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ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

A robust star identification algorithm with star shortlisting

Deval Samirbhai Mehta [a,*], Shoushun Chen [a], Kay Soon Low [b]

[a] Satellite Research Center, School of Electrical and Electronic Engineering, Nanyang Technological University, 639798 Singapore, Singapore
[b] Satellite Technology and Research Centre, Department of Electrical and Computer Engineering, National University of Singapore, 119077 Singapore, Singapore

Received 11 November 2017; received in revised form 24 January 2018; accepted 21 February 2018

Abstract

A star tracker provides the most accurate attitude solution in terms of arc seconds compared to the other existing attitude sensors. When no prior attitude information is available, it operates in "Lost-In-Space (LIS)" mode. Star pattern recognition, also known as star identification algorithm, forms the most crucial part of a star tracker in the LIS mode. Recognition reliability and speed are the two most important parameters of a star pattern recognition technique. In this paper, a novel star identification algorithm with star ID shortlisting is proposed. Firstly, the star IDs are shortlisted based on worst-case patch mismatch, and later stars are identified in the image by an initial match confirmed with a running sequential angular match technique. The proposed idea is tested on 16,200 simulated star images having magnitude uncertainty, noise stars, positional deviation, and varying size of the field of view. The proposed idea is also benchmarked with the state-of-the-art star pattern recognition techniques. Finally, the real-time performance of the proposed technique is tested on the 3104 real star images captured by a star tracker SST-20S currently mounted on a satellite. The proposed technique can achieve an identification accuracy of 98% and takes only 8.2 ms for identification on real images. Simulation and real-time results depict that the proposed technique is highly robust and achieves a high speed of identification suitable for actual space applications.

Keywords: Star tracker; Lost-in-space mode; Star pattern recognition; Star identification; Star shortlisting

1. Introduction

Developing an autonomous and reliable attitude determination system is one of the most important requirement for satellite missions as these missions demand a high accuracy for determining their attitude in the space. Many attitude sensors such as the sun sensor, magnetometer, star tracker, and earth sensor have been developed for estimating the orientation. Of all above sensors, star trackers have become widely popular in the past two decades because they provide a highly accurate orientation information in terms of arc seconds (Wie, 2008; Wertz, 2012).

A star tracker is an optoelectronic device which utilizes the position of stars to determine the orientation of the satellite. When no prior attitude information is available, the star tracker operates in the "Lost-In-Space (LIS)" mode. The basic principle of operation of a star tracker in the LIS mode is based on firstly identifying the stars captured in the image and later calculating the attitude from the position measurements (stored in the star catalog) of the identified stars. The latter part of calculating the attitude can be easily accomplished by the existing QUEST or TRIAD methods (Shuster and Oh, 1981). The challenging part is the correct identification of the stars in the image captured despite the problems of patch mismatch, magnitude uncertainty, and false stars in the image. Many star pattern recognition techniques have been proposed in the

* Corresponding author.
E-mail addresses: meht0004@e.ntu.edu.sg (D.S. Mehta), eechenss@ntu.edu.sg (S. Chen), k.s.low@ieee.org (K.S. Low).

https://doi.org/10.1016/j.asr.2018.02.029
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last two decades (Ho, 2012) for solving the problem of star identification.

The star pattern recognition techniques can be segregated into two parts – geometric based and pattern based. Geometric based techniques utilize the features such as the angles and distances formed by the star clusters for constructing the star pattern database (SPD) and identification purposes. Star clusters can range from a size of three (Liebe, 1993), four (Mortari et al., 2001) or can consists of all the stars which lie within the field of view (FOV) of the center star (Kolomenkinet al., 2008). Some geometric based techniques form features such as utilizing the area formed by all the possible star clusters for comparison purposes (Cole and Crassidis, 2006). Many variations of the geometric based approach have also been proposed in the recent years where different transformations (Delabie et al., 2013; Jafar et al., 2016; Samirbhai et al., 2016; Hernández et al., 2017; Schiattarella et al., 2017) are applied to the geometric features for pattern recognition. The grid algorithm (Padgett and Kreutz-Delgado, 1997) initiated the pattern-based approach, which develops a coded pattern of the stars for comparison and identification purposes. The research community has widely adopted the pattern-based idea and many modified approaches of this idea have also been developed (Na et al., 2009; Yoon et al., 2013). Recently, an optimized grid algorithm (Aghaei and Moghaddam, 2016) specifically for tackling false stars was proposed, which has significantly improved the performance of the initial grid approach. Some star pattern recognition techniques – low memory SPD (David et al., 2010), optimized SPD (Pham et al., 2013) were developed specifically for achieving a high speed of recognition. Apart from the above two general approaches, a multi-purpose panoramic camera based star pattern recognition was proposed recently in Opromolla et al. (2017). An exhaustive review of all the existing star pattern recognition approaches is provided in Star Identification (Zhang, 2017).

A star pattern recognition technique is evaluated based on two parameters – the recognition reliability (identification accuracy) and the run time for identification. For achieving a high recognition reliability, more features are preferred to be extracted along with more combinations of star clusters and thus, more comparisons must be made. However, such an exhaustive process will increase the time required for feature extraction and comparison with the SPD. This will lead to a low speed of identification. On the other hand, if fewer features are used with only some selected combinations of star cluster then the number of comparisons to be made are reduced significantly which will lead to a high speed of identification. However, the accuracy of correct star identification may decrease because of the selected number of features used for extraction and comparison. Thus, there is a trade-off between recognition reliability and speed.

In this paper, we propose a novel combination of star shortlisting and pattern recognition algorithm which excels at both the recognition reliability and speed. The first part of the proposed combination deals with shortlisting the stars based on worst-case patch mismatch, and the second part of the algorithm comprises of the pattern recognition technique which is based on an initial match confirmed by a running a sequential angular match. The former leads to achieving a low time complexity for identification and the latter leads to attaining a high recognition reliability. The proposed idea is benchmarked with the state-of-the-art star pattern recognition techniques on simulated images containing magnitude uncertainty, false stars, positional deviation and varying size of the FOV. Later, the proposed idea is also tested on the real images captured by a star tracker SST-20S. The paper is concluded by analyzing the results of the proposed combination of star shortlisting and pattern recognition algorithm.

2. Research problem

Before explaining the proposed approach of robust and fast star identification, we will first concentrate on analyzing the problems faced in star pattern recognition in this section. In Fig. 1, we show an illustrative example to describe the major problems faced in star pattern recognition. Image captured by the star tracker is restricted by a defined FOV. The star pattern database (SPD) is constructed by taking the same FOV and utilizing the features extracted from the neighboring stars which lie within the FOV of the center star. In Fig. 1, the solid circle is the SPD of the center star A and the stars which lie in the FOV of the star A are labeled from 1 to 10. The dotted circle is the image captured by the star tracker, where I_c is the center of the image. Let us assume that the star A is the closest to I_c and needs to be identified. The major problem as can be seen from the example in Fig. 1 is that in the SPD

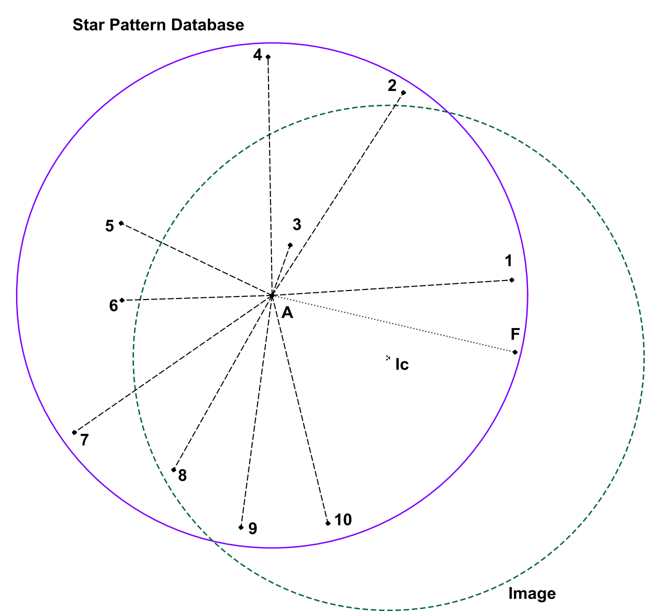

Fig. 1. An illustrative example demonstrating the problems faced by star pattern recognition techniques.

Please cite this article in press as: Mehta, D.S., et al. A robust star identification algorithm with star shortlisting. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.02.029