitude determination in spacecraft, to also serve the purpose of RSO imaging. This dual-use approach not only enhances the capabilities of current systems but also reduces the need for new, costly equipment to be launched into space, thereby making the technology more accessible and efficient. The mission, named Resident Space Object Near-space Astrometric Research II (RSONAR II), was successfully launched in August 2023. The payload included a sophisticated imaging system with two main cameras that could adjust imaging parameters in real-time. This flexibility allowed the researchers to evaluate the effectiveness of different configurations for RSO imaging under varying conditions. During the mission, the team collected a substantial dataset, including over 95,000 images captured under diverse light conditions and altitudes. These images are being annotated and utilized for the development of algorithms aimed at improving RSO detection and characterization. The research also involved a comparison study between two different imaging systems, assessing their capabilities for stellar observation and RSO detection, which is crucial for refining the algorithms used in SSA. In addition to the technical advancements, the study highlights the importance of effective data management and communication during the mission. The researchers implemented a downlink capability that allowed them to monitor the performance of the payload in real-time, which is particularly vital for long-duration stratospheric missions. An important finding from the analysis was the advantage of using standard microSD cards over weather-rated ones, as the internal temperatures of the payload supported the operation of these standard cards, which also offered faster writing speeds at lower costs. Looking ahead, the team plans to further process the data collected during the mission and incorporate uplink commands to enable real-time adjustments based on the data received. This iterative approach to mission management and algorithm development is expected to enhance the overall effectiveness of SSA efforts, contributing to safer space operations and better management of the increasing number of objects in orbit.