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A novel star identification technique robust to high presence of false objects: The Multi-Poles Algorithm

Vincenzo Schiattarella [a,1], Dario Spiller [b,2], Fabio Curti [a,*]

[a] Sapienza University of Rome, School of Aerospace Engineering – ARCAlab, Italy
[b] Sapienza University of Rome, Dept. of Mech. and Aerospace Eng. (DIMA), Italy

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Abstract

This work proposes a novel technique for the star pattern recognition for the Lost in Space, named Multi-Poles Algorithm. This technique is especially designed to ensure a reliable identification of stars when there is a large number of false objects in the image, such as Single Event Upsets, hot pixels or other celestial bodies. The algorithm identifies the stars using three phases: the acceptance phase, the verification phase and the confirmation phase. The acceptance phase uses a polar technique to yield a set of accepted stars. The verification phase performs a cross-check between two sets of accepted stars providing a new set of verified stars. Finally, the confirmation phase introduces an additional check to discard or to keep a verified star. As a result, this procedure guarantees a high robustness to false objects in the acquired images. A reliable simulator is developed to test the algorithm to obtain accurate numerical results. The star tracker is simulated as a 1024×1024 Active Pixel Sensor with a 20° Field of View. The sensor noises are added using suitable distribution models. The stars are simulated using the Hipparcos catalog with corrected magnitudes accordingly to the instrumental response of the sensor. The Single Event Upsets are modeled based on typical shapes detected from some missions. The tests are conducted through a Monte Carlo analysis covering the entire celestial sphere. The numerical results are obtained for both a fixed and a variable attitude configuration. In the first case, the angular velocity is zero and the simulations give a success rate of 100% considering a number of false objects up to six times the number of the cataloged stars in the image. The success rate decreases at 66% when the number of false objects is increased to fifteen times the number of cataloged stars. For moderate angular velocities, preliminary results are given for constant rate and direction. By increasing the angular rate, the performances of the proposed algorithm decrease, since the location errors of the stars become much higher.
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Keywords: Star pattern recognition; Lost in Space; Single Event Upsets; False objects

1. Introduction

Star trackers are accurate devices, capable of determining the attitude within the magnitude of arc-seconds without any a priori information (Liebe, 1993). In fact, when the spacecraft does not have any attitude knowledge, the star tracker operates in the Lost In Space (LIS) mode in order to identify the stars in its Field Of View (FOV). The star tracker camera provides images of an unknown region of the sky to the on-board processor where a star identification algorithm recognizes the visible stars in the FOV by using a star catalog stored on-board (Spratling and Mortari, 2009). Once the attitude is determined, the star tracker switches to the tracking mode, which ensures continual attitude measurements using a limited set of pre-

* Corresponding author at: Via Salaria 851, 00138 Rome, Italy.
E-mail addresses: vincenzo.schiattarella@uniroma1.it (V. Schiattarella), dario.spiller@uniroma1.it (D. Spiller), fabio.curti@uniroma1.it (F. Curti).
[1] Addr.: Via Salaria 851, 00138 Rome, Italy.
[2] Addr.: Via Eudossiana 18, 00184 Rome, Italy.

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viously identified stars. The LIS mode is largely sensitive to the presence of false objects in the acquired image, while the tracking phase is commonly more robust (Berrighi and Procopio, 2003). The use of star trackers in harsh environments that are characterized by a great number of Single Event Upset (SEU), is potentially limited due to the star identification sensitivity to false objects. Interplanetary missions in an intense radiation environment need to always consider this problem during the selection of a proper star tracker design (Liebe et al., 1999; Lauer et al., 2007; Buemi et al., 2000; Boldrini et al., 2004; Jørgensen et al., 2000; Beaumel et al., 2015). All the methods for the identification of detected stars are based on the evaluation of some geometric *patterns* that are related to the relative positions of the stars, for the recognition of triangles (Liebe, 1993; Cole and Crassidis, 2004; Cole and Crassidis, 2006), polygons (Gottlieb, 1978), pyramids (Mortari et al., 2004) or grids (Padgett and Kreutz-Delgado, 1997; Clouse and Padgett, 2000; Lee and Bang, 2007). Some approaches identify the detected stars by evaluating the angular distances of all the stars from a single selected one, defined as the *pole* of the image (Silani and Lovera, 2006; Xie and Wang, 2012; Xie et al., 2012). The magnitude of the stars can be included as a further feature (Accardo and Rufino, 2002), but its usefulness can be severely degraded in the presence of false objects that heavily corrupt the intensity of the pixels belonging to proper stars. Generally, the star identification algorithms are poorly robust to false objects; Kolomenkin et al. (2008) show a method able to successfully manage a number of false objects up to 3 times the number of the cataloged stars when the spacecraft is in a fixed attitude.

In this work a novel star identification algorithm for the LIS mode is proposed, named Multi-Poles Algorithm. This algorithm is especially designed for managing images, highly corrupted by false objects so as to ensure a reliable identification of stars in harsh scenarios. The algorithm is tested when a spacecraft has a fixed attitude and when it experiences an angular velocity.

The paper is organized as follows: Section 2 presents a brief description of the problems related to false objects and image pre-processing, Section 3 describes the Multi-Poles Algorithm and Section 4 briefly shows the developed simulator to simulate the sky and the star sensor including the noises and the SEUs. Numerical results through a Montecarlo approach are given in Section 5. Finally, concluding remarks are given in Section 6.

2. Analysis of the image

2.1. False objects

A false object is a generic spot or cluster in the image which is recognized as a signal of a star. Various phenomena lead to false objects:

- Low energy stars or celestial bodies falling in the FOV that are not included in the on-board catalog; they appear as persistent objects.
- Sensor aging and thermal drifts, where some pixels reach a value of energy higher than the detection threshold of the sensor leading to hot pixels.
- SEUs, which occur when highly energetic particles penetrate the surface of a spacecraft and deposit charges into the sensor detector.

In harsh environments, SEUs can cause the loss of the attitude control and could potentially jeopardize the mission.

2.2. Image pre-processing and clustering

The high-energy pixels must be distinguished by the low-energy pixels. Accordingly, an image pre-processing selects the pixels whose signal-to-noise ratio is greater than a user-defined detection threshold, and discards the other ones (Wellner, 1993). Because the energy of a detected object is spread out in some close pixels, a *clustering* technique groups those pixels in a cluster $\mathcal{C}$ and removes isolated pixels in the image.

According to the pinhole model of a star tracker camera (Burger and Burge, 2008), we introduce two reference frames as shown in Fig. 1: the *focal reference frame* $\mathcal{F}$ defined in $\mathbb{R}^2$, attached to the star tracker detector, and the *sensor reference frame* $\mathcal{S}$ defined in $\mathbb{R}^3$, centered in the focal point of the camera (where f is the focal length). This model provides the mapping function $T_{\mathcal{F}\to\mathcal{S}}$, which projects the pixel positions that belong to $\mathcal{F}$, onto points on the surface of the unit sphere.

The centroid $\mathbf{d}_i = [y^{\mathcal{F}}_{c_i}, z^{\mathcal{F}}_{c_i}]^T$ of the ith cluster $\mathcal{C}_i$, i.e. the reference position on the detector of the ith object, is computed using the pixels $\mathbf{p}_j = [y^{\mathcal{F}}_j, z^{\mathcal{F}}_j]^T$ that belong to the cluster ith throughout an energy-weighted average:

$$\mathbf{d}_i = \frac{1}{E_{\mathcal{C}_i}} \sum_{j|\mathbf{p}_j \in \mathcal{C}_i} E(\mathbf{p}_j) \cdot \mathbf{p}_j \tag{1}$$

where $E(\mathbf{p}_j)$ is the energy of the pixel $\mathbf{p}_j$ and $E_{\mathcal{C}_i} = \sum_{j|\mathbf{p}_j \in \mathcal{C}_i} E(\mathbf{p}_j)$ is the total energy of the ith cluster.

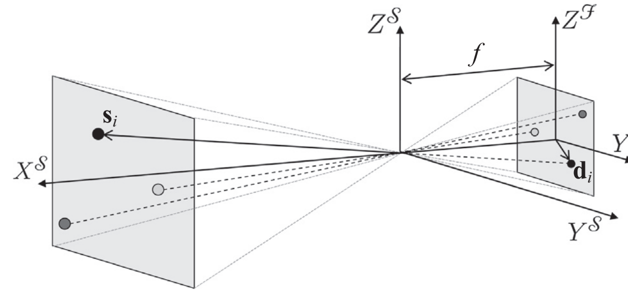

Fig. 1. Mapping from $\mathcal{F}$ to $\mathcal{S}$.

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