



Simulation System for Space Debris Intelligent Detecting

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Abstract. Space debris has become a major potential safety hazard to the on-orbit spacecraft, which must be considered when launching a spacecraft. A simulation verification system which ground-based and can simulate the debris detecting onboard was established. The system consists of three sub-systems. The background generation sub-system could ensure maximum coverage of the debris targets by adjusting parameters such as satellite orbit, satellite attitude, optical load observation angles, and observation direction. The target identification and tracking sub-system could improve the ratio of track recognition and accuracy by adjusting the detection capability of optical load, switching target recognition and trajectory tracking algorithm. The orbit cataloging sub-system, the processing method of cataloging data can be determined by the process of determining the initial orbit, associating the initial orbit and determining the orbit accurately etc. The system will lay a foundation for updating and enriching the debris cataloging library in the future.

Keywords: Debris intelligent detecting · Simulation system · Target identification and tracking · Orbit cataloging

1 Preface

With the developing of space technology, space activities of human are continual more and more. And at the same time, artificial spacecraft was launched in the space more and more. Risks of collide between spacecraft are increasing simultaneously. Safety operation of spacecraft faces serious threaten. Therefore, technologies of space collision warning, space evasive operation, space debris removal etc. have been carrying out by space superpower countries. The base research of those technologies is detecting and cataloging space targets effectively [1–5].

Research on space debris cataloging is inadequate in China now. Simulation system for space debris intelligent detecting was established in this paper. The system is consisted of background generation sub-system, target identification and tracking sub-system, and orbit cataloging sub-system. The functions of the system are carried out by

inputting the parameters and total control manage. The system can be used to simulate the procedure of debris detecting in space. This integrated simulation system is aimed at verifying the feasibility of the space debris catalog system. The research will lay a foundation for updating and enriching the debris cataloging library in the future.

2 Background Generation Sub-system

Background generation sub-system could achieve the functions to simulate the real sky, including stars, space debris, sun, moon, etc. and to simulate starry sky shot by satellite camera system and put out the image data as projection.

The functions of the sub-system are mainly achieved by image simulator. To develop image simulator, development of optic-coupling system, development of micro-mirror array and driver, and development of controlling system are all carried out. Beyond that, development of landscape-simul computing is also achieved.

In brief, based on Multi-Coordinary transforming and Julian Day computing algorithm, we have realized a dynamical and synchronized landscape generating of aerospace fragments and stars. Our work could serve as data provider of discussing of key parameters of observing, recognizing and labeling aerospace fragments.

3 Target Identification and Tracking Sub-system

Data receiving and processing is critical for target identification and tracking sub-system. Structure of the sub-system is showed in Fig. 1. The sub-system consists of receiving system, data processing and display system, and calibration system. The sub-system can achieve the functions such as simulation of optical load on space debris image acquisition process, obtaining the trajectory data by extracting the debris target in the space debris and analyzing the trajectory.

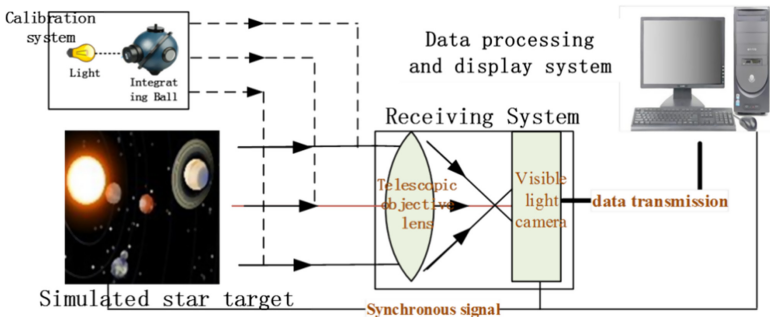


Fig. 1. Structure of target identification and tracking sub-system

Data processing and display system processes the data obtained from receiving system. The first step is image subtraction. The second step is image denoise. The third step

is star debris target recognition. The fourth step is debris trajectory tracking. And then, the trajectory data will be passed to cataloging system.

Subtract star target recognition method and interframe difference recognition method are used together in star debris recognition algorithm for take advantages of these two methods. Combination of two method will guarantee quickness and accuracy in targets recognition. First, use interframe difference recognition method. If effective data cannot be obtained, subtract star target recognition method follows. After analyzing, centroid error limits at 0.5 pixel in Interframe difference recognition method. The error is about 0.021 mrad under condition of $4^\circ \times 4^\circ$ FOV.

For guarantee trajectory tracking identification accurately, trajectory tracking algorithm integrated advantages of two methods which are search method based on centroid domain and algorithm based on mean shift target tracking. Trajectory tracking algorithm use these two method together.

After trajectory tracking identification accurately, trajectory description is carried out. Trajectory description method use 3D curve display function in Teechart. The character of the method is coordinates of any target are visible at any time. The coordinates are azimuth, elevation angle and time. Schematic diagram of target identification and tracking result showed in Fig. 2.

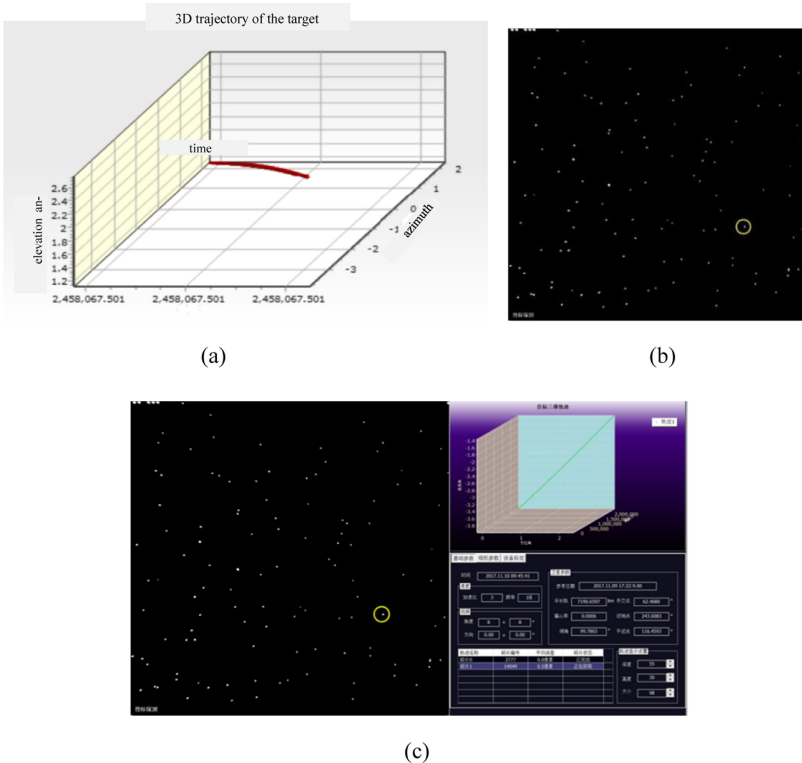


Fig. 2. Schematic diagram of trajectory simulation: (a) 3D display result; (b) Circle the target from FOV; (c) identification

4 Orbit Cataloging Sub-system

Orbit cataloging sub-system could simulate new-found debris cataloging and maintain existing debris cataloging. Also could match obtained cataloging data in database to decide how to deal with it, then update the database. Data processing flowchart of orbit cataloging sub-system showed in Fig. 3.

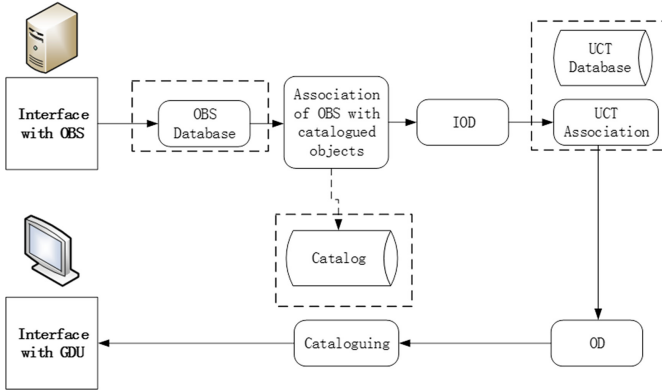


Fig. 3. Flowchart of data processing

Association of observations with catalog objects is carried out by using the orbits of the catalogued objects, and the predicted observations are computed. The differences between the computed and true observations are the basis to judge whether the true observations are of a catalogued object. Flowchart of association of observations showed in Fig. 4.

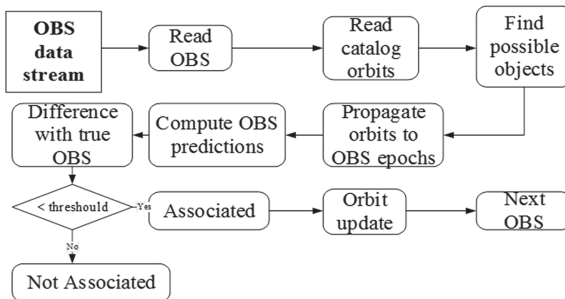


Fig. 4. Flowchart of association of observations with catalog objects

Characteristic of very short-arc (VSA) is short length (may be only several seconds), dense observations (>1 Hz), and low accuracy (5–10''). Distance search method was used to initial orbit determination.

Track Association is given by two independent tracks (IODs), and to determine whether they are of the same object. For the VSA IOD solutions, the errors of IOD

elements are usually very large, so the track association is very difficult. To solve this problem, a geometrical approach is applied which based on geometrical distances to achieve track association. Simulation experiment of track association for space targets under a large scale nearly circular orbit were carried out. This approach was studied carefully. Track Association of SBSS IOD solutions are showed in Table 1. Track Association of ground EO array IOD solutions are showed in Table 2. Performance assessment shows the approach is high true positive rate, high computing efficiency, resilient on the errors of the semi major axis, sensitive to the eccentricity errors. When two IOD solutions are less than 24 h apart, the track association success rate is more than 80%.

Table 1. Track association—SBSS IOD solutions

Pairs from same objects			Pairs from different objects		
Association number		Rate	Association number		Rate
Total	15060	100.00%	Total	35690415	100.00%
Correct	12551	83.34%	Correct	35533470	99.56%

Table 2. Track association—ground EO array IOD solutions

	<3 day		<2 day		<1 day	
Same object pairs	35,100		25132		11252	
Correct	30287	86.26%	22043	87.71%	10255	91.14%
Wrong	4813	13.74%	3089	12.29%	265	8.86%
Different object Pairs	46332919		32424093		16277733	
Correct	46159605	99.63%	32305591	99.63%	16235490	99.74%
Wrong	173314	0.37%	118502	0.37%	42243	0.26%
Mean separation time (min)	1095		1741		438	

Debris cataloguing was carried out based on simulation data of detecting and track association result. A summary of cataloguing new objects using the SBSS simulation data is given in the Table 3. The results shows, When an object has three or more IOD solutions, the cataloguing success rate is more than 80%. When an object has four or more IOD solutions, the cataloguing success rate is more than 90%. It was showed that more numbers of observation, the more feasibility of orbit cataloguing will be achieved. The procedure of this paper to processing the data is designed reasonable and is easy to be realized. Meanwhile, the cataloguing success rate of the approach is high.

Table 3. Cataloguing new objects test using the SBSS simulation data

Number of IOD solutions	Number of objects	Number of catalogued objects	Success rate (%)
≥ 3	559	466	83.36%
≥ 4	328	309	94.21%

5 Conclusion

Simulation system for space debris intelligent detecting was established. The system is illustrated particularly, including three sub-system. We have realized a dynamical and synchronized landscape generating of aerospace fragments and stars, star debris recognition algorithm, trajectory tracking algorithm, IOD of very short-arc (VSA) angles data, track association etc. Target identification and tracking, initial orbit determination were both carried out to ensure the study of debris cataloguing. Simulation system established in this paper, the track association success rate is more than 80% when two IOD solutions are less than 24 h apart. The cataloguing success rate is more than 80% when an object has three or more IOD solutions. The rationality of the space debris intelligent detecting system could be verified by this simulation system. This simulation system also could be an important method of demonstrate key technology for orbit cataloguing. The simulation system will lay a foundation for updating and enriching the debris cataloguing library in the future.

References

1. Li, C., Ouyang, Z., Heng, D.: Space debris and space environment. *Quat. Sci. J.* **22**(6), 540–551 (2002)
2. Huang, B.: *Space Environment Engineering*. National Defense Industry Press, Beijing (1993)
3. Stansbery, G.: *Orbital Debris Research in the United States*, NASA Orbital Debris Program Office, 1–19 June 2009
4. Barton, D.K., Brillinger, D., El-Shaarawi, A.H.: *Final Report of the Haystack Orbital Debris Data Review Panel*. NASA, Technical Memorandum 4809 (1998)
5. *Monthly Number of Objects in Earth Orbit by Object Type*: NASA Orbital Debris Quarterly News 8 (2013)