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MINISTAR: a miniaturized device for the test of star trackers

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ABSTRACT

Star trackers are electro-optical devices that are used to determine the attitude of satellite platforms. The test of star trackers is typically carried out by means of Optical Ground Support Equipment (OGSE). In this paper we present a new prototype of OGSE, the MINISTAR, recently developed by a consortium of Italian enterprises and the Applied Physics Institute of the National Research Council. The MINISTAR is a miniaturized electro-optical device able to generate synthetic images of dynamic star fields for the simultaneous test of up to three star trackers. Their performance can be evaluated in terms of its optics, electronics and on-board attitude software. The MINISTAR is able to perform a dynamic simulation of the apparent motion of the observed scene in order to test the star tracker in a realistic working scenario. It can be placed directly on the star tracker under test and, thanks to its reduced dimensions and weight, the test and validation phase can be performed while the star tracker is assembled on the satellite platform. The MINISTAR is also able to simulate the presence of large objects, such as the Sun, the Earth and the Moon, custom objects and disturbances like cosmic rays and stray light effects. The prototype has been built paying special attention to the employed materials and technology in order to minimize the weight and to ensure its compatibility with most star tracker models available on the market.

Keywords: Star trackers, test equipment, dynamic star fields, OGSE

1. INTRODUCTION

Star trackers are fundamental devices for determining the attitude of a satellite platform in the (inertial) frame reference of fixed stars. Satellite orientation with respect to the Celestial Sphere is extrapolated from the image of the observed star field. In general, there are more than a single star tracker installed on a platform, in order to guarantee a continuous availability of satellite attitude data, both in case of failure and partial/total field of view occupation by large objects, such as the Earth or the Moon. The validation of the star trackers operation is therefore a crucial step for any space mission.

Star trackers are usually tested by using Optical Ground Support Equipment (OGSE) and Electrical Ground Support Equipment (EGSE). OGSE are "optical stimulators" used to test both the optical characteristics of the star trackers and their internal algorithm for star recognition. EGSE are devices which permit the integration and validation of the electrical and software functions of the star tracker. While EGSE are able to test only some parts of the star tracker, OGSE can be used to verify the performance of the system as a whole.

Most OGSE are designed for testing star trackers performance in the laboratory, before their installation on the platform. These systems present a static or a dynamic simulation of the scene observed by the star tracker so that the output of the star tracker can be compared with the input data provided by the OGSE[1, 2]. Some laboratory facilities rely on the use of laser or light emitting diodes (LEDs) to mimic a static scene that portraits the brightest stars of the night sky. An example of such facilities is the Celestial Object Simulator at John Hopkins Applied Physics Laboratory[3], which uses a large number of LEDs to simulate the night sky of the northern hemisphere. Another approach is the one that relies on the use of a large LCD screen showing the simulated star-field viewed by the star sensor. In this case, the laboratory facility can perform either static or dynamic simulations. During static simulations the LCD screen mimics a static star constellation, while during the dynamic simulation LCD screen displays time series of star field scene that takes into account the apparent motion of the observed scene. All these methods are based on some simplifications that can limit the accuracy of the test. Efforts have been made to overcome some of these limitations, such as the radiometric modulation of the source used in the simulation[4].

The validation of star trackers after their assembly on the platform is more challenging and, under some aspects, is still an open problem. A first step forward was provided by the implementation of test systems able to simulate dynamic star fields as those observed during the on-board operational activity. A further improvement was the development of miniaturized test systems to be installed directly on the star tracker. Despite the growing interest aroused by such miniaturized devices, their availability on the market is still very limited. Presently, only few miniaturized devices are available, e.g. the STOS (Star Tracker Optical Stimulation for Sensors) manufactured by Airbus Space Equipment[5] and the Optical Sky Stimulator (OSI) for ASTRO APS star sensors by Jena-Optronik[6]. Both systems simulate a dynamic scene of a star field. These devices use a miniaturized LCD monitor showing the simulated image in apparent motion to the star tracker and an optical system projecting the simulated image in the star tracker optics. These systems can simulate large non-star objects and different disturbances (like stray light and the effects due to charged particles). They can be used either in open-loop configuration for sensor test or in close-loop configuration to test the behavior of the star tracker operating in a realistic scenario.

In this paper, we present a new OGSE prototype, the MINISTAR, recently developed by a consortium of Italian enterprises and the Applied Physics Institute of the National Research Council. The MINISTAR is a miniaturized electro-optical device able to generate synthetic images of dynamic star fields. Its innovative design permits the simultaneous test of multiple star trackers, both for optics, electronics and on-board attitude software. The MINISTAR is able to perform a dynamic simulation of the apparent motion of the observed scene in order to test the star tracker in a realistic working scenario. It can be placed directly on the star tracker under test and, thanks to its reduced dimensions and weight, the test and validation phase can be performed while the star tracker is assembled on the satellite platform. The MINISTAR is also able to simulate the presence of large objects such as the Sun, the Earth and the Moon, custom objects and disturbances such as cosmic rays and stray light effects.

2. THE MINISTAR PROTOTYPE

2.1 Prototype's description

A block diagram of the MINISTAR prototype is outlined in Figure 1. The prototype consists of the main following blocks:

- *Star field simulation software*. The simulation procedure needs as input: a star catalogue (star magnitude and position), the orientation of the satellite platform and the star tracker attitude with respect of platform. The output of the procedure is the simulated star field that will be depicted on a display.

- *Opto-mechanical system*. The simulated star field is projected in the star tracker's field of view by means of a collimating optical system. The opto-mechanical assembly permits an accurate coupling between the MINISTAR device and the star tracker.

- *Processing unit and electronics.* This module generates the synthetic star field scene and renders it on the display. The processing unit controls the correct operation of the MINISTAR and permits the test and the validation of the star tracker.

Figure 2 shows the assembled MINISTAR prototype (Figure 2A) and the monitor with the rendered star-field (Figure 2B).

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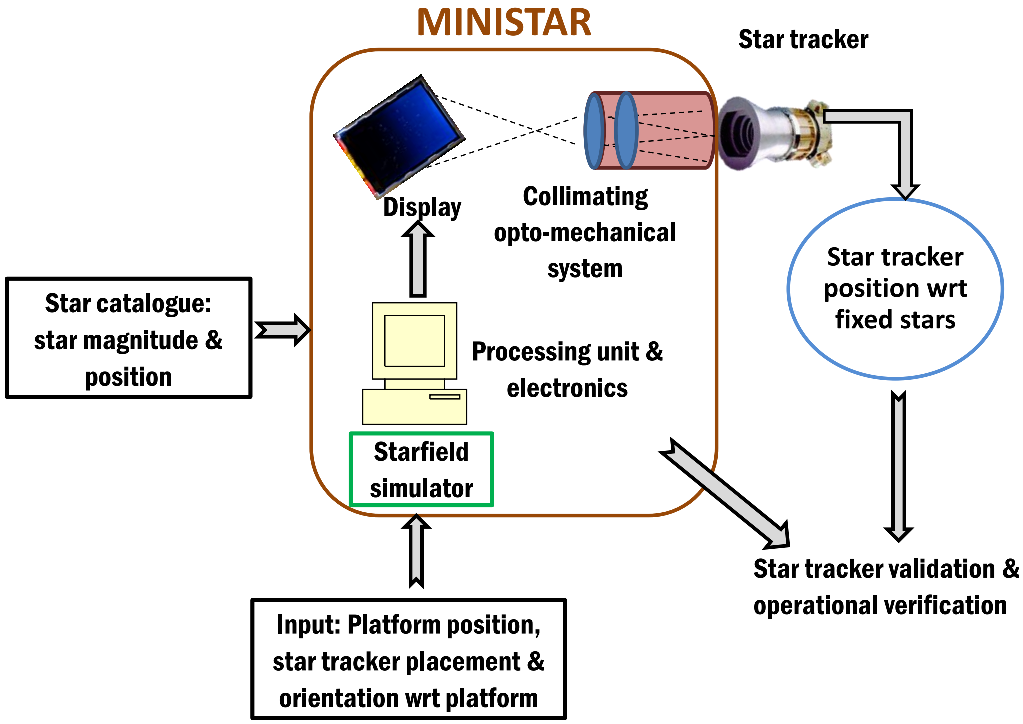

Figure 1. Block diagram of the MINISTAR system.

(A)

(B)

Figure 2. The MINISTAR: (A) the assembled prototype, and (B) the monitor with the rendered star field.

2.2 Main technical features of the prototype

The main requirements taken into account for the design of the MINISTAR were: 1) fast computation, 2) system miniaturization, and 3) system capability of testing different types of star trackers commercially available.

The request for a computationally fast algorithm lead to the choice of a modular structure for the design of the simulation model and control interface. The MINISTAR simulation model provides a real time computation of the dynamic synthetic scenes. It also permits the simulation of both stellar and non-stellar objects, stray light and other disturbance effects (like SEU (*Single Event Upset*). It also renders the selected scenarios in the Field of View (FOV) with a custom radiometric dynamics.

The MINISTAR software was also designed using a modular approach: the MINISTAR is controlled through a graphic user interface that permits the simulation of both the HIPPARCOS[7] star catalogue and non-star objects. The software was also designed for the simultaneous test of multiple-head star tracker.

Miniaturization of the final device was one of the key for the mechanical design of MINISTAR. Its construction was carried out using innovative materials for in order to obtain a light-weight, miniaturized opto-mechanical assembly (weight: < 1 kg; dimensions: 175 mm (⌀) x 150 mm). These characteristics makes it possible the mounting directly on the star tracker's baffle.

Compliancy with several star tracker models available on the market was also a key parameter for the optical design of the collimating optics, with particular reference to the pupil and the FOV. In particular, the MINISTAR was designed so as to have a large pupil and FOV in order to be compatible with most of the star trackers on the market;

Table 1 shows the main technical data of the MINISTAR prototype, together with the main characteristics of other two miniaturized test systems (STOS and OSI) presently available on the market.

Table 1. Comparison between the main specifications of three different miniaturized devices for star tracker testing.

Parameter	MINISTAR	STOS	OSI
Operational mode			
Open Loop Stimulation	Functional testing of Star Tracker	Functional testing of Star Tracker	Functional testing of Star Tracker
Close Loop Stimulation	Yes	Yes	Yes
Optical head			
Display dimensions	1920x1200 pixels	1280x1024 pixels	1280x1024 pixels
FOV	20° (± 10°)	25° (± 12.5°)	>20°
Frame rate for dynamic scene	85 Hz	>= 65 Hz	>=60 Hz
Pupil diamter	35 mm	---	--
Device dimensions	175 mm (⌀) x 150 mm	200 mm (⌀) x 350 mm	77 mm (⌀) x 180 mm
Weight	< 1Kg	< 2 Kg	< 1 Kg
Alignment error	0.001°	0.001°	--
Attachment	direct on the star tracker housing	direct on the star tracker housing	direct on the star tracker housing
Simulated objects			
Single Star Accuracy	0.005°	0.005°	0.0075°
Star Catalougue	Hipparcos	Hipparcos	Hipparcos
Star magnitude range	4.5 ± 0.2 mag	4.5 ± 0.2 mag	4.5 ± 0.2 mag
Star diameter	0.005°	< 0.13°	<0.04°
Large Objects	Yes	Yes	Yes
Protons simulation	Yes	Yes	Yes
Stray light simulation	Yes	Yes	Yes

2.3 Functioning verification

Each functional block of the MINISTAR prototype was individually verified. The simulation model and the system software were tested after the integration of the star field simulation library with the application software. As an example, Figure 3 shows the results of the test performed to verify the capability of the system to display an image with 2000 stars. For this purpose, a logic signal analyzer was used to check the timing: the total time measured for the display of 2000 stars is about 1.2 msec.

The quality of the optical system was tested. The test included the surface imperfection tolerance, the surface form tolerance, the centering tolerance, the lens thickness and the spectrophotometric response. The final alignment after the mechanical assembly of the lenses was also verified by means of interferometric measurement.

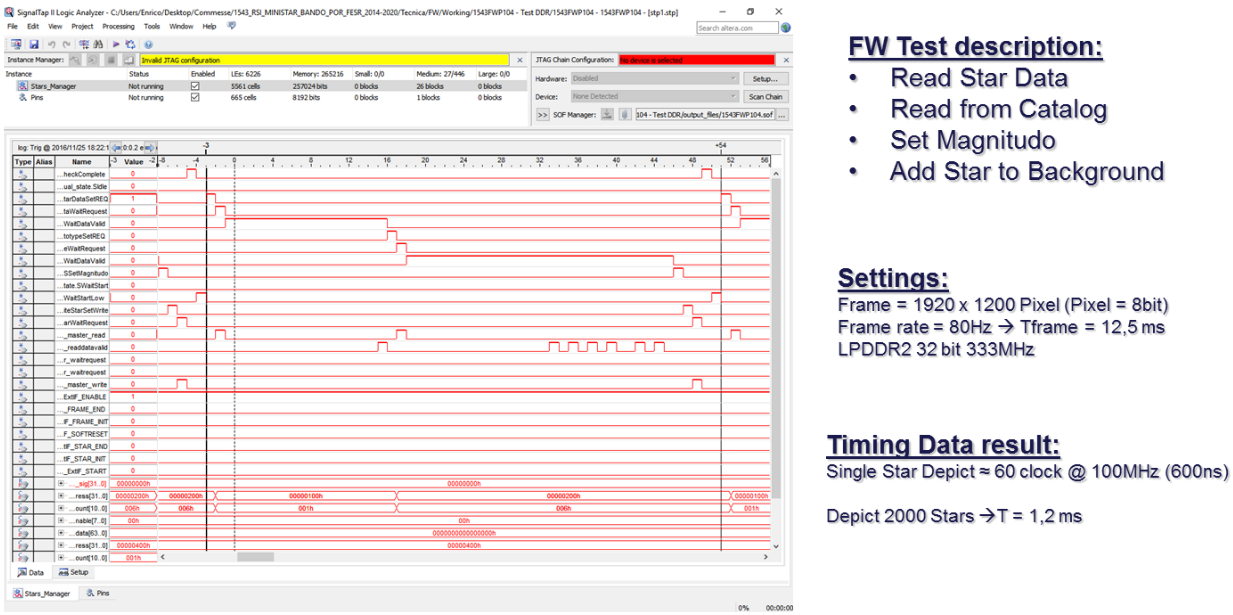

Figure 3. Test results for verifying the capability of the system to display an image with 2000 stars.

3. CONCLUSIONS

A miniaturized lightweight prototype of a multi-head test equipment for star trackers was constructed. The main features of the device include:

- dynamic simulation of the apparent motion of the observed scene, which permits the test of the star tracker in a realistic working scenario;
- simultaneous test of multiple star trackers both for optics, electronics and on-board attitude software performance;
- possibility to mount the device directly on the star tracker while already assembled on the platform, thanks to its reduced dimensions and weight;
- capability of simulating the presence of large objects (e.g. the Sun), custom objects and disturbance effects like cosmic rays and stray light.

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REFERENCES

[1] Rufino G., Accardo D., Grassi M., Fasano G., Renga A., and Tancredi U., “Real-Time Hardware-in-the-Loop Tests of Star Tracker Algorithms,” International Journal of Aerospace Engineering, 505720 (2013).

[2] Yang J., Liang B., Zhang T., Song J., Song L., "Laboratory Test System Design for Star Sensor", Journal of Computers 7(4), 1056 – 1063 (2012)
[3] Boone B. G., Bruzzi J. R., Dellinger W. F., Kluga B. E., and Strobehn K. M., "Optical Simulator and Testbed for Spacecraft Star Tracker Development", Optical Modeling and Performance Predictions II, 586711, (2005).
[4] Dzamba T. and Enright J., "Ground Testing Strategies for Verifying the Slew Rate Tolerance of Star Trackers", Sensors, 14, 3939-3964 (2014)
[5] https://spaceequipment.airbusdefenceandspace.com/testing/ground-system-equipment/stos/
[6] Samaan M.A., Stees S. R., and Theil S., "Star Tracker Real-Time Hardware in the Loop Testing Using Optical Star Simulator," Spaceflight Mechanics, 140 (2011)
[7] Perryman M. A. C., Lindegren L., Kovalevsky J., Hoeg E., Bastian U., Bernacca P. L., Crézé M., Donati F., Grenon M., Grewing M., van Leeuwen F., van der Marel H., Mignard F., Murray C.A., Le Poole R. S., Schrijver H., Turon C., Arenou F., Froeschlé M., Petersen C. S., "The HIPPARCOS Catalogue, Astronomy and Astrophysics, Vol. 323, p.L49-L52 (1997).