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A Survey of Star Recognition Algorithms

Jiazong Yu*
*(Department of Computer Science, Jinan University, Guangzhou-510632, China)

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Abstract:

Star recognition is the fundamental guarantee of star sensor working, it is also an important part of astronomical navigation. This paper summarizes the existing star recognition algorithm, and analyzes the advantages and disadvantages of each kind of algorithm.

Keywords **—Star recognition, pattern recognition, triangle algorithm.**

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I. INTRODUCTION

Since Gottlieb et al.[1]Proposed the first one star recognition algorithm,star recognition algorithm has been over 40 years. Theexisting star recognition algorithms are various, but it can be divided into three categories:

(1) Subgraph isomorphism algorithm. Based on the star diagonal distance, the simple geometric configuration is constructed as the matching element and matched. The corresponding representative algorithm has the triangular algorithm[2], the quadrilateral algorithm[3], and the improved algorithm based on the classical triangular algorithm and the quadrilateral[4, 5] and so on, this kind of method is simple, intuitive and easy to implement.

(2)Pattern recognition algorithm. The distribution characteristics of the surrounding stars are as the matching pattern, and the highest similarity of the patterns in the CCD image is chosen as the matching star. Representative algorithms include grid algorithms[5, 6], radial and cyclic algorithms[7], and the improvements based on these methods[8, 9].

(3) Other types algorithms. For example: singular value decomposition[10], KMP[11], ant colony algorithm[12], particle swarm algorithm[13]also has a corresponding expansion applicationin the star recognition.

No matter which type of star recognition algorithm, the identification process can be roughly shown as Fig. 1. Thenavigation library is from the catalog[13], which records the direction vector of the star in an inertial reference coordinate system; The observation library records the position coordinate information set of the stars in the celestial sensor coordinate system.

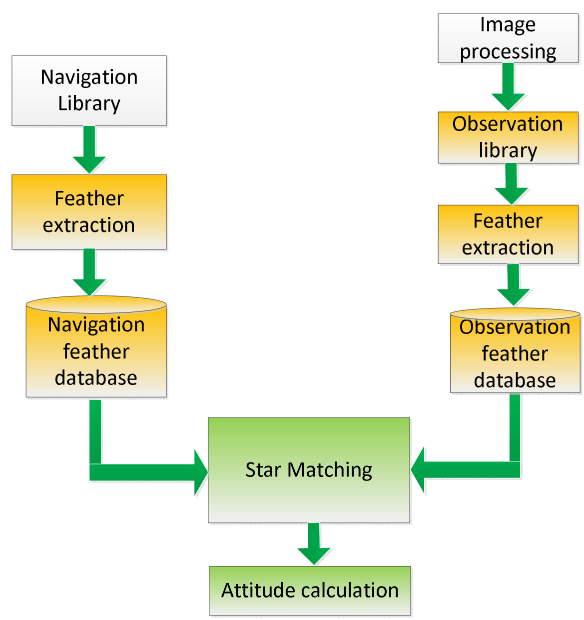


Fig. 1 star recognition

As it can be shown from Fig. 1, star recognition can be divided into two phases roughly: the construction of feature database phase and matching phase. These two phases are also the most important parts of star recognition, which affect the efficiency of the star recognition algorithm. The main difference of different star recognition algorithms is that the construction method of feature database is different. For example, the feature extraction of subgraph isomorphism algorithm is mainly based on the construction of geometric configuration; The feature extraction of pattern recognition algorithm is mainly based on the feature pattern(such as grid, radial and cyclic et al.) ofsurrounding star. Other types algorithms establish the characteristics according toits specific application algorithm. The task of matching phase is finding a matching feather in the navigation feather database for a observation feather. The task of the posture solution is to determine the position of the aircraft based on the result of the star recognition.

II. STAR RECOGNITION ALGORITHMS

A. Subgraph isomorphism algorithm

Triangle matching algorithm is currently the most used, but also the development is the most mature[14]. The core idea of the triangular star recognition algorithm is based on the isomorphic triangle, which is based on the judgment condition model of isomorphism triangle such as "edge-edge-edge" or "edge-angle-edge". Based on the navigation star database The navigation feature database finds the only one with the observational star based on the observation model built.

In 2006, Zhang G J et al.[4] proposed the use of "internal cube method" to divide the celestial sphere into 486 blocks, and in order to reduce the storage with the redundant informationthe angular distance(edge), the algorithm does not directly store the relationship of the triangle, instead recording all the angular distance.Then separating them todifferent areas.During matching phase,query the angular distance to its correspondingarea, then to check whether there are three edges, which are from the same triangle, finally verify the matching relationship of the triangle;

In 2011, Wu L L et al.[15] proposed for constructing a unique triangle for everyreference star, the algorithm need to record the three edges of triangular and the normal vector of the plane, which triangle located.During matching phase this normal vector can be used to determine the candidate triangle, and finally verify withthe three edges of the triangular.

In 2004, Zheng S et al.[16] proposed some methods to improve the triangle algorithm,the direction of improvement can be divided into four categories:(1) reducing the size of the navigation feature database; (2)reducing the query range by rough attitude;(3) reducing the number of matching; (4)using some search technology to speed up the search.

The main difference between the quadrilateral algorithm and the triangular algorithm is that the quadrilateral algorithm requires four stars to be modeled and contain more features. In recent years, the quadrilateral algorithm developedmore slowlythan the triangular algorithm.

In 2000, Lin et al.[3] decompose the quadrilateral into two triangles with one common edges. The algorithm first finds the triangles satisfying the conditions. On the basis of finding the triangles whether has common edge or not.

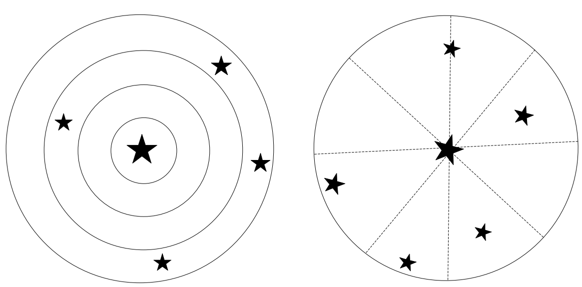
In 2013, JS Heyl[5] proposed the use of quadrilateral area distortion invariance, to overcome the distortion caused by the shooting error, which would bring about the failure of matching. Respectivelyusing the diagonal of the quadrilateral to divide quadrilateral into two triangles, and then sorting these four triangles, it is assumed that the ordered triangular area relation is $A<B<C<D$, then $A+D=B+C$, using this proportional relationship to create the k-dtree index, and speed up the matching phase.

In addition to the triangular algorithm and the quadrilateral algorithm, there are other recognition algorithms, such as the pyramid matching algorithm[17], the matching algorithm, which is essentially passed through the constant addition of angular distance relations[18], the matching group algorithm[19] and so on. Directly or indirectly use the angle distance to complete the matching.

B. Pattern recognition algorithm

The grid algorithm is the most representative algorithmof the pattern recognition, and was first proposed by Padgett[6] in 1997. The grid algorithm distributes the surrounding star which is from the reference star within a certain radius of pr into an N*N grid. If there is a star in the grid, the grid is encoded as 1, Otherwise it is 0; Finally, the surrounding star distribution of the reference star is transformed into a N*N 01 bit vector. Assuming that the surrounding star distribution of star i and star j are pat_i and pat_j respectively, the algorithm will calculate max match (pat_i, pat_j),which is $\sum_{k=0}^{g^2-1}(pat_j[k]\,\&\,pat_i[k])$, if the bit vector satisfies a certain matching threshold, then the two stars are considered to be matched.

In 2003, Li C[20] put forward a pattern recognition algorithm based on neural network, the input model of neural networkuses the pattern of grid algorithm, in order to reduce the pressure of the neural network training, the algorithm first uses a BP neural network to classify these pattern, and then train the neural network according to different categories.



(a)cyclic pattern (b)radial pattern

Fig. 1cyclic and radial pattern

In 2004, Wei Xinguo[7] proposed a pattern recognition algorithm based on radial and cyclic pattern. The algorithm establishes the radial and cyclic characteristics for every selected reference stars. The pattern is shown in Fig. 2, after the division of the radial and cyclic, if there is surrounding star in the radial and cyclic area, then1 is used to representation; If there is no star, 0 is used to representation, if the star has the same radial and cyclic pattern distribution in the matching process, which will be as the candidate match object.

In 2008 J Xie et al.[21] use the surrounding star's distributioncharacteristics ofreference star to complete the star recognition with statistical methods. The algorithm first calculates the angular distances of all stars in the navigation library and save them in navigation feature library. For the observation star, it is also necessary to calculate all the angular distances between the reference star and the surrounding star in a certain radius, and then find the edges that have thesame angular distance in the navigation feature library, count the number of occurrences of these points, and the point that has the largest number will be as the matching point. In 2012, J et al. improved the method based on statistics. The algorithm encloses the surrounding star in a certain radius into a counterclockwise circular chain M, and then calculates the angle between the points on the chain, finally going to the navigation feature library to find a chain that matches these angles, the chain that has a longest relation of matching chainwill be as the matching chain to complete the match.

2009 Na M et al.[8] improvedthe original grid algorithm, the improved grid algorithm can overcome the drawbackof original grid algorithm due togreater error of the star's position and magnitude. For example, as shown in Fig. 3, if in the original grid algorithm these cases will be considered as three different patterns, but these three cases easilycaused during the picture processing Phase, so Na M et al. proposed "elastic gray grid algorithm" based on the original grid algorithm. The three cases in Fig. 1.3will be considered as matching pattern in theproposed algorithm.

In 2012, Yang J et al.[22] improved the star recognition algorithm based on neural network algorithm to accelerate the matching speed and the rate of matching success. The designed algorithm uses grid algorithm as a neural network input, but Yang et al.thought that the original grid algorithm only concerned about the existence of stars in the grid, and ignore the number of starsthe grid, which greatly reduced the matching recognition rate, so they add the statistics information based on original grid algorithm. For example, Fig. 3(a) in the original grid algorithm would be encodedas [1, 0, 0, 0, 0,0,0], but the improved algorithm was encodedas [3,0,0,0,0,0]; after obtaining the pattern of reference star in the navigation library, then the algorithm is trained by the neural network.

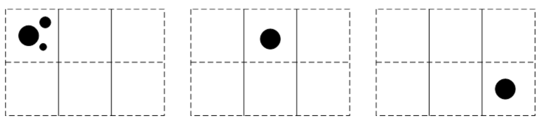


Fig. 2improved grid pattern

2013 F Ji et al.[9] proposed a unified redundancy patternsfor star recognition, the algorithm proposed that theradial and cyclic feature have a relatively large redundancy, as shown in Fig. 4, the surroundingstar's distribution of reference star is significantly different, but they have the same radial feature pattern, even though the algorithm can use the cyclic feature pattern to further narrow the redundancy, but the establishment of the cyclic feature pattern depends largely on the distribution of the surrounding star that has a smallest angle with reference star, the determination of this surrounding star will affect the accuracy of the entire star recognition, so authors proposed a unified redundancy patternsto improve these drawbacks. The algorithm calculates the angular distance between stars, and then converts these angular distance to a discrete value though certain formula. The discrete angular distance will be rounded down and then recorded in a bit vector, corresponding integer is set to 1, according to certain conditions, the adjacent integer bits are also set to 1 (redundant bits); then calculate the angular distance between the reference star and the surrounding star, according to the above method to discrete and use another bit vector to record, the adjacent bit vector is also set to 1 according to certain conditions. The algorithm reduces the low recognition rate caused by the noise of position and magnitude by setting the redundant bits.

In 2016, Tang Wusheng[23] proposed some improvements to the grid algorithm,for the case when the original grid algorithm had a low recognition rate due to a small number of observation stars in CCD image, the author set a thresholds that determined by dynamically adjusting the number and the boundary distance of the matching star, and did some improvement to the grid in the case of the observation project vector has overlap, so as to improve recognition ratein the case of lessnumber of observation stars in CCD images.

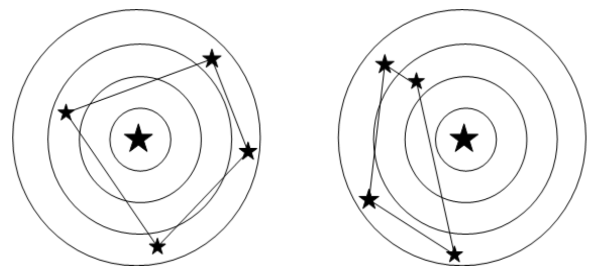


Fig. 3 cyclic feather drawback

C. *Other types*

In 2004, Li Baohua et al[11]. proposed star recognition method based on KMP, which divides the starsof the navigation database according to certain methods, and then uses 0-1 method to establish the characteristic database of the navigation star, where 1 denotes the region There is a star, 0 that the sub-region without stars, so that the stars can guide the star library can use 0-1 string, for the observation of the image is also a similar way to get a 0-1 string, and finally use the KMP mode for string matching

In 2008, Q W[12] proposed a fast star recognition algorithm based on ant colony clustering algorithm; In 2014, Mao et al.[13] proposed a star recognition algorithm based on particle swarm optimization algorithm.both of them are based on swarm intelligence algorithm, The common feature of them is that using the group intelligence algorithm to solve a shortest path from the master star to the surrounding star, and then matching according to the shortest path angle feature.

In 2013, Yin H[24] proposed a star recognition method based on finite automaton. The algorithm uses the radial and cyclic feature patterns of the surrounding star in a certain radius to generate a string, then using a finite automaton to match.

In 2014, Xing Yifan[10] proposed a star recognition algorithm based on singular value decomposition. The algorithm uses invariant property of singular value relative to coordinate transformation. Firstly the stars in the navigation library must have at least four stars in the field of view, then for every star in the navigation library calculate a singular value, which according to the four brightest surrounding stars within a certain field of view; matching phasejust finds star as matching star, which has the same singular value.

III. Performance Analysis of Various Algorithms

(1)The star recognition algorithm based on subgraph isomorphism uses angular distance pattern, which its implementation is simple and easy, the requirement for CCD image is also the lowest. But as the geometric model becomes more and more complex (extending from simple angle to triangular, quadrilateral, pyramid or even more geometrical models), the size of the navigation feature database grows exponentially, which will result to the required time of building a navigation feature databasewill increase greatly, at the same time, the corresponding requirements for computer storage also will increase, even the matching phase will become more difficult due to the size of query objects expanded. However, as the complexity of the geometric model becomes higher, the similar model in the navigation feature database will be reduced owing to the geometric model with more feature and more distinguishable, it also means the redundancy of the models in the navigation feature database isreduced, which will greatly reduce the times of entering the verification phase, which will happen when the recognition algorithm finds the matching model during the matching process, and greatly speed up the matching process.

(2)The star recognition algorithm based on pattern recognitionmakes full use of the surrounding star's distribution characteristics of the reference star, comparing to the algorithm based on subgraph isomorphism, its matching is more efficient and robust. Firstly, the size of the navigation feather database increases linearly with the increase of the navigation library, which is much smaller than the size of the navigation feature database constructed by the subgraph isomorphism algorithm; In addition, it is less possibleto occur errorin matchingphase. However, the implementation of pattern recognition algorithm is relatively cumbersome, and the requirements for the CCD imagesare relatively strict, for the shooting tool and the image processing part it also has a higher demand, which has the great impact to the rate of recognition. Above all, on the one hand, because the pattern recognition algorithmexecuted mainly according tothe surrounding star's distribution characteristics, if the surrounding stars in the shooting stage or picture processing stage have a loss, it will seriously affect the recognition rate of matching, for example, as shown in Fig. 5,though both of them are from the same image, what is different is that they image under different gray values, but it is obvious there is differences in imaging. Even for some bright stars, although there may be imaging under different gray value settings, there will be a significant difference in the distribution of surrounding star; On the other hand, the selection of navigation library also has a significant impact on the method of pattern recognition, although the data ofnavigation library is from space agent and is relatively complete, but with the impact of experimental environment and other aspects, only part of the data form navigation library is used, but only when the data form navigation library is as far as possible to maintain the integrity, the navigation feature database can be constructed relatively complete, so the size of navigation library also can affect the navigation features database, and this effect is also directly affect the success rate of star recognition.

Fig. 4same picture under different grayscale values

(3)other types of algorithms, which usually expands on the basic of pattern recognition algorithm, directly or indirectly.With the use of pattern recognition feature pattern, in addition to the advantages and disadvantages of the pattern recognition method, it is also affected by the algorithm of its application. For example, the group intelligence algorithm itself is time-consuming and vulnerable to its control parameters. Essentially the algorithm alsoneeds to collect the characteristics of surrounding star's distribution, but the background of applicationis different.

IV. CONCLUSIONS

In this paper, firstly, we have a detailed overview for the existing commonly used star recognition algorithm; secondly, we give an detailed analysis for its advantages and disadvantages were analyzed.

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