DEVELOPMENT AND TESTING OF A FULLY AUTONOMOUS STAR TRACKER

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ABSTRACT

This paper presents the working progress for the development, and testing of a third generation Star Tracker system. FAST (Fully Autonomous Star Tracker) is a sensor capable of real-time autonomous attitude measurements. The full autonomy is guaranteed by enhanced accuracy and sensitivity, and by capability of self-selection among different operating modes.

1. INTRODUCTION

Recently, technical and scientific communities have pointed out the importance of mini and micro satellite missions. Following this trend in space technology, the authors have designed and developed a prototype of a fully autonomous attitude sensor. The whole prototype has been realized to the extent of develop a compact and modular device, which, due to the low power consumption and lightness, is suitable for any small spacecraft.

2. HARDWARE DESCRIPTION

A prototype of the hardware segment has been realized starting from the enhancement of basic features of third generation star trackers.

Basically, FAST is composed of three main sub-systems: image forming system, image sensor, image acquisition and processing electronics. Their main characteristics are reported in Table 2.1.

Parameters	**Values**
Field Of View	15.4°×13°
Effective Focal Lenght	27mm
f-number	3.8
Star sensitivity	Up to 6 M_v
Image sensor type	Interline transfer CCD
Image sensor format	752 ×582 pixel
Instantaneous Field Of View	66″×63″
Angular accuracy	< 1″
Data transfer rate	11MB/sec
Power consumption	< 5 W
Mass	1.1 kg

Table 2.1: FAST hardware characteristics and expected performances.

The image forming system is a two-element optical device that has been realized as a symmetrical combination of simple plano-convex lenses, in order to obtain a system suited for infinite conjugates [1]. The lenses morphology and positions have been chosen in such a way to minimize symmetrical and non-symmetrical aberrations (fig. 2.1). FAST uses an interline transfer CCD image sensor whose sensitivity is enhanced by means of HAD (Hole Accumulation Diode) technology. The high sensitivity CCD sensor combined with a high light gathering (f-number < 4) and a wide field of view (15.4°×13°) allows the system to reveal stars up to the sixth magnitude, thus getting a large number of stars in a single acquisition and reducing the risk of misidentification errors.

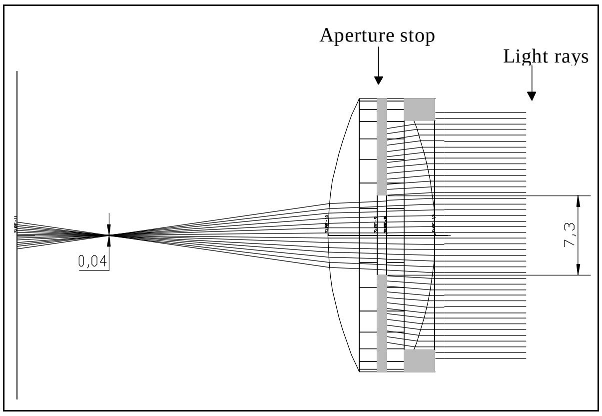

Fig. 2.1– Optical system sketch showing the ray tracing. The measures shown are in millimeters.

The high accuracy in star angular position measurement has been obtained combining a high number of CCD sensitive elements with a slight defocusing, so that star spot is extended over an area of 5x5 pixels, in order to apply centroiding technique [2]. As a matter of fact, the position on CCD plane of the area center of the image can be estimated with an accuracy of 1/100 the pixel linear extent, thus allowing an angular accuracy of almost 1/100 IFOV to be attained.

The image sensed by the CCD device is read out in CCIR video format. The frame grabber used has a transfer rate of 11MB/sec thus allowing the system to acquire up to 25 fps in CCIR video format.

3. SOFTWARE SEGMENT

3.1 On board Star Catalog generating and testing

In order to satisfy the full autonomous requirement, FAST catalog of 2500 stars has been extracted by the Skymap Catalog [3] to uniformly cover on the celestial sphere and enclose all the sensor detectable stars (visible magnitude <7, proper spectral class, etc.). As a matter of fact, the natural distribution of visible stars is far to be spherically uniform because the star density nearby the Milky Way equator is higher than in polar regions. However, Boltzman’s entropy [4] of selected catalog, which tends to zero as the distribution tends to be perfectly uniform, is $\Phi = 0.00054$ instead of $\Phi = 0.00850$ for the whole catalog up to 7th magnitude.

Moreover, it has been evaluated the probability of acquiring enough stars, in each observed sector, to achieve the desired measurements. Since the event of finding a star, among N uniformly distributed, in a sector of the sky under a given solid angle Q (steradians) can be modeled as a Poisson process of mean and variance $\beta = (4\pi N)/Q$, the probability of finding at least k=4 stars (minimum number of stars to achieve a measure) in a single FOV is given by:

$$P(k \geq 4; \beta) = 1 - e^{-\beta}\left[1 + \beta + \frac{\beta^2}{2} + \frac{\beta^3}{3}\right] \tag{3.1.2}$$

In the case of FAST (N=2500 and β=12.132) it results P(k≥4; β) = 0.99633. Because of the non-uniformity in star distribution increasing the star number does not affect the success in recognition.

3.2 Control Algorithm Design

Recent studies [5] on star trackers pointed out that a true autonomous sensor is capable of adapting the type and accuracy of attitude measurement to the spacecraft's attitude conditions. Therefore FAST provides 3 main operating modes, divided into 7 sub-modes, to guarantee a good adaptivity to environmental conditions. These are: High Angular Rate Mode (HAR), Low Angular Rate Mode (LAR) and Safe Mode (SM). Mode and sub-mode transitions are automatic, depending on angular rates, or on command. In particular, HAR to LAR and LAR to HAR transitions are achieved when the angular rate module is below (or above) 0.2°/s. In fact, below this rate stars are recognized as circular blurs instead of elongated strips by FAST CCD sensor.

The main difference between the two modes is the adopted image processing technique. Indeed, in LAR mode FAST outputs both rate and angular measurements through a classical two step sequence. The first step is known as "image registration" and is used to detect star position in the frame, with a precision of 1/10th of pixel, centroiding the light distribution of a star over its field pixels. The second step is a template matching algorithm, known as "triplet method", that permits the identification of observed stars and hence the attitude computation.

When in HAR mode FAST images stars as strips. Thanks to "image segmentation" technique [6], the body reference components of angular rates are derived, which are sufficient for de-tumbling and slewing.

Furthermore, the sub-modes provide increasing accuracy as far as the measurement stability of each main mode grows. Indeed, in order to gain the desired accuracy statistical interpolation techniques are used (least square estimate and Kalman filtering).

4. INDOOR TESTING SYSTEM

Besides procedures for accurate spectral, radiometric and angle measurement calibration, a system for indoor testing of the sensor under the programmed operating modes has been developed. It is based on a computer-controlled high-resolution CRT display. Its primary concern is the validation of the software routines for template recognition and star identification, the correct timing of the overall software system, and the algorithms for the measurement of angular velocity.

The system consists of a 21" CRT display controlled by a Pentium II PC to generate the simulated star field and a collimating optics to make the CRT pixels appear as at infinity. The system set up has been designed in order to make the CRT screen cover the whole sensor FOV. The display and the computer video controller are capable of addressing a maximum of 1800 x 1440 pixels at vertical refresh rates up to 160 Hz, depending on the resolution. The refresh rate is adjustable so that the same number of light bursts is emitted from pixels of any area of the screen during the exposure time.

This guarantees the correct acquisition of relative magnitude when several stars are displayed simultaneously in different regions of the screen.

The pixel output luminosity is adjustable over 256 digital levels. The range of levels 10 ÷ 255 [7] produces simulated visual magnitudes at earth surface varying from 6 to 0, so that more than 200 levels are available in the interval of those detectable by the sensor. In addition, a limited capability of simulating stars having different color temperature is also available by varying the RGB components of the addressed pixels.

A preliminary series of tests is performed for fine mutual calibration of the overall system, with regards to the star tracker measurements of angular position and magnitude of the imaged star-like light sources. Subsequent tests of the software procedures require the generation of static and dynamic star fields, in order to check recognition and identification algorithm efficiency [8] and verify some of the sensor capabilities, such as angular velocity measurements or automatic switching between operating modes. In addition, it is possible to test the sensor operation during phases of a planned mission and include perturbation, such as platform vibrations, partial FOV occultation, observation of the sun or planets.

5. CONCLUSIONS

An innovative star tracker has been described, which is under development thanks to the financial sponsorship of Consortium Technapoli, Napoli, Italy, in the mainframe of a project of technology transfer between research centers and local aerospace industries. This system is aimed at satisfying the requirements of autonomy and flexibility, in order to be used as the only attitude sensor on-board and applied to the widest range of space missions. A brief description of the hardware, software and testing has been given.

Further activities will be addressed to improve the realized system. In particular, the goal of this activity is the realization of the space-qualified model of the sensor, performing in-house qualification tests. Hardware evolution will deal with the development of a multi-head device in order to notably decrease the occurrence of misidentification errors and simultaneously increase the acquisition rate.

6. REFERENCES

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