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ScienceDirect

Advances in Space Research xxx (2017) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

A triangle voting algorithm based on double feature constraints for star sensors

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Received 7 April 2017; received in revised form 23 November 2017; accepted 29 November 2017

Abstract

A novel autonomous star identification algorithm is presented in this study. In the proposed algorithm, each sensor star constructs multi-triangle with its bright neighbor stars and obtains its candidates by triangle voting process, in which the triangle is considered as the basic voting element. In order to accelerate the speed of this algorithm and reduce the required memory for star database, feature extraction is carried out to reduce the dimension of triangles and each triangle is described by its base and height. During the identification period, the voting scheme based on double feature constraints is proposed to implement triangle voting. This scheme guarantees that only the catalog star satisfying two features can vote for the sensor star, which improves the robustness towards false stars. The simulation and real star image test demonstrate that compared with the other two algorithms, the proposed algorithm is more robust towards position noise, magnitude noise and false stars.

Keywords: Star sensor; Star identification; Triangle voting; Feature extraction; Double feature constraints scheme

1. Introduction

Attitude determination plays an important role in aerospace missions. As the high-precise and drift-less attitude measurement devices, star sensors are widely used in spacecraft.

Star identification is one of the critical techniques in the spacecraft attitude determination. It finds the correspondence between sensor stars and catalog stars to determine the spacecraft attitude. Generally, the star identification includes two basic parts: lost-in-space mode (LIS) and tracking mode. The algorithms under LIS mode need to seek all sky regions to find the corresponding matches between sensor stars and catalog stars, which are more difficult and challenging than the algorithms under tracking mode. Therefore, the research on LIS algorithms is necessary and attractive.

Available star identification algorithms can be categorized into two classes (Padgett and Kreutz-Delgado, 1997): subgraph isomorphism algorithms and pattern recognition algorithms. The subgraph isomorphism algorithms tend to regard the stars in the obtained star image as the vertexes of the subgraph and treat the angular separation between two sensor stars as the edge in the subgraph. In this case, the star identification is implemented by searching the unique subgraph in all sky regions. These algorithms include: triangle algorithm (Liebe, 1993), pyramid algorithm (Mortari et al., 2004), match group algorithm (Van Bezooijen, 1998), geometric voting algorithm (Kolomenkin et al., 2008) and iterative algorithm (Li et al., 2015). Generally, there are many similar star pairs and triangles in all sky regions, so there are a lot of candidate matches for the given star pairs or triangles. But as

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https://doi.org/10.1016/j.asr.2017.11.042

Please cite this article in press as: Fan, Q., Zhong, X. A triangle voting algorithm based on double feature constraints for star sensors. Adv. Space Res. (2017), https://doi.org/10.1016/j.asr.2017.11.042

more subgraphs in the obtained star map have matched, the redundant matches can be eliminated and the unique match subgraph remains. This class of algorithms usually utilizes the star pairs or triangles to construct database which requires large memory and the identification time of these algorithms is relatively long.

Another category of star identification algorithms are pattern recognition algorithms. These algorithms associate each star with its surrounding stars to generate a unique pattern for it. The identification can be completed by searching the most similar pattern between sensor stars and catalog stars. This class of algorithms include: grid algorithm (Padgett and Kreutz-Delgado, 1997) and its modified version (Aghaei and Moghaddam, 2016; Lee and Bang, 2007; Na et al., 2009), Polestar algorithm (Silani and Lovera, 2006), radial and cyclic algorithm (Zhang et al., 2008), log-polar transforming-based algorithm (Wei et al., 2009), flower algorithm (Gong et al., 2009), unified redundant algorithm (Jiang et al., 2015) and HMM pattern algorithm (Sun et al., 2016). This category of algorithms performs well when there are many stars in sensor images, while the performance is degraded with few stars in sensor images.

Among the available star identification algorithms, the triangle algorithms and the algorithms based on voting scheme are commonly used in the practical applications.

Existing voting algorithms implement star identification by utilizing the angular separations between the pivot star and its surrounding stars to get the votes from catalog stars. Then the candidate matches for the pivot star are obtained according to the catalog stars votes. But the angular separations between the pivot star and its neighbors are low-dimensional information. Therefore, after the initial match process, there are numerous candidates for the pivot star, which result in the time-consuming verification process. Also, in the case of many false stars in the sensor image, the sensor star is likely to be mismatched because the sensor star might receive wrong votes from catalog stars. In order to accelerate the speed of voting algorithm and improve the robustness towards false stars, the triangle voting algorithm based on the double feature constraints scheme is presented in this study. In this proposed algorithm, the star identification is implemented by the triangle voting process, in which the triangle is considered as the basic voting element. In the period of database construction, each catalog star generates multi-triangle pattern with its bright surroundings, and feature extraction process is adopted to reduce the dimension of triangles. Each triangle is described by its base and height after feature extraction process. During the identification period, double feature constraints method is proposed to implement triangle voting process, and the catalog stars with higher votes are considered as the candidates and put into the verification period. The proposed algorithm uses the triangle as basic voting element, which can reduce the number of the redundant matches and accelerate the speed of the algorithm. And the voting scheme based on double feature constraints improves the robustness towards false stars.

The remainder of this paper is organized as follows. Section 2 describes the algorithm in detail, including the pattern generation, database construction and the matching algorithm. The determination of parameter values in the algorithm and the experimental results together with discussions are given in Section 3. Finally, some conclusions are drawn in Section 4.

2. Algorithm description

In this section, the implementation of the proposed algorithm is described thoroughly. Firstly, the pattern generation and feature extraction are provided. Then the star database generation and data structure are presented. Finally, the details of the algorithm, its pseudocode and an algorithm example are shown.

2.1. Multi-triangle pattern generation

The proposed algorithm constructs the multi-triangle pattern for each catalog star and generates the corresponding features by feature extraction. Given a catalog star C_I, its pattern generation and feature extraction are as follows.

2.1.1. Determination of the bright neighbor stars

As shown in Fig. 1, the catalog stars whose angular separations from C_I are greater than the minimum radius D_min and less than the pattern radius PR are considered as the neighbor stars of C_I. Among these neighbor stars, the λ brightest neighbors C_{Ni} $(i = 1, \ldots, \lambda)$ are selected to generate the pattern with C_I. The value of parameters PR and λ will be determined in Section 3.1. The position information of a catalog star in star catalog $\boldsymbol{C}$ is its right ascension and declination (α, β) in the celestial coordinate. Therefore, the angular separations between C_I and its bright neighbor stars C_{Ni} $(i = 1, \ldots, \lambda)$ are calculated by Eq. (1).

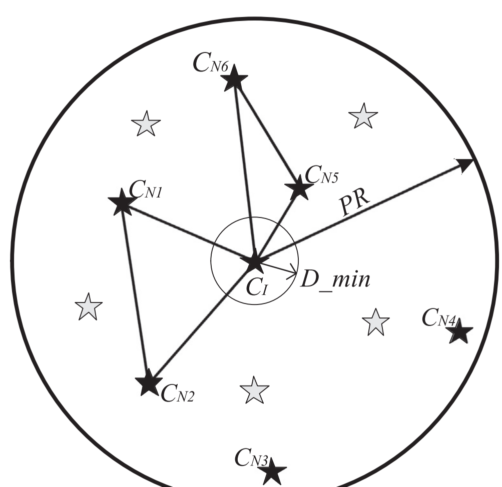

Fig. 1. Star configuration to be matched.

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