The Design and Operational Principle of Star Trackers

Unlike other navigational environments, outer space offers very few options for reference when attempting to orient oneself. For one, gravity no longer offers the concept of up or down, and thus a spacecraft must reference its orientation with the position of celestial bodies. In many cases these bodies are the earth, moon, and sun. While the earth or moon may function as adequate reference points some spacecraft, spacecraft operating outside of sphere of influence of earth or require higher pointing accuracy need other reference points. Star trackers solve this problem by allowing spacecraft to use distant stars as a reference point for celestial travel and are employed on almost all major spacecraft today. Figure 1 for example shows the powerful star tracker on the space shuttle Columbia, however star trackers come in all shapes and sizes. This paper will give a basic overview on how star trackers work, the components involved and the various types of star tracker in use today.

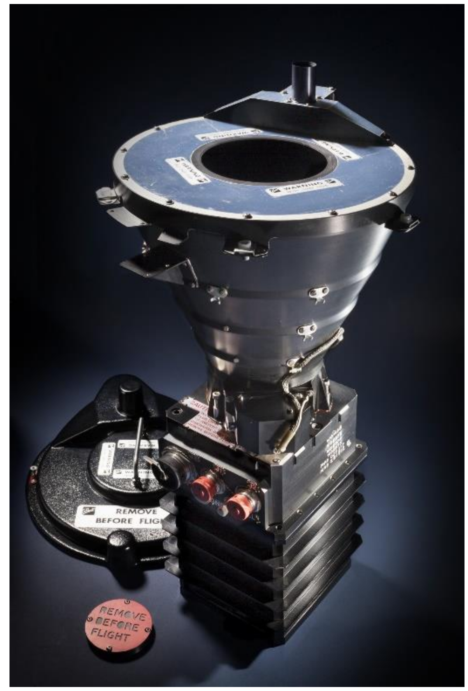

Figure 1 *The Star tracker on the Space Shuttle Columbia[1]*

How a Star Tracker works:

Broadly speaking a star tracker works similar to facial recognition or real-time translation software found in cellphones. Figure 2 shows the basic operational principle behind a star tracker. An image is taken by the sensor of the stars while recording the direction at which the picture was taken by the spacecraft. The image is then analyzed, and cross referenced by a database of the position of stars. Once a match is found, it is used along with information of the current orientation of the spacecraft from other sensors on the spacecraft to determine the direction the craft is pointing. This data is then sent to the spacecraft's attitude control system for changes in the spacecraft's orientation. All this this done in a split second so that the onboard computer doesn't have to account for large discrepancies between the current orientation and orientation of the spacecraft when the picture was taken.

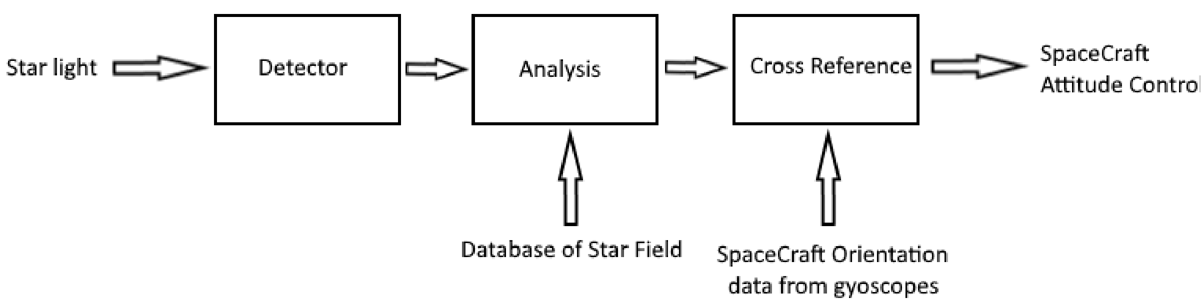

Figure 2. *Basic flowchart of how a star tracker functions.*

Basic components of a Star Tracker.

While different types of star trackers may work on slightly different principles, most star trackers include the following basic components as seen on Figure 3.

Stray light shield: Star trackers must track dim stars, and thus stray light can add a large amount of error or even render star trackers inoperable. Light from the Sun, Earth, moon, and reflections off the spacecraft itself are major sources of stray light. For example, most star trackers are inoperable within 60 degrees of the sun, and none are operable within 30 degrees. To mitigate the issue of stray light, a large conical shield, much like those seen on conventional cameras, is placed at the end of the sensor.

Optical System: The optical system is a set of lenses which converges the image of the star field into focus. Furthermore, the system filters the different wavelengths of light from the stars such that individual stars can be identified from their characteristic wavelengths. Wavelengths which can heat the sensor are also filtered out to ensure the stability of the detector.

Image Definition Device: The detector rarely requires the full image, and often cannot handle so much light. Therefore, the image definition device restricts the image depending on the type of star tracker. The device is often simply a set of thin slits on a plate or combined with the detector in an image dissector tube.

Detector: As the name suggests, a detector takes the light from the optical system and "detects" it, taking the optical image and turning it into an electrical signal. Broadly speaking there are two types of detectors, an analog image dissector tube and the charge coupled device which directly converts the signal into digital pixels.

Electronics: Finally, the electronics of the sensor amplifies and further filters the signal of noise. Specialized sensors may make further changes to the signal depending on the application. This signal is then sent to the onboard computer for analysis.

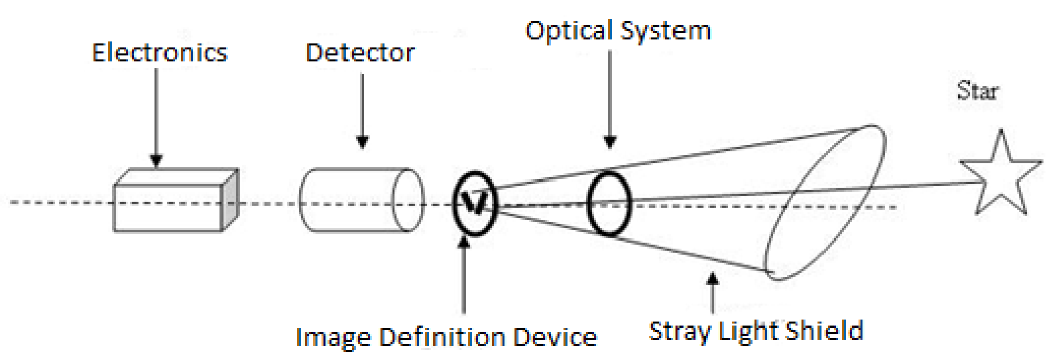

***Figure 3**. The basic components of a Star tracker. The particular type of star tracker is a star scanner. [2]*

Types of Star Trackers

While most star trackers are relatively similar there are three main types of star trackers currently in use, each with their own advantages and disadvantages

Star Scanners: Star Scanners are star trackers fixed to the side of a spinning spacecraft; an example of one can be seen in Figure 3. The aperture of the camera is a small slit, and as the spacecraft spins the slit can "scan" a view of star field around the spacecraft. The accuracy of this scanner is dependent on the size of the slit, a larger slit allowing for a larger field of view and thus higher accuracy. Another key factor is the nature of the spin of the craft, if the spin of the spacecraft deviates from a uniform, rigid body spin (meaning no wobble) accuracy is decreased. This has historically not been an issue, however as spacecraft technology continues to improve spacecraft with non-uniform spin have begun to emerge.

Gimballed Star trackers: Gimbaled star trackers work differently from other types of star trackers, and instead usually operate on select few target stars. These stars trackers are often found on spacecraft which work in a variety of different orientations and altitudes around earth. The gimbal allows for the optical system to have an effective wider field of view than other types of star trackers, allowing for spacecraft to perform more complex maneuvers and orientations (Figure 4). However, the mechanical nature of the gimbal reduces the lifetime of the sensor in comparison of the Star Scanners and head Star Trackers. Spacecraft which do not spin and remain inertially fixed (such as geostationary satellites) often employ gimballed star trackers. The targeting nature of the gimballed star tracker on few stars can lead to errors such as targeting the wrong star or being affected by stay light, such as from space craft debris.

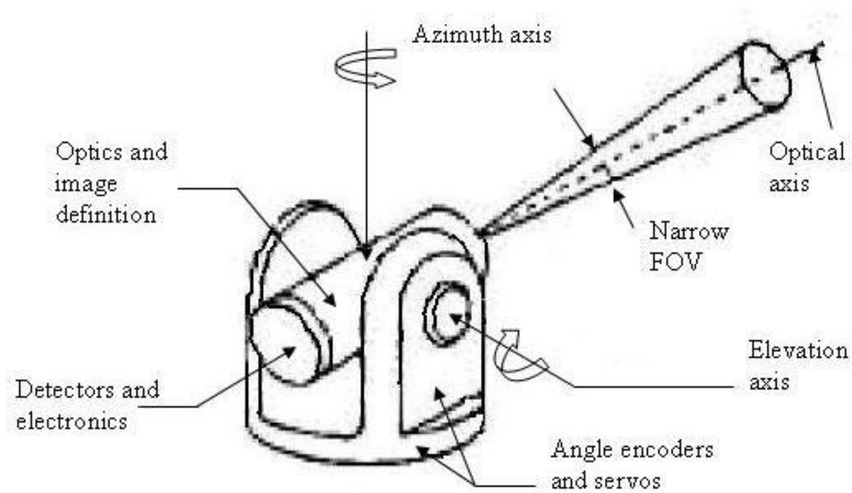

Figure 4. A simplified diagram of a gimbaled star tracker [2]

Head Star trackers: Fixed head trackers differ from the other two type of star trackers by having an electronic searching and tracking capabilities directly built within the design of the star tracker, differing from the traditional purely optical star trackers. A simplified diagram can be seen in Figure 5, one should note the greater complexity in comparison to Figure 3. Light from the stars are shown on a photosensitive array which produces a charge pattern identical to the image. This charge pattern is then read into the electronics. Instead of moving the spacecraft or tracker to scan for stars, the scanning is done purely by reading the charge pattern of the photo sensitive array line by line. Once a match is found tracking is engaged on the star pattern until it is out of sight and will begin searching again for a match. However due to the nature of the photosensitive array, it is susceptible to errors and noise due to radiation and magnetic fields. Despite this, Head star trackers boast high sensitivity and mechanical ruggedness due to a lack of moving parts. The accuracy is largely dependent on the field of view of the tracker. A larger field of view is more susceptible to error; however a smaller field of view requires the sensor to be sensitive to dimmer stars.

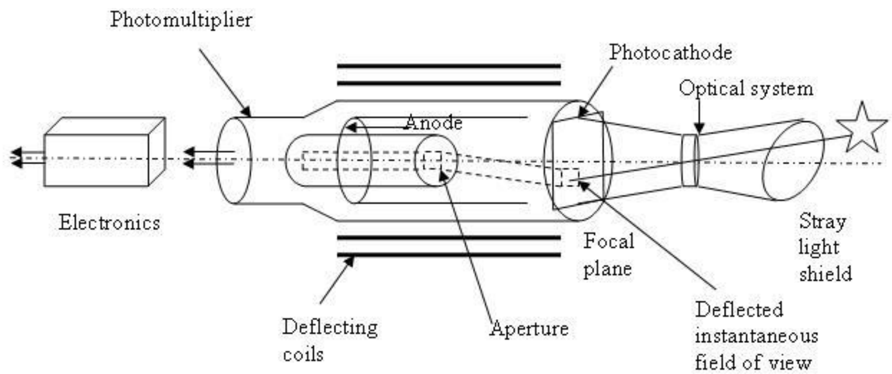

***Figure 5**. A simplified diagram of a head star tracker. [2]*

A look to the future

The technology behind star trackers is constantly changing and improving. The existence of many different types of star trackers is proof of just that. It is inevitable that improvements will continue to be made as humanity looks to the stars and begin to navigate the heavens in earnest. Star Trackers are our sextant and compass in a new age of exploration.

Image Sources:

1. *Smithsonian National Air and Space Museum*
2. *Spacecraft Attitude Determination and Control* (First Edition) by James R. Wertz