DEVELOPMENT OF STAR TRACKER FOR SATELLITE

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Introduction

Star trackers are optoelectronic devices used onboard the satellite for its autonomous attitude determination in space relative to the inertial reference frame. In recent years star trackers acquired the popularity and importance among the sensors used in attitude determination and control system of the satellite due to the fact that other sensors can work only under certain conditions (distance, luminance, existence of a magnetic field and etc.).

Currently development of star trackers are engaged first of all in the countries implementing their space programs on creation of space systems for different purposes, for example:

- SRI RAS (Russia), developing Block of Determination of Coordinates of Stars (BOKS) intended for high-precision attitude determination of satellite in real time using the images of arbitrary areas of the stellar sky;
- SODERN (France), releasing autonomous star devices SED16, SED26, SED36 and HYDRA;
- Jena-Optronik (Germany), producing three models of autonomous star devices: ASTRO 10, ASTRO 15 и ASTRO APS;
- SSTL (Great Britain) develops and produces microsatellites for different purposes and its components, including star trackers Altair-HB;
- etc. [1].

The cost of produced star trackers depending on marketing policy of the producer, quality, accuracy of measurements, reliabilities and operating life is quite high. It can be one of the main obstacle for their use in the process of development of satellites or microsatellites in the conditions of the restricted budget.

Space branch is actively developed in Kazakhstan at present. Development and launch of ERS spacecrafts, development of microsatellites are planned. In this regard there is actual a question of creation of inherent technological base and development of components of satellites. By the force of domestic experts in Kazakhstan own star tracker is being developed. At the initial stage it is planned to develop its experimental model. At this moment works on design of star tracker, production of optical system and electronic unit, development of mathematical support and software of experimental model of star tracker have been carried out. The present article deals with the description of main stages of development of star tracker experimental model and its testing.

1 Design of star tracker

At the initial stage main requirements to star tracker were determined: attitude determination accuracy - 15 sec of arc, update rate - 2 Hz, mass of optical head with blend - 1,5 kg., output parameter - orientation quaternion in the inertial frame of reference. More detailed requirements to optical system of star tracker were also determined: field of view - 20 degrees, diameter of entrance pupil - 25 mm, spot of confusion diameter - 85% of energy in 39 micrometer [2]. Requirements to detector, structure of electronics unit, CPU capacity, RAM memory space and permanent memory capacity were determined.

Then at the second stage within preliminary design selection of optical system variant of star tracker experimental model was carried out with account of developed requirements. Herewith, three variants of optical system were considered. Design and calculations with help of program sys-

tem ZEMAX was carried out for each variant of optical system. The change of qualitative characteristics of optical system was studied in the process of design. As a result the six-lens optical system was selected as it allows compensating the majority of aberrations, and values of main qualitative parameters were not worse than the values of given parameters received for other variants of optical system. Work on selection of detector, blend and equipment of electronics unit were also carried out at the stage of preliminary design.

At the stage of detailed design the drawings on objective construction, drawings on star tracker experimental model construction were developed. Functional diagram of electronics unit and software architecture was also developed.

2 Production of star tracker optical system

At the following stage on the basis of results of preliminary and detailed design the optical system of experimental model of star tracker was produced. The production technique of star tracker optical system consists of the following main stages: a) preliminary work (material acquisition, preparation of required equipment, instrument fabrication, production of trial glasses); b) production of optical details of star tracker (lens); c) production of mechanical details (case, different thread ring gage and spacers); d) assembly of star tracker optical system.

Different marks of optical glass were used for production of lens of optical system of star tracker. Production process of optical system consists of stages of oversplitting and cutting, roughing, rough and fine grinding, polishing and covering of work surface of optical details. Herewith at each stage of technological process of optical details production their control was performed. In particular, at the stage of rough and fine grinding the control of radius of curvature, cock and thickness of lens work surface was performed. At the stage of polishing control of lens work surfaces by means of trial glasses was performed. As a result three kits of lens were produced, one of which is given in fig. 1.

Also the kit of mechanical details of star tracker optical system was produced, which consisted of objective case, spacer and thread ring gage used for division and fastening of optical system lens.

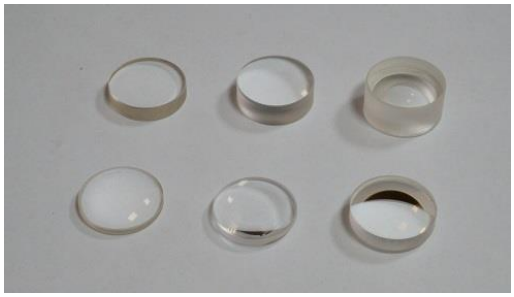

Fig. 1 - Optical system lens of star tracker experimental model

After production of optical and mechanical details of star tracker optical system its assembly was performed that consisted in installation of optical and mechanical details in case of star tracker objective in the order established at a stage of preliminary design. The result of optical system assembly of star tracker experimental model is given in fig. 2.

Fig. 2 – Optical system of star tracker experimental model

3 Development of mathematical support and software of star tracker

Mathematical support and software of star tracker experimental model is based on algorithms of preliminary image processing, star identification and attitude determination. Its general scheme is given in fig. 3.

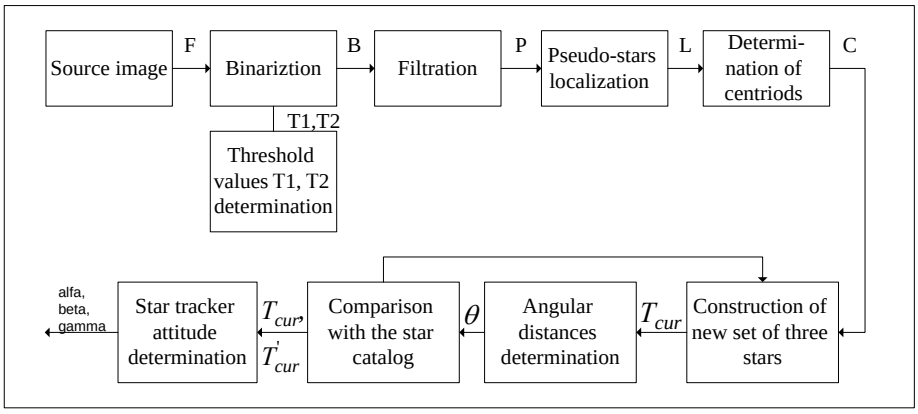

Fig. 3 – General scheme of mathematical support and software of star tracker

Image formation is based on processing of the detector output data of the star tracker. The resulting image is a matrix of pixels (F) with the intensity in a certain wavelength range.

After the source image acquisition its binarization is carried out which transforms source image into binary. For this purpose it is used the threshold values of binarization that are calculated for every image and allow excluding excessive information on image and marking out objects contours.

At the following stage after binarization image filtering with the use of median filter is performed [3], which provides smoothing and maximal preservation of image contours and noise elimination of different nature.

Then localization of pseudo-stars is performed which involves the allocation of connected regions by image tracking with help of special eight-coherent mask. After that determination of pseoudostar centriods (coordinates of its centers) is performed.

Here it is necessary to note that binarization, filtration and localization of pseudo-stars is executed on EPLD, as they represent the operations requiring high-computing power.

After all pseudo-stars is allocated and array of its centroids is formed, it is transmitted to CPU where the stars identification is performed by comparison of pseudostars with the star catalog. Generally identification of stars is performed by some pseudo-stars configurations, in this case for identification the set of three pseudo-stars were used (T_{cur}), which constructed on the basis of one

pseudo-star and two its nearest neighbours. Herewith for each pair of pseudo-stars, belonging to the set of three, the angular distance(θ) is calculated which is compared with angular distances of stars in star catalog by means of the K-vector method [4]. K-vector method passed successful verification on spacecrafts and has much better performance in comparison with traditional search methods, for example method of binary search.

As a result of identification it becomes known the coordinates of three stars in the coordinate system of star tracker and corresponding to it inertial coordinates in star catalog. Attitude determination of star tracker in the inertial frame of reference is performed on the basis of correlation connecting the coordinates of identified stars in the field of view of star tracker and corresponding star coordinates in star catalog.

For testing the mathematical support and software of star tracker program simulation complex was developed which allows imitating the image acquisition process of star tracker with account of clutter and noise conditioned by operation of detector and optical system errors, also with account of star tracker dynamics. This program simulation complex allowed comparing the star tracker attitude obtained by means of its software with star tracker attitude obtained by means of star tracker dynamics model embedded in simulation complex. As a result of comparison the assessment of attitude determination accuracy of star tracker by means of its software was carried out. Star tracker optical axis attitude determination accuracy is 18, 5673 sec of arc, rotation angle around optical axis determination accuracy is 21, 4973 sec of arc. These results correspond to the requirements to star tracker and by that testifies the adequacy of work of its software that gives the grounds for its usage on experimental model of star tracker.

4 Testing of star tracker experimental model

Carrying out the tests for evaluation the performance of star tracker and defects correction is the important stage in the process of star tracker development. Monitoring and testing of certain components of star tracker experimental model - optical system and software - was carried out at the stage of its development, as described in the previous sections. The next stage is testing the experimental model of star tracker as a whole.

Currently assembling of star tracker experimental model is carried out, the results of which are shown in fig. 4. In particular, assembling of the optical head and electronic unit of star tracker experimental model is carried out and lens hood is installed. To test the developed experimental model of star tracker laboratory bench is being developed. The general scheme of laboratory bench is shown in fig. 5.

Fig. 4 - Experimental model of star tracker

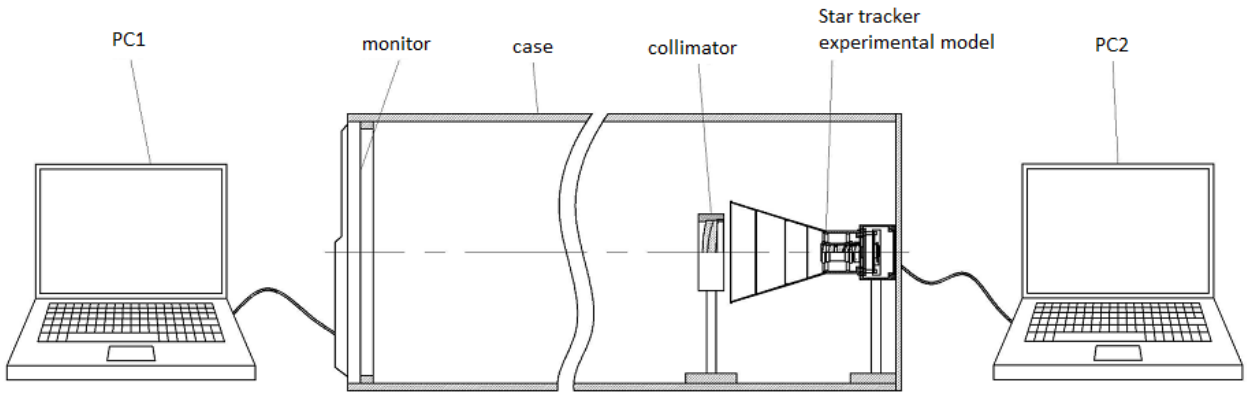

Fig. 5 - The scheme of laboratory bench for testing the software and optical system of star tracker experimental model

Laboratory bench consists of a case providing the external light sources protection, star tracker experimental model, collimator and two personal computers. One of the PCs (PC1) with high-resolution monitor is a simulator of the starry sky, which reproduces the image of the starry sky with account of satellite dynamics. Second personal computer (PC 2) is used for running the software for analysis of obtained star tracker attitude parameters in order to determine their deviation from star tracker attitude parameters obtained with help of satellite dynamics equations, also this software is used for analysis the quality of obtained images.

After the ground tests the next stage is testing the star tracker in the conditions of space. One of the possible versions to do this is the usage of star tracker as the payload on the microsatellite. Known example are the successful european projects PROBA-1 [5], PROBA-2 [6], allowed to carry out verification of star trackers and other devices of platform and payload of the spacecraft in the conditions of the space. The other possible version is the verification of the star tracker by means of commercially available service platform, for example CubeSat 6U, which at present finds application for the solution of many scientific and technological problems [7], [8].

Conclusion

Main stages of development of star tracker experimental model for satellite are considered in this article. At this moment the optical system, electronic unit, mathematical support and software of star tracker experimental model have been developed, the work on development of testing equipment for star tracker is being carried out. Versions of testing the star tracker in space with help of microsatellite are considered.

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