Available online at www.sciencedirect.com
SCIENCE DIRECT®

Pattern Recognition Letters 26 (2005) 147–165

Pattern Recognition Letters

www.elsevier.com/locate/patrec

# An efficient star acquisition method based on SVM with mixtures of kernels

Sheng Zheng *, Jian Liu, JinWen Tian

*State Education Commission Key Laboratory for Image Processing and Intelligent Control, Institute for Pattern Recognition and Artificial Intelligence, Huazhong University of Science and Technology, Wuhan 430074, China*

Received 25 October 2003; received in revised form 16 April 2004
Available online 8 October 2004

**Abstract**

Star acquisition and star pattern recognition are the most time-consuming routines in star tracker operation. To speed up the star acquisition procedure, the innovative efficient star cluster grouping method is based on the mapped least squares support vector machine (LS-SVM) with mixtures of radial basis function and polynomial kernels. By convolving star image with the second order directional derivative operators deduced from the mapped LS-SVM, the maximum extremum points (the possible center of stars) on the two-dimensional star image intensity surface are reliably determined, and then the star cluster grouping process in star acquisition procedure is significantly speeded up. The mixtures of kernels provide more optimal performance than any single kernel. Computer experiments for the simulated star images are carried out. The results demonstrate that the proposed algorithm is efficient and robust over a wide range of sensor noise.


*Keywords:* Star tracker; Star acquisition; Least squares support vector machine (LS-SVM); Mixtures of kernels; Second order directional derivative operators; Maximum extremum intensity pixels

## 1. Introduction

Star observations are widely used by spacecraft as a primary means of attitude determination. Satellites must use imaging, identification, and tracking of stars if their mission requires knowledge of attitude to a high (arcsecond) precision. Star patterns in the field of view (FOV) of a star camera are identified using an appropriate star identification algorithm, based on their coordinates in an onboard star catalog, finally the attitude estimate is calculated. The star trackers provided high-precision three-axis attitude information due to extremely accurate reference information as well as

* Corresponding author. Tel.: +86 27 87556302(o).
*E-mail addresses:* zhengsheng6511@sohu.com, zsh@ctgu.edu.cn (S. Zheng).

0167-8655/$ - see front matter 
doi:10.1016/j.patrec.2004.09.003

improvement of star sensing devices (Accardo and Rufino, 2002a,b). Currently, star tracker sensors based on charge coupled devices (CCD) enable one to obtain the best spacecraft attitude estimation among the existing sensors for attitude determination. The most important development trend of the modern star trackers is the achievement of full autonomy of operation, with which their operation capability to cover most or even all mission phases can be widened and all attitude data required for control can be supplied. To obtain full autonomous attitude estimation, the star tracker should perform a prompt identification of the viewed star field by comparing observed star features and star characteristics stored in its on-board catalog. Once a correct match is made, it is reliable to generate good attitude estimation.

Star acquisition and star pattern recognition (SPR) are the most time-consuming routines in star tracker operation. To generate a best match between the measured star pattern in FOV and the subgraph of the on-board catalog, many SPR algorithms have been proposed. The inter-star pair angular separation-based matching methods are the first class of the algorithms, in which the stars are treated as vertexes in a graph whose edges correspond to the angular separation between neighboring stars that could possibly share the same sensor FOV, such as those reported in (Accardo and Rufino, 2002a; Motari et al., 2002). The grid algorithms, such as those reported in (Padgett and Kreutz-Delgado, 1997; Clouse and Padgett, 2000), belong to the second class of the algorithms, in which the well-defined pattern that can be determined by the surrounding star field has been associated with every star. The third class of algorithms is the developing neural networks-based recognition algorithms (Accardo and Rufino, 2002b; Hong and Dickenson, 2000), in which the star images of FOV are treated as patterns that can be recognized directly, since the neural network structure itself contains the information about the star feature vectors.

Usually, star acquisition procedure is composed of threshold scanning, star cluster grouping, and sub-pixel centroiding processes (Kim, 2002). In the threshold scanning, the whole image is scanned to find threshold pixels, of which the intensity is greater than a given threshold value. For the highest intensity pixel among threshold pixels, the adjacent pixels are collected and grouped. If their average intensity exceeds a given value, the cluster is considered as a star. For the remaining highest intensity pixels, this process does not repeat until the pre-specified number of clusters is obtained.

To efficiently complete the star acquisition procedure, some approaches have been proposed. For example, the star acquisition method implemented for StarNva I, which is introduced in (Ju, 2001), includes the determination of a minimum threshold level, pixel cluster formation, removal of double stars, and the calculation of centroid for each star light cluster. Motari et al. (2002) introduced two integer vectors, including $n_h$ and $n_v$ elements, where $n_h$ and $n_v$ are the numbers of the CCD horizontal and vertical pixels, respectively, to keep record of the location of the relative maximum in the corresponding row/column, by scanning all CCD pixels just once. And Kim (2002) developed the recursive star acquisition method, which uses the estimated attitude to predict the positions of subcatalog stars in the image plane and only perform the threshold scan in the small windows around the predicted guide star positions, and can reduce the scanning time drastically. To effectively discard the spurious stars generated from the noise and extract the fainter stars from partial or uneven background image, it is necessary to develop a new efficient and reliable approach, which can provide small total number of measured stars and fewer loss of the fainter stars for the followed SPR and measurement generation.

In recent years, the support vector machines (SVM), based on statistical learning theory, as a powerful new tool for data classification and function estimation, has been developed (Vapnik, 1998a,b; Cortes and Vapnik, 1995). SVM maps input data into a high dimensional feature space where it may become linearly separable. Recently SVM has been applied to a wide variety of domains such as pattern recognition and object detection (Burges, 1998), function estimation (Vapnik et al., 1997; Vapnik, 1998b) etc. One reason that SVM often performs better than earlier methods is that SVM was designed to minimize structural risk whereas previous techniques are