DETECTION OF SMALL GEO DEBRIS USING AUTOMATIC DETECTION ALGORITHM

Toshifumi YANAGISAWA[(1)], Atsushi NAKAJIAMA[(1)], Hirohisa KUROSAKI[(1)]

[(1)] *Japan Aerospace Exploration Agency, 7-44-1 Jindaiji-Higashi-Machi Chofu Tokyo 182-8522, Japan,*
Email: tyanagi@chofu.jaxa..jp, nakajima@chofu.jaxa.jp, kurosaki@chofu.jaxa.jp

ABSTRACT

We developed an automatic detection algorithm for unresolved small GEO debris that is impossible to detect for usual method. Many CCD images are used to detect GEO debris. With this method, streaks of stars except debris are disappeared completely and the sky background fluctuation decreases extremely. This means very dark debris, which is not visible on a single image, is detectable.

We evaluated this algorithm using actual observation images taken by a 35cm telescope of Mt.Nyukasa Astronomical Observatory and a 2K2K back-illuminated CCD camera. The observation was carried out on 2005 Jan 12 and 13. The total sky coverage of the image area of the CCD camera is about 1.69 square degrees. 68 geostationary regions were observed in the observation. 50 images with a 10-second exposure time were taken for each region. Many GEO objects were detected by analyzing the images with the algorithm. Some of them were unknown GEO objects with a size of 30cm. If a 1m telescope and a back-illuminated CCD camera are used, the algorithm can detect 10cm GEO debris.

1. INTRODUCTION

Advanced space technology research group of Japan Aerospace Exploration Agency (JAXA) has started research on observation technologies of space debris in 1999. A 35cm telescope and a 2K2K back-illuminated CCD camera were set up at Mt.Nyukasa Observatory in Nagano Prefecture, Japan in 2002. We are developing software to detect space debris by using the actual observed data (Yanagisawa et al., 2002: Yanagisawa et al. 2005).

In this paper, we describe an automatic detection algorithm to detect unresolved small GEO debris. A large number of CCD images are cut out to match a target movement and a median image is created from these sub-images. This process removes the effects of fixed stars and enables to detect very dark objects not visible on a single CCD image. We used this algorithm to analyze actual CCD images and confirmed its effectiveness.

The details of the algorithm are described in Section 2. Observations were carried out to evaluate the algorithm. The observation details are indicated in Section 3. The analysis and its results are explained in Section 4. Finally, we discuss the algorithm in Section 5.

2. DETAILS OF THE ALGORITHM

GEO debris moves among fixed stars in the sky. In this paper, GEO debris does not mean debris that is exactly on the geostationary orbit but is around it. This means the GEO debris moves in the sky because of its inclination, semi-major axis and/or eccentricity. Usual observations of GEO debris require a short exposure frame (a few seconds) without an equatorial movement of a telescope. Point sources as GEO debris in the frame are searched. Fixed stars create streaks on the frame. A long exposure time is needed to detect dark GEO debris, but as the exposure time becomes longer, the streaks of fixed stars extend beyond the frame and new fixed stars enter it. These obscure the weak light from small GEO debris. As a result, the exposure time is limited to a few seconds. This process does not detect dark GEO debris below the one frame limiting magnitude.

Taking a median value of many frames with a short exposure solves the problem. The median eliminates any effects from an unexpectedly high signal (in this paper, streaks of stars) and improves the signal-to-noise ratio that enables to detect dark GEO

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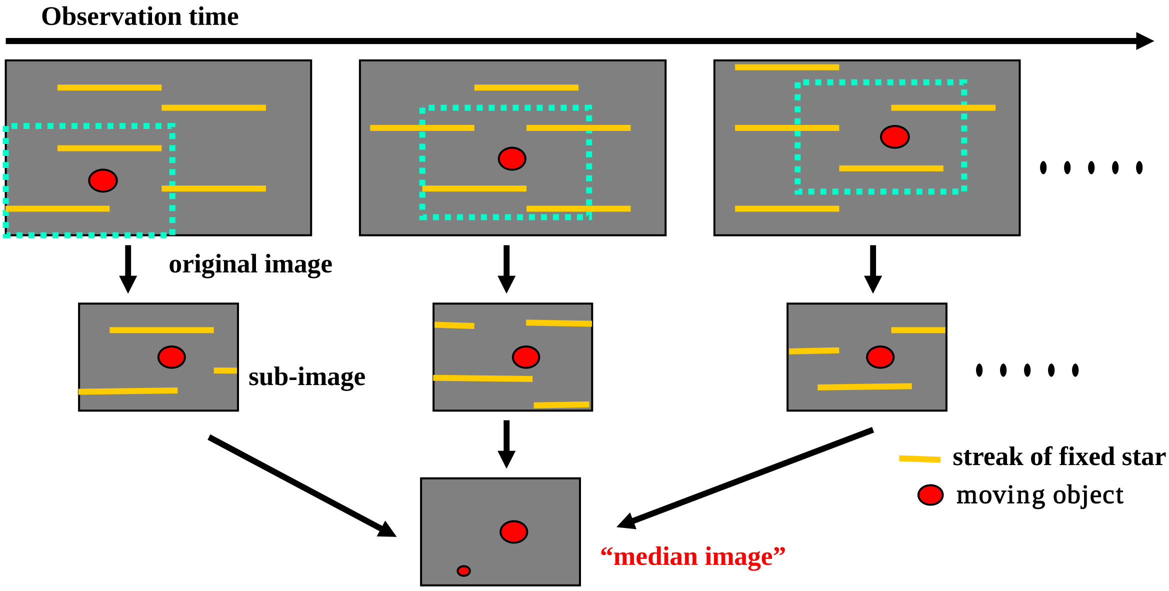
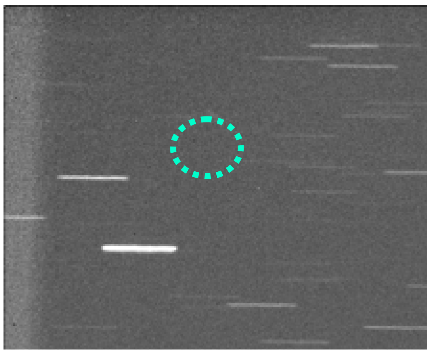


Figure 1. Process of the algorithm



(a)

(b)

Figure 2. An example of debris detected using the stacking method. (a) shows a part of one CCD image and (b) the same region of the final image of the stacking method. Fifteen images are used.

objects. Although the average also improves the signal-to-noise ratio, it is affected by the high value.

As shown in Fig. 1, the algorithm cuts out sub-images from many CCD images to fit GEO debris movement. A median image of all the sub-images is then created. In this algorithm, photons from objects are accumulated on the same pixels of sub-images and streaks of fixed stars are completely removed by taking the median because they are moving on the sub-images. Fig. 2 shows an example of debris detected using the stacking method. Fig. 2 (a) shows a part of one CCD image and Fig. 2 (b) the same region of the final image after the process has been carried out. Fifteen images are used. It is difficult to confirm the presence of the debris in Fig. 2 (a), whereas the debris is bright and no streak of fixed star exists in Fig. 2 (b). Fig. 2 shows that the algorithm is able to detect very dark GEO debris that is invisible on a single CCD image. In order to detect invisible GEO debris on one image, various movements of the GEO debris are assumed and many processes as shown in Fig. 1 are needed.

3. OBSERVATIONS

We performed a trial observation of the algorithm in order to evaluate its effectiveness. The observation was carried out on 2005 January 12 and 13, at Mt.

Table1. Details of detected GEO objects

No.	time0(UT)	R.A.0	Dec0	time1	R.A.1	Dec1	Flux(ADU)	mag(V)
1	9 00 48	47.729	-5.851	9 19 37	52.446	-5.838	7001.92	13.74
2	9 00 48	47.850	-5.727	9 19 37	52.565	-5.724	5128.60	14.08
3	9 40 48	55.619	-5.701	9 59 38	60.339	-5.700	15721.40	12.86
4	10 00 48	58.351	-5.713	10 19 36	63.063	-5.713	9192.58	13.44
5	14 20 49	127.999	-5.629	14 39 41	132.725	-5.627	30621.26	12.13
6	14 20 49	127.943	-5.546	14 39 41	132.673	-5.532	25213.74	12.35
7	15 00 49	135.794	-5.641	15 19 38	140.507	-5.641	23107.40	12.44
8	15 20 49	138.552	-5.667	15 39 34	143.252	-5.667	18849.37	12.66
9	10 40 48	66.099	-5.717	10 59 35	70.805	-5.717	86010.85	11.01
10	11 20 49	73.859	-5.728	11 39 36	78.567	-5.727	20055.83	12.59
11	16 00 48	146.262	-5.689	16 19 30	150.949	-5.689	78179.85	11.12
12	16 40 48	154.048	-5.674	16 59 30	158.733	-5.674	21540.36	12.52
13	12 40 48	89.379	-5.714	12 59 36	94.090	-5.718	24611.90	12.37
14	17 20 48	161.812	-5.680	17 39 32	166.508	-5.680	3213.99	14.58
15	17 20 48	162.092	-5.316	17 39 32	166.808	-5.364	193.17	17.64
16	18 00 48	169.535	-5.758	18 19 37	174.249	-5.760	7486.10	13.66
17	13 00 48	92.590	-5.783	13 19 37	97.323	-5.719	27370.19	12.26
18	13 40 48	99.862	-5.683	13 59 36	104.571	-5.647	5132.92	14.07

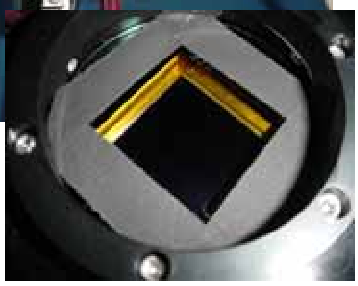



Figure 3. 2K×2K CCD camera mounted on the 35cm telescope and its CCD chip.

Nyukasa Astronomical Observatory founded by amateur astronomers in Nagano Prefecture, Japan. The site is at 138 ° 10 ′ 30 ″ E, 35 ° 54 ′ 00 ″ N, 1810m altitude. JAXA set up a 35cm Newtonian telescope and a 2K × 2K back-illuminated CCD camera at the site for the development of GEO debris and asteroid observation technologies and data analysis processes (Nakajima et al., 2002). Fig.3 shows our CCD camera and installed back-illuminated CCD chip (Marconi CCD42-40). The chip is consist of 2048×2048 pixels whose size is 13.5 × 13.5-micron. Its quantum efficiency at 500nm is about 85%. The total sky coverage of the image area of the system is around 1.27 ° ×1.27 ° . We observed 34 regions on the geostationary orbit without an equatorial movement of the telescope. 50 images were taken with a 10-second exposure time for each region. The readout time of the CCD camera is about 10 seconds. It took 20 minutes to observe one region. 1 dark image was taken before the observation of each region. We also took a 1-second exposure image in order to determine the accurate observed position. In this image, streaks of fixed stars are so short that we can identify them with normal star shapes and compare their pixel coordinates to the Guide Star Catalog. The weather condition was very good and the observation was not bothered by any significant clouds. At twilight time, we got flat field

Table2. Simple orbital elements of detected GEO objects

No.	a(km)	i(°)	Ω(°)	longitude(°)	drift rate(°/day)
1	42165	0.173	92.5	157.95	-0.013
2	42176	0.022	100.1	158.05	-0.148
3	42171	0.016	284.2	156.05	-0.091
4	42169	0.023	258.5	154.04	-0.067
5	42182	0.037	42.0	157.99	-0.232
6	42161	0.179	85.6	157.94	0.038
7	42184	0.035	18.0	156.01	-0.262
8	42165	0.024	7.5	154.02	-0.011
9	42179	0.024	263.6	152.02	-0.188
10	42168	0.014	264.1	150.02	-0.051
11	42167	0.013	341.3	151.98	-0.041
12	42178	0.022	38.2	150.00	-0.176
13	42174	0.070	282.7	146.04	-0.126
14	42164	0.022	54.5	148.01	0.005
15	42058	0.624	15.8	148.26	1.355
16	42179	0.054	288.3	145.98	-0.189
17	42079	0.663	94.3	144.46	1.075
18	42183	0.369	92.4	142.03	-0.256

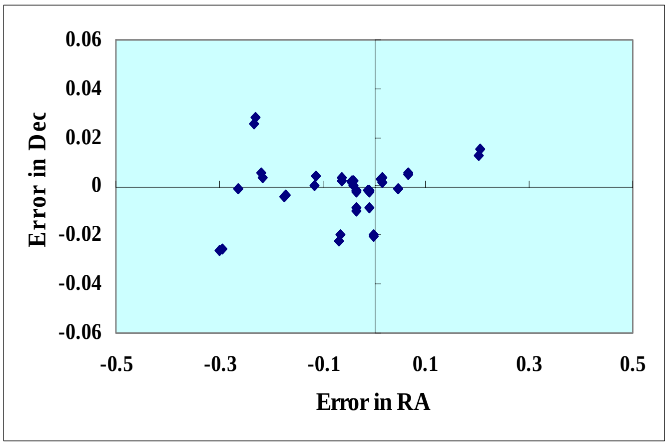


Figure 4. Detected GEO objects' actual positions of second night minus estimated positions from simple orbital elements of same objects calculated from first night data.

images by taking the twilight sky images.

4. ANALYSIS AND RESULTS

The data is stored in the local hard disk and later processed offline. The soft ware IRAF (Image Reduction and Analysis Facility (http://iraf.noao.edu)) was used for the image processing concerning the algorithm. The IRAF can be carried out with the script mode. We developed an automatic analysis process using the IRAF, a script language perl and C language.

In order to detect invisible GEO debris on one image, various movements of the GEO debris are assumed and many processes as shown in Figure 1 are needed. Various types of space debris are closing the observing field. If we try to detect all of the debris, a vast number of processes are needed and that is not realistic for the present machine calculating ability. We concentrate to detect GEO objects whose semi-major axis is 41696-42647 km and inclination angle is 0-1.43 degree. We carried out about 1680 processes for the data of one geostationary region. The detection threshold of the GEO objects is 4 times of the background noise of the median image of the set. If one candidate is detected, the real shift value is searched around the detected shift value until the peak value of the candidate is the maximum. This process does not take time because small images around the candidate are used. We used 5 PC workstations DELL Prescision 340 for the analysis. This machine has one Pentium 4 CPU and 4 GB memories. OS is Red Hat linux ver.8. The time for analyzing one set for one PC is about 12 hours. It takes about 7 days to analyze the data of all regions. We detected 52 GEO objects. Tab. 1 shows the details of some detected GEO objects. 6 of them are un-cataloged objects. Magnitude of the darkest object was 17.8 in V band. This corresponds to a 30cm-size object at geostationary orbit.

We can get 2 positions of the GEO objects with about 20 minutes arc and the times when the objects are at the positions. We determined simple orbits of detected objects using theses positions. Eccentricity was assumed to be zero. Tab. 2 shows the determined simple orbital elements of detected objects calculated from the position data of Tab. 1. By using these orbital elements, we can estimate the objects' position of a few days later.

5. DISCUSSIONS

As we showed in previous sections, the algorithm is powerful tool to detect very small GEO debris that is invisible on a single CCD image. We estimated detection ability of the algorithm. The magnitude of darkest GEO objects detected in this observation was 17.8 with S/N 33. Therefore, the algorithm can detect 19.1-magnitude objects with S/N 10 and 19.9-magnitude objects with S/N 5 which correspond to 20cm-size objects and 15cm-size objects at geostationary orbit, respectively. If a larger telescope is used for the observation, smaller debris is detectable. A 1m telescope can detect less than 10cm-size GEO objects (21 magnitude) using the algorithm. The Japan Space Forum has established the observatory, Bisei Spaceguard Center (BSGC) that is used solely for the observation of space debris and NEOs (near earth objects: asteroids and comets) (Isobe and Japan Spaceguard Association, 1999: Isobe et al., 2000). It comprises one 1m telescope and one 0.5m telescope. Wide-field CCD cameras consisting of back-illuminated chips are installed on both the telescopes. We would like to apply the algorithm to the observation system of the BSGC in the future.

After detection of GEO objects, we need to determine orbits of theses objects. In order to get precise orbital elements, many observation data may be needed. We also want to observe as many GEO objects as possible for limited observation time. We investigated re-detection probability using two night data. Fig. 4 shows errors of position determination that are objects' actual positions of second night minus estimated positions from simple orbital elements of same objects calculated from first night data. The standard deviation along R.A and Dec direction are 0.135 degree and 0.012 degree, respectively. The field of view of our observation system is 1.27×1.27 square degrees. These means that 2 positions with 20 minutes arc are enough to detect same target next day. After getting many positions, precise orbital determinations should be carried out.

Although the algorithm can detect very dark GEO debris, it takes much time to analyze. For the practical use of the method, we need to reduce the analyzing time. The progress in the processing performance may help to reduce the time required. Or many PCs should be prepared.

We need to manage a number of detected GEO debris in the future. The accurate orbital determinations of all the GEO debris are required for that. We should detect same GEO debris many times in order to determine the orbit of it. Furthermore, we have to observe many regions of the sky for many detections of unknown GEO debris. We need to consider the advantage and the disadvantage of the stacking method, required accuracy for the orbital determination, characteristics of the observation system (for example, readout time, field of view of the CCD camera and pointing accuracy of the telescope.) and so on. Then the best solution of the observation (number of field, images, exposure time, intervals and so on) must be found out for the practical. Umehara and Kimura found out a very efficient procedure that takes following things into considerations (Umehara and Kimura, 2000). (A) A broad observation is realized by scanning GEO. (B) In order to carry out a systematic observation, surveyed range should be sorted according to orbital elements. (C) An efficient observation is considered to reduce operational costs. This type of observation strategy must be established for the systematic observation and the management of GEO debris in the future.

6. CONCLUSIONS

We developed an automatic detection algorithm for unknown small size of GEO debris. This algorithm uses many CCD images and enables us to detect very dark GEO objects that are below the detection limit of one CCD image. Sub-images from many CCD images are cut out in order to fit the GEO object's movement. A median image of all the sub-images is then created. This eliminates the streaks of fixed stars and reduces the sky background noise efficiently. We showed this algorithm can detect 15cm-size objects at geostationary orbit using a 35cm. A 1m telescope can detect less than 10cm objects.

Although the algorithm is very useful to detect very small GEO debris, it takes much time to process whole the data. We need to find out an efficient strategy using the method for the future systematic observation of GEO debris.

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