General Technology Research of GEO Space Debris Exploration System Based on Hosted Situation Awareness Payload

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Abstract. Hosted payload is a typical pattern which is capable of realizing flexibility and separate space system. In this paper, aiming at the shortage that the ground-based facility can not detect small and medium scale space debris, the general index of GEO hosted payload was analyzed, and the working pattern of GEO hosted payload system was designed. The general framework of GEO hosted payload system was studied, accordingly, the efficiency of the system was analyzed. It is hoped that the study will be helpful reference for technology development of hosted payload system general design and space-based debris cataloging.

Keywords: GEO space debris · Hosted payload · Space-based detection · Feasibility research

1 Introduction

Hosted payload is a typical pattern which can be capable of realizing flexibility and separate space system [1, 2]. Putting the payload made from the third party, which has the advantage of relatively small volume and little resource consumption, onto the platform made from another company, and accordingly the hosting platform needs some improvement to supply the setting space, carrying capacity, power supply, orientation control and data transfer to the hosted payload, then some value-added service can be brought to satisfy different need from the consumer, which doesn't affect the satellite's original function. There are many tasks which can be fulfilled by the hosted payload, such as information access, space debris exploration and new technology experiment, etc. [3].

As the human develop more and more space activity, the number of spacecraft and the debirs gets larger and larger. Currently, the debris density of the LEO, especially the polar has already approached critical point, the possibility of the Kessler effect will take place progressively. As to the GEO, there will be no orbit place resource to use in 20 years as long as the trend goes on [4]. As the number of space traffic gets larger and

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larger, the collision possibility between the spacecrafts and debris increase progressively, which will threaten the safety of our GEO space assets.

Developing the GEO hosted payload system of space debris exploration, namely, to host the space debris exploration payload onto the GEO satellite, then, we can take full advantage of GEO orbit and close-distance observation, high efficiency exploration and small debris detection capability for local important area will be developed relatively rapidly and economically. In this paper, aiming at the shortcomings that the current ground-based equipments can not detect small and medium scale debris, the feasibility of hosted payload detection for GEO debris was studied. General index of the hosted payload was analyzed, the working pattern for hosted payload detection was designed, the general frame design approach for GEO hosted payload was put forward and the system efficiency was studied. This paper will offer beneficial reference to the study of hosted payload system.

2 General Index Analysis for the GEO Hosted Payload

2.1 Analysis for Detection Pattern and the Spectrum

According the distribution characteristic of the space debris, there are quite a few GEO space debris more than 97%, whose orbit altitude distribution is at the range of GEO ± 100 km and the orbit inclination is no bigger than 15°.

During the period when the space debris move on the orbit, in quite a few percent of the duration, the debris is in the period of sunlight, then the debris can be detected by using the reflex spectrum characteristic. There are short umbrage at vernal equinox or at autumnal equinox, for different space debris of different inclination, the duration when the debris is in the umbrage is shown as the following table (Table 1).

Table 1. Duration in the umbrage for different debris of different inclination

Inclination	The time of day	umbral/h	penumbra/h	umbrage/h
0°	Vernal equinox	1.12	0.04	1.16
	Midsummer	0	0	0
	Autumnal equinox	1.12	0.04	1.16
	Midwinter	0	0	0
15°	Vernal equinox	0	0	0
	Midsummer	0	0.45	0.45
	Autumnal equinox	0	0	0
	Midwinter	0	0	0

In one year, for debris of different inclination, the duration when the debris is in the daylight and in the umbrage are shown as the following table (Table 2).

Table 2. The umbrage duration of different inclination space debris in one year

Debris inclination	Daylight	umbrage	umbrage percent
0°	363.33 day	3.67 day	1%
10°	363.27 day	3.73 day	1%
15°	363.43 day	3.57 day	1%

In summary, the duration when the debris moving in the umbrage is very small, which takes up almost 1% time percent. At the same time, to detect these debris, the long wave infrared approach will be used. So, thinking about the efficiency-expense ration, the visible light camera will be used as the detection payload. Synthetically thinking about the permeance ability of the optical material and the spectrum response of the detector, the spectrum is determined as 0.45–0.85 μm.

2.2 Analysis for the Detection Ability

In this paper, 30 cm debris will be used as the typical scale object to be detected. Thinking about the feasibility of the payload, the detection ability is chosen as 10 cm@3000 km. The illumination angle is chosen as 45°, then the detection ability of the optics should be 15.4 Mv.

2.3 Analysis for the Centroid Determination Precision

Angle precision and centroid determination precision have the influence on the measurement precision of chronometer angle [5]. According to the precision analysis of STARE, the measurement error caused by angle precision and centroid determination precision is relatively bigger, which is above 25% for STARE and above 40% for MOST, so the angle precision and centroid determination precision should be optimized. According the centroid determination ability of foreign payload, the angle precision is required to be 60 μrad and centroid determination precision should be 1/3pixel.

2.4 Relative Motion of Detection Payload

The bigger the inclination of the debris is,the relative motion magnitude of the hosted payload will get bigger. Take the debris of 15° inclination as classical object, relative motion between the debris and the hosted payload was analyzed. When the pointing longitude difference between the debris and hosted payload vary from 1° to 12.25°, the maximum azimuth, elevation and relative angular motion are shown as the following table (Fig. 1 and Table 3).

2.5 Analysis of the Caliber of the Hosted Payload

We chose the detector of 12 μm dimension pixel, and the field of view is 6° × 6°, the pixel number is not smaller than 2k × 2k. Then the focal length of the camera is 235 mm.

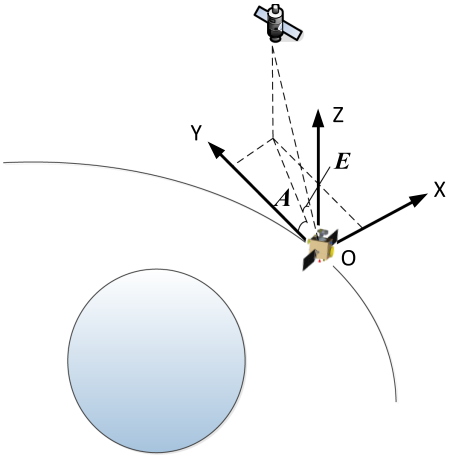

Fig. 1. Sketch of relative motion reference frame.

Table 3. Relative motion of 15° inclination debris

Pointing longitude difference between the debris and hosted payload	Maximum azimuth	Maximum elevation	Maximum relative angular motion
1°	89.97°	86.80°	0.0630°/s
5°	25.12°	72.07°	0.0126°/s
10°	16.30°	56.80°	0.0063°/s
12.25°	15.3057	50.9696	0.0051°/s

The integration time was considered as 0.5 s, then as to the debris of 15° inclination whose pointing longitude between itself and the payload is 12.25°, we can see that during the period of integration time the movement of debris onto the detector is no longer than one pixel. We chose the SNR as 5, then the caliber was almost 135 mm, and the F number was 1.74, the camera like this will have a relatively better engineering feasibility.

In summary, the general technology index demand of the hosted payload is:

- detection spectrum: 0.45–0.85 μm.
- detection ability: 30 cm@9000 km (15.4 Mv).
- field of view: 6° × 6°
- pixel number: 2k × 2k.
- caliber: 135 mm.
- focal length: 235 mm.
- SNR: 5

3 System of the GEO Hosted Payload

3.1 Detection Pattern of Hosted Payload

The hosted payload is fixed on the eastern and western side of the hosting satellite platform, taking the advantage of big field of view, high detection sensitivity and space-based observation distance, to detect and catalogue the GEO debris near to the hosting platform. As is known from the knowledge of GEO characteristic, as long as the sunlight condition is available, the hosted payload can detect the debris real time, which will make up the deficiency that the current ground-based equipment can not detect small and medium scale debris. At the same time, for the same debris, the observation angle from eastern and western payload will be different as almost 90°, which can make up the time-window that the ground-based equipment can not work at the daytime, and it will be benefical for long-term surveillance ability come into being (Fig. 2).

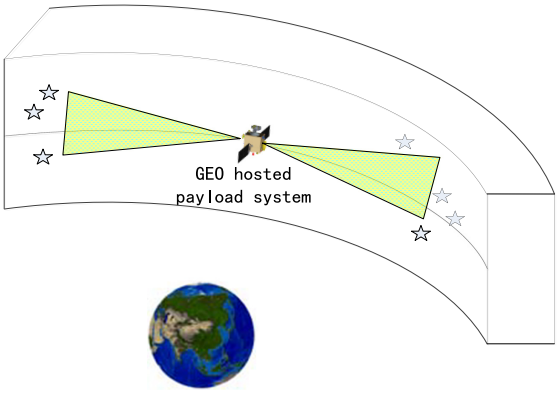

Fig. 2. Working pattern of hosted payload detection

Duration of the Hosted Payload Along Sunlight Observation

The table below shows that when the host-payload is at the along sunlight observation condition, the duration of observation at the vernal equinox, the autumnal equinox, the midsummer, and the midwinter will be as long as 5–8 h (Fig. 3 and Table 4).

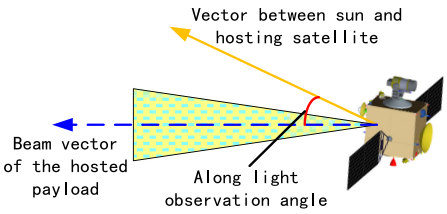

Fig. 3. Along sunlight observation angle.

Table 4. Total duration of the hosted payload along sunlight observation in one day

Observation time	Total duration of the hosted payload	
	Along sunlight observation angle 45°	Along sunlight observation angle 60°
The vernal equinox, the autumnal equinox	6 h	8 h
The midsummer, and the midwinter	5.27 h	7.62 h

The Platform Stability Demand from the Payload

The integration time was considered as 0.5 s, the platform should offer enough stability, to make the drift of debris onto the detector no longer than 1/3 pixel, then the platform stability can be derived as 0.002°/s.

3.2 Sunlight Elusion Pattern

Taking the remote sensing satellite as the hosting platform, in a typical day, the along sunlight angle of two payloads and the main earth observation payload are shown as the following figure (Fig. 4).

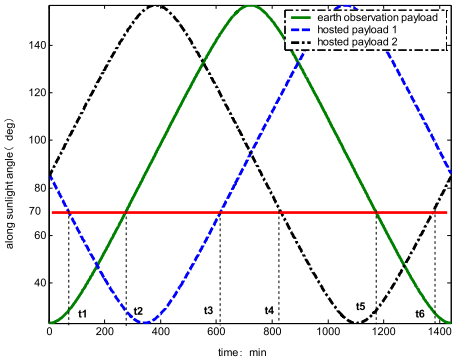

Fig. 4. The along sunlight observation duration alternate with time for the hosted payload and the main earth observation payload.

Therefore,to satisfy the need that the along sunlight angle should be no bigger than 70°, the payload will go into standby working pattern when the sunlight condition is not permitted. In addition, the payload should maneuver when the payload is against the sunlight and go into sunlight elusion mode. To minish the effect to the hosting platform, considering that if the whole satellite's attitude change, the cost will be too high for the platform to accept, so the payload should be designed with two-dimensional rotational machine collocated as shown as following figure (Fig. 5).

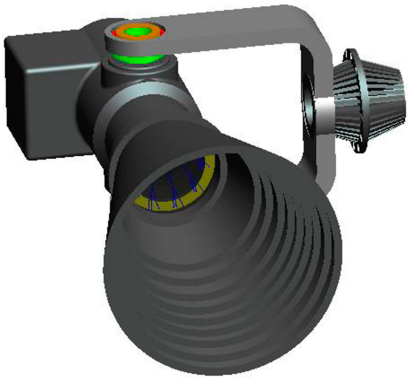

Fig. 5. Hosted payload with two-dimensional rotational machine collocated.

4 General Design and Efficiency Evaluation of GEO Hosted Payload System

Ideally, suppose hosted payload system constellation can be disposed according to demand, and the hosted payload can be placed onto the eastern and western side of the GEO satellites, then the debris between two neighbor hosting satellites can be detected one-fold coverage or two-fold coverage.

4.1 Design Approach

As is shown from the figure below, the hosted payloads are placed onto N evenly distributed GEO satellites. To realize one-fold coverage, the smallest detection range of the payload should be (Fig. 6)

$$L = R \cdot tan(\alpha)$$

$$\text{where } \alpha = \frac{360}{2\text{N}}$$

The smallest field of view should be

$$\theta = \frac{\pi}{2} - \left(\frac{\pi - \alpha}{2}\right) = \frac{\alpha}{2} = \frac{360}{4N}$$

To realize two-fold coverage, the smallest detection range of the payload should be (Fig. 7)

$$L = 2R \cdot \sin(\alpha)$$

The smallest field of view should be

$$\theta = \alpha = \frac{360}{2N}$$

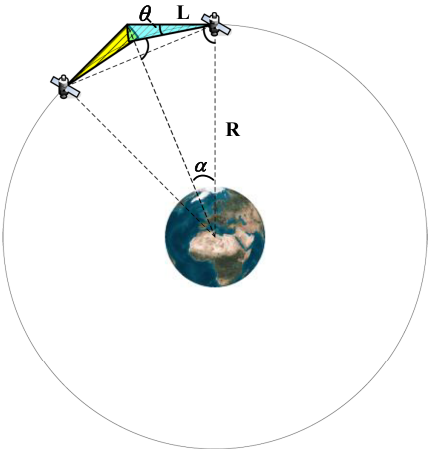

Fig. 6. Sketch of one-fold coverage.

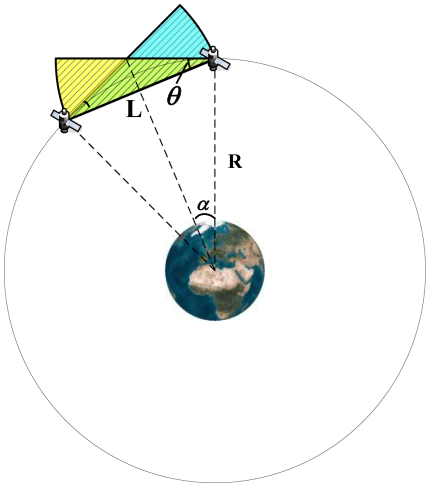

Fig. 7. Sketch of two-fold coverage.

4.2 Design Result

To realize one-fold or two-fold coverage real time to the whole GEO belt debris, when the number of constellation is from 12 to 30, the required detection range, detection ability and the minimum field of view are shown as the table below (Tables 5 and 6).

So, according to general index analysis of the hosted payload, one-fold coverage can be realized when the number of satellites of constellation is at least 15, and two-fold coverage can be realized when the number of satellites of constellation is at least 30.

Table 5. GEO hosted payload constellation design of one-fold coverage

The number of satellite	One-fold coverage design		
	Detection range (km)	detection ability (Mv)	Field of view (°)
12 sats	11297.9	15.8971	7.5
14 sats	9623.7	15.5488	6.43
15 sats	8962.3	15.3942	6
16 sats	8387	15.2502	5.625
28 sats	4750.8	14.0160	3.2143
29 sats	4585.6	13.9391	3.1034
30 sats	4431.6	13.8649	3

Table 6. GEO hosted payload constellation design of two-fold coverage

The number of satellite	Two-fold coverage design		
	Detection range (km)	Detection Ability (Mv)	Detection range (km)
12 sats	21825.8	17.3270	15
14 sats	18764.8	16.9988	12.86
15 sats	17533	16.8514	12
16 sats	16452	16.7132	11.25
28 sats	9441.8	15.5074	6.4286
29 sats	9117.5	15.4315	6.2069
30 sats	8814.7	15.3582	6

4.3 Efficiency Estimation

From the hosted payload constellation, 15 satellites and 30 satellites constellation are shown as the figure below (Figs. 8 and 9).

Hundreds of GEO debris were selected to do simulation, the simulation duration was one day. From the table below it can be seen that compared with one-fold coverage constellation, two-fold coverage constellation can make up working time window between the eastern and western neighbor payload caused by the sunlight condition, and mean detection duration will be increased from 485.93 min to 888.43 min, which will be benefical to constant detection for GEO debris (Table 7).

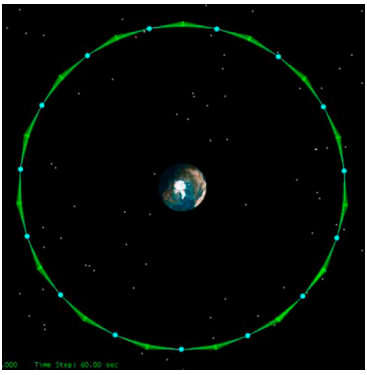

Fig. 8. One-fold coverage constellation made up of 15 satellites

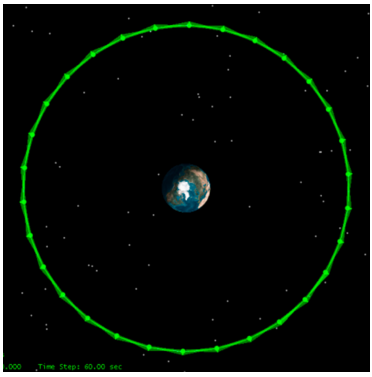

Fig. 9. Two-fold coverage constellation made up of 30 satellites

Table 7. One-fold and two-fold observation efficiency of GEO hosted payload constellation.

Number of constellation	Detection proportion of the GEO debris	Mean observation times	Mean single time detection duration	Mean total detection duration
One sat	8.17%	1.94 times	417.45 min	833.31 min
One-fold coverage 15sats	96.78%	1.92 times	485.93 min	880.49 min
Two-fold coverage 30sats	99.75%	1.54 times	888.43 min	1032.11 min

5 Conclusion

By analyzing the general index, designing the working pattern, developing general design and efficiency evaluation for the hosted payload of GEO debris detection, the feasibility

of the hosted payload system was completed. In conclusion, the proposed GEO debris hosted payload can be capable of detecting small and medium scale debris, which will provide support to the development of integral space-based and ground-based debris detection system.

References

1. Hong, H., Ni, S., Chai, L.: Hosted payload can the development situation. China Space **2014**(8), 25–28 (2014)
2. Liu, H.: Research on hosted payload development of foreign commercial satellitesp. Foreign Space **2014**(1), 24–30 (2014)
3. Kalmanson, P.C., Schueler, C.: A standardized interface and accommodation methodology for commercially hosted payloads on the Star Bus. In: Proceedings of SPIE, vol. 7087, p. 70870R (2008)
4. Gong, Z., Xu, K., Mou, Y., Cao, Y.: Current space debris situation and active removing technology. Spacecraft Environ. Eng. **2014**(1), 24–30 (2014)
5. Yu, J., Su, Z., Tan, Q.: Space-based detection mode of space objects. Quant. Electron. J. **2006**(6), 772–776 (2006)