Inception of Star Sensors in Attitude and Orbit Control System

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Abstract— Star sensors play an important role in attitude determination for satellites in celestial navigation system (CNS) because it has high accuracy and high reliability devices. The main steps for attitude determination include star point location, star identification and attitude tracking Star tracker. A 'Star Sensor' that determines the orientation of a spacecraft with respect to stars is one of the important contributions from the scores of private and public sector units that have played a key role in the Chandrayaan-2 Moon mission. The 'Star Sensor' has been developed by Hyderabad-based Ananth Technologies Ltd (ATL), which has for long been associated with the satellite missions of the Indian Space Research Organisation (ISRO). The Chandrayaan-2 mission comprises the GSLV-MkIII launcher, the Orbiter and the Lander.

Keywords: Orbit Control System, celestial navigation system (CNS), Star Trackers Lights the Way

I. INTRODUCTION

A star tracker is an optical device, it estimate the positions of stars using photocells or a camera. As the positions of many stars have been measured by astronomers to a high degree of accuracy, a star tracker on a satellite or spacecraft may be used to determine the orientation (or attitude) of the spacecraft with respect to the stars, In order to do this, the star tracker must obtain an image of the stars, measure their evident position in the reference frame of the spacecraft, and identify the stars so their position can be compared with their investigated absolute position from a star catalog. A star tracker may include a processor to recognize stars by comparing the pattern of observed stars with the known pattern of stars in the sky.

Fig. 1: An image of Orion's Belt composited from digitized black-and-white photographic plates recorded through red and blue astronomical filters, with a computer synthesized green channel. The plates were taken using the Samuel Oschin Telescope between 1987 and 1991.

II. HISTORY

In the 1950s and early 1960s, star trackers were an important part of early long-range ballistic missiles and cruise missiles, in the era when inertial navigation systems (INS) were not sufficiently specific for intercontinental ranges.

Selecting a guide star depends on the time, due to the Earth's rotation, and the location of the target. Generally, a selection of several bright stars would be used. For systems based merely on star tracking, some sort of recording tackle, typically a magnetic tape, was pre-recorded with a signal that represented the angle of the star over the period of a day. At launch, the tape was forwarded to the appropriate time.

During the flight, the signal on the tape was used to unceremoniously position a telescope so it would point at the look forward to position of the star. At the telescope's focus was a photocell and some sort of signal-generator, typically a spinning disk known as a chopper. The chopper caused the star to repeatedly appear and disappear on the photocell, producing a signal that was then smoothed to produce an alternating current output. The phase of that signal was compared to the one on the tape to produce a guidance signal.

The system could be further improved by combining it with an INS, in which case additional circuitry on the INS generated the reference signal, eliminating the need for the separate tape. These "stellar inertial" systems were especially common from the 1950s through the 1980s, although some systems use it to this day.

III. STAR TRACKERS LIGHTS THE WAY

The idea of a Star Tracker probably can be traced back to the early sailors who used to navigate the open seas. The opinion is they use star field patterns in order to tell them where they're pointed, at that time they are sailing from east to west or north to south, whatever direction they were going. The Star Tracker is a lot more complicated in that it operate the entire star field pattern to provide attitude knowledge or, in the laymen's term, more of the direction in which the spacecraft is pointing while it is orbiting the Earth or doing wherever its science mission requires it to do. So, essentially, it's an optical device to access the eyes of the spacecraft. The Star Tracker was built for the Lunar Reconnaissance Orbiter and the Solar Dynamics Observatory, both NASA missions in Florence, Italy by Galileo Avianica. They write their own software used to operate the star trackers, ground all of their optics, fabricate the structures, and assemble and test the electronics.

Once the star trackers are assembled, Galileo Avionica works with NASA engineers in order to ensure that the star trackers are built to achieve their performance prerequisite as well as their environmental requirement. The LRO and SDO missions both use two star trackers for redundancy, so that if you get a fair unit in one, the second star tracker will be used as the backup.

Also, the use of two star trackers provided added or increased performance rightness so that the spacecraft will have a more accurate compression of where it's pointed while its orbiting either the moon, the Earth, or the Sun. NASA is an educational extension of the government.

Through all the information we get from all our various missions, we learn things about our Earth, space, how space effects Earth, and our changing environment. All of these things are important to everyone in the world, whether we know it or not, and the importance of star tracker, is they act as the eyes of the satellite to let the satellite know where it's going in order to get the information we need.

IV. CURRENT TECHNOLOGY

Currently many models are available. Star trackers, which require high sensitivity, may become confused by sunlight reflected from the spacecraft, or by exhaust gas plumes from the spacecraft thrusters (either sunlight reflection or contamination of the star tracker window). Star trackers are also liable to a variety of errors (low spatial frequency, high spatial frequency, temporal...) in addition to a variety of optical sources of error (spherical aberration, chromatic aberration, etc.).

There are also many potential sources of confusion for the star identification algorithm (planets, comets, supernovae, the bimodal character of the point spread function for adjacent stars, other nearby satellites, point-source light pollution from large cities on Earth,). There are roughly 57 bright navigational stars in common use. However, for more complex missions, entire star field databases are used to determine spacecraft orientation. A typical star catalog for high-fidelity attitude determination is originated from a standard base catalog (for example from the United States Naval Observatory) and then filtered to remove problematic stars, for example due to apparent magnitude variability, color index uncertainty, or a location within the Hertz sprung-Russell diagram implying unreliability. These types of star catalogs can have thousands of stars stored in memory on board the spacecraft, or else processed using tools at the ground station and then uploaded.

Fig. 2: Pleiades: The Seven Sisters Star Cluster

The first Star Tracker ASTRO 1 has proven its space competence on the space station MIR for more than 15 years. Today, the ASTRO 15 Star Tracker developed for long-term missions with high accuracy pointing is successfully operating e.g. on DirecTV's satellites. Application examples for the company's ASTRO 10 Star Tracker are the Earth Observation programs Terra SAR-X as well as Tandem-X and the German SARLupe. The next generation star sensor ASTRO APS is based on innovative CMOS detector technology and will be integrated on the European large telecom satellite AlphaSat.

More than 60 flight units of the Precision Sun Sensor PSS are operatingvery successfully on space missions since 1997, e.g. on several Alcatel Spacebus 3000 satellites. The successor model FSS (Fine Sun Sensor) is an analogue sun sensor with a high degree of flexibility to cope with a large variety of customer requirements and has been delivered for Radarsat-2, Cosmo-Skymed and Galileo GSTB-V2.

The unmanned transfer vehicles ATV (ESA) and HTV (JAXA), but also the American "Cygnus" approach the International Space Station ISS with the help of the Rendezvous- and Docking Sensor RVS.

A. ASTRO 10

1) Autonomous Star Sensor

The ASTRO 10 is an autonomous star sensor for a wide range of LEO and GEO applications.

Its Electronic Box is separated from the Optical Head for a flexible accommodation on the spacecraft, giving minimum impact on the S/C structure with respect to thermal and mechanical stress and therefore providing maximum pointing accuracy.

B. ASTRO 15

1) Autonomous Star Sensor

The ASTRO 15 combines a high degree of flexibility with outstanding features for lifetime, reliability and robustness. The sensor is a flight proven, autonomous star tracking system for long-term GEO and LEO missions on telecom, science and Earth observation satellites.

More than 130 flight units of the ASTRO 15 sensor have been ordered for geostationary communication / Earth observation satellites. More than 50 Flight Models are operating successfully in orbit. The ASTRO 15 has been selected as the standard star sensor for Boeing's 702 platform.

Jena-Optronik is the first German company awarded "Supplier of the Year 2006" from the US technology group Boeing. Boeing selected the Jena-based company as one of only 11 chosen from a field of more than 27,000 suppliers in nearly 100 countries around the world. This award from Boeing is the company's premier supplier award, presented annually to its top suppliers for their commitment to excellence and customer satisfaction. The winning suppliers were chosen based on statistical measurements of quality, on-time delivery, post-delivery support and cost for performance in 2006.

ASTRO 10 has a mission lifetime of more than 12 years and has been designed on the basis of more than 20 years' experience in star sensor development. The ASTRO 10 is fully space qualified and operates successfully in orbit without any failure.

Combining low weight and power consumption with a very attractive cost-performance ratio, the ASTRO 10 is an ideal product for all satellite missions.
Jena-Optronik GmbH has been awarded as "Master Supplier" by Astrium fir ASTRO 10 on Tandem-X due to the outstanding performance, schedule and cost.

C. ASTRO APS

1) Active Pixel Sensor

ASTRO APS is an autonomous star sensor with the most advanced radiation hard CMOS Active Pixel Sensor (APS) detector technology.

A single box design has been chosen with minimized dimensions, low mass and low power consumption while maximizing the ease of integration on the spacecraft. ASTRO APS shows high reliability and radiation hardness by careful selection of EEE Parts, reduced number of components and special software algorithms to cope with radiation events.

The technical key parameters of the APS based star sensor are the low mass budget with approx. 2kg, the low power consumption with approx. 5W and the attitude quaternion accuracy of <1arcsec (1sigma). These data define a new level of compactness compared to CCD-based star sensors for the GEO telecom market (>18 years life time, <25 years radiation robustness for GEO missions).

The improvements in dimensions and performance are realized with the replacement of the CCD detector by the APS detector technology. The mass and envelope benefit is based on the very high functional integration of the APS detectors. The whole analogue read-out and sampling electronics is placed on the detector chip. This saves PCB area compared to CCD-based systems. The parts count for an APS based star sensor is reduced accordingly. Along with that, the unit costs are reduced and the system reliability is increased. The concept is modular and allows the use of either the STAR1000 or the HAS2 detector chip.

A Flight Model of ASTRO APS is integrated on the European large telecom satellite AlphaSat and demonstrates its outstanding capabilities since June 2013. ASTRO APS has been contracted by numerous satellite integrators for the most diverse space missions.

D. ASTROgyro

An integrated and cost efficient attitude sensor system. The ASTROgyro is an innovative system combining the advantages of both star sensors and gyroscopes in one product. Primary Benefits of the ASTROgyro include:

Direct availability of both raw and merged data from all sensors (gyro & star sensors)

Full redundancy (two star sensors and, for each axis, two gyro channels)

Identical quality of attitude measurement for all axes (typ. 1 arcsec (1σ)), including the out-of-plane axes of the star sensors

1) Outage and Agility Bridging

Coverage of a wide range of rates up to 20°s^{-1}
Facilitation of AOCS FDIR (Fault Detection Isolation and Recovery)
Optional use as Ultimate Safe Mode (USM) Sensor
ITAR-free design available
Suitable for LEO, MEO, and GEO Orbits

Due to the direct broadband communication between the ASTRO APS and the gyroscope, the signal noise of the star sensor is significantly reduced especially at higher angular rates. The gyroscope, in return, benefits from attitude measurement based in-situ re-calibration of drifts, scaling errors, and temperature effects.

The ASTRO APS star sensor has space proven heritage on LEO, MEO, GTO, and GEO orbits. The inertial reference unit has been designed to complement the ASTRO APS star sensor on all these orbits.

Additionally to the technical benefits mentioned above, customers will experience reduced integration and alignment efforts resulting in cost savings during the satellite AIT process. Thus ASTROgyro is the perfect solution for your AOCS needs

The principle of operation is to image stars and match the observed constellation to a star catalogue. Calibration of the star sensor is essential for the accurate determination of the angular distance between stars and to pin point the star centroids.

A High Performance Star Sensor System for Full Attitude Determination on a Microsatellite W.H. Steyn, M.J. Jacobs and P.J. Oosthuizen Department of Electronic Engineering, University of Stellenbosch Stellenbosch 7600, South Africa

V. Conclusions and Future Work

In conclusions, we studied new and exciting application of digital image processing which is helpful for Satellite Communication System. In this paper we look basic things on star tracker. We studied the initial steps required to implement the low cost with potential high-accuracy star tracker system. For coming time, we would like to research possible automation process such as the Pyramid algorithm and neural network computing. Also we actually work on Star tracking system performance.

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