Space Debris Observation Programs in JAXA

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ABSTRACT

Institute of Aerospace Technology(IAT) of Japan Aerospace Exploration Agency(JAXA) has been studying overall the space debris problems from the viewpoint of observation, modeling, protection and mitigation. In the field of observations, optical and radar system are operational. Japan Space Forum(JSF) constructed optical telescopes named Bisei SpaceGuard Center(BSGC) and radar system named Kamisaibara SpaceGuard Center(KSGC) in Okayama prefecture. At BSGC, there are 1.0 meter telescope with 3-degree field-of-view(FOV) and the 0.5 meter telescope with 2 degrees FOV, which have been operated by Japan Spaceguard Association for GEO/GTO debris and asteroids observations. The radar system is operated from Tsukuba Space Center of Office of Space Flight & Operations/JAXA. IAT/JAXA has prepared for space debris optical observation facility for R&D of observation technologies at Nyukasa-highlands, the altitude of which is about 1,900m, in Nagano prefecture last year. The facility has two domes, in which a 35cm Newtonian optical telescope with 2K2K CCD camera and a 25cm BRC optical telescope with 2K2K CCD or 4K4K CCD camera are installed. One of the most important study items in our research and development is to develop an automatic small size GEO debris detection software. In usual case, a long exposure time is necessary to detect faint object by accumulating weak light energy during the time. On the contrary, short exposure observation is necessary for GEO debris detection to avoid the influence of the fixed star streaks image. We have proposed a stacking method for detecting noise level faint GEO debris to accumulate the signals by using a number of images. In this paper, the introduction of JAXA's new observatory and some evaluation results of the developing software are described.

1. INTRODUCTION

JAXA(Japan Aerospace Exploration Agency) has been studying overall the space debris problems from the viewpoint of observation, modeling, protection and mitigation technologies and paying important roles to the international space debris activities; IADC(Inter-Agency Debris Committee) and UNCOPUOS(United Nations Committee on the Peaceful Uses of Outer Space). The consideration of debris problem requires the accurate information of present state of the contamination of real space environment. For that purpose, IAT(Institute of Aerospace Technology)/JAXA has been developing optical observation technologies and constructed a small optical observation facility at Nyukasa-highlands. 35cm and 25cm small aperture telescopes with back illuminated CCD cameras are prepared for data acquisition. This facility was built at an altitude of 1,870 meters with good optical environmental conditions for faint objects observations. The detectable star magnitude is about 20-magnitude and 22 magnitude-class asteroid could be detected by this small aperture telescope by using the developing moving objects detection software. For GEO debris observation, 19-magnitude, nearly equivalent to 20cm-size debris, will be expected to detect. One of the most important study items in our R&D is to develop an automatic small size GEO debris detection software. We have proposed a stacking method[1]-[3] for detecting noise level faint GEO debris to accumulate the signals by using a number of images. For detecting debris for all movements(variety of directions and moving speed), this stacking method requires many calculation time. For shortening the time, parallel processing technologies are added to the developing software.

2. NYUKASAYAMA OBSERVATORY

For the GEO debris observation and detection technology developments, IAT/JAXA has finished the construction of optical observation facility at Nuykasa-highland last autumn[4]. The new observation site is

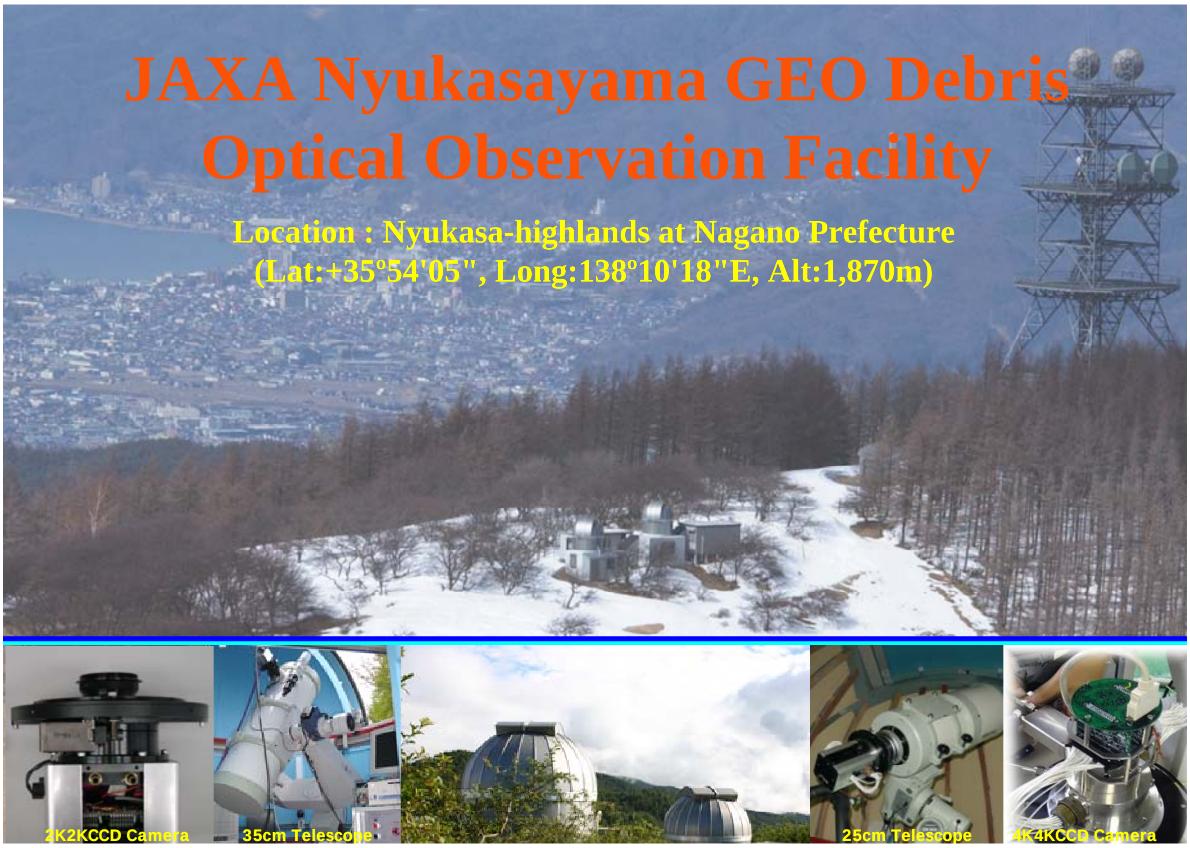


Fig.1 JAXA Nyukasayama Observatory

Table 1 Main Characteristics of the Facility

Coordinates
  Longitude : 138°10'18", Latitude : 35°54'05", Altitude : 1,870m.
Telescopes
  (a) Takahashi ε-350, φ355mm, f=1,248mm, F/3.6, Image Circle φ70mm
  (b) Takahashi BRC-250M, φ250mm, f=1,268mm, F/5.1, Image Circle φ100mm
Mount types
  (a) Showa Kikai Equatorial Folk-Mount
  (b) Takahashi EM-500 Temma2(BRC-250MQT2) → Showa Kikai new Folk-Mount(from Oct.2007)
Domes
  Nisshin dome, φ3m, 2 sets
Cameras
  (a) NIL 1Kx1K back illuminated CCD, 13μmx13μm, Mechanical and Electric Shutters
  (b) NIL 2Kx2K back illum. CCD, 13.5μmx13.5μm, Mechanical Shutter, FOV:1.3°x1.3° for ε-350
  (c) NIL 2Kx4Kx2 back illuminated Mosaic CCD, 15μmx15μm, Mechanical Shutter
    FOV:2.4°x2.4° for BRC-250M
Debris Detection Accuracy
  (a) Time resolution : 10 msec(mechanical shutter on/off time are measured by GPS time)
  (b) Position : 0.2 arc sec(for bright debris), 1 arc sec(for faint debris by the calculation of mean motion)

consisted of two 3-meter domes for 35cm and 25cm telescopes with equatorial mounts, 1Kx1K and 2Kx2K back-illuminated CCD cameras cooled by perch devices and 4Kx4k CCD camera cooled by refrigerator. 35cm telescope is supported on the folk-mount and 25cm telescope is supported on the german-equatorial-mount system, which will be soon replaced with a new folk-mount system with the capability of supporting multi telescopes. Two 25cm telescopes will be mounted on the system. Fig.1 shows the overview of the facility and their characteristics are shown in Table 1.

3. DEBRIS DETECTION SOFTWARE

One of the most important study item in our R&D is to develop an automatic small size GEO debris detection software. The stacking method using a number of images taken in the same field-of-view(FOV) will be useful for detecting noise level faint GEO debris. The detecting debris size, in other words, the detecting magnitude is fully dependent on the numbers of the image. 5 frames are minimum number used for this processing. For faint debris detection, few-tens of frames or more are necessary. This method will be adequate to the tracking mode of faint objects by using a small aperture telescope.

3.1 Stacking Method

The automatic debris detection software flow chart is shown in Fig.2.

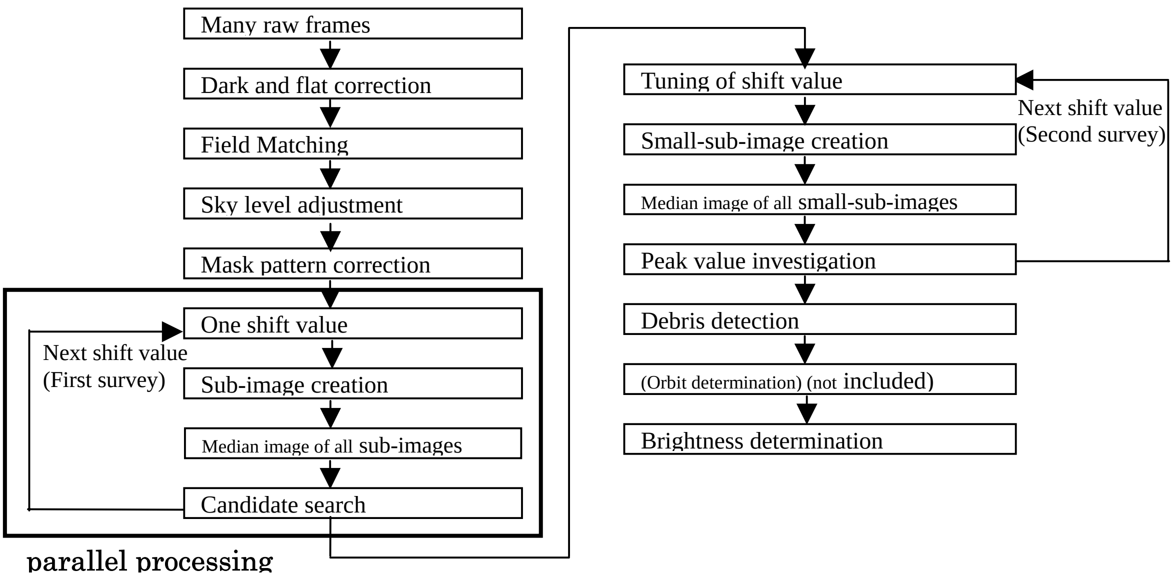


Fig.2 Automatic Debris Detection Software Flow Chart

(1) Dark/Flat Correction
The first process of this software is dark/flat correction. By proceeding this process, hot pixels and some optical distortions are compensated After the correction, image data are stored as image files and used for the following process instead of the raw data.

(2) Field Matching
For the determination of the center coordinate of the FOV, some standard stars are picked up and compared with star catalogue GSC-ACT. For that purpose, raw data with short exposure time(about 1 sec.) is used. After this process, the accurate azimuth/elevation angles of the FOV, accurate area of the FOV and the origin of the time are fixed. The observed time of each debris is counted from this original point.

(3) Mask Pattern Correction

After the sky level adjustment(uniform the sky value in the all images), mask pattern correction is followed. After this process, streaks of the stars are eliminated and debris candidates and other unknown signals are remained.

(4) First Survey

The first survey process picks up the signals larger than a threshold level after stacking sub-images for the given direction and movement. They are given as shift values of pixels for X and Y components. Surveying time(calculation time) of this process is depend on the shift values for X and Y directions and step values. As a typical examples for GEO satellites detection, shift values for each axis are given as –5 to +5 pixels(about –11.25 to +11.25 arc sec.) for X direction and –30 to +30 pixels(about –67.5 to +67.5 arc sec.) for Y direction at every 4 steps during the observation time(10 minutes). In this case, the search counts are calculated as 30 times and the calculation time is about 1 hour. For searching GEO debris with some inclinations, shift values, for example, are given as –30X to +30X pixels and –300Y to +300Y pixels with every 4 steps during 10 minutes observation time. In this case, search counts are 2250 and the calculation time is more than 10 hours by using 1 PC. In order to decrease the calculation time, parallel processing function is added to the software.

(4-1)Parallel Processing method

The parallel processing subsystem is consisted of client PC and server PCs as shown in Fig.3. The operator sets some calculation parameters, i.e. shift values, step value, threshold levels and some information of server PCs to the client PC. Each server PC calculates its own search area, which is distributed by the client PC according to the capability of each PC. The calculation time decreases in inverse proportion to the number of server PCs.

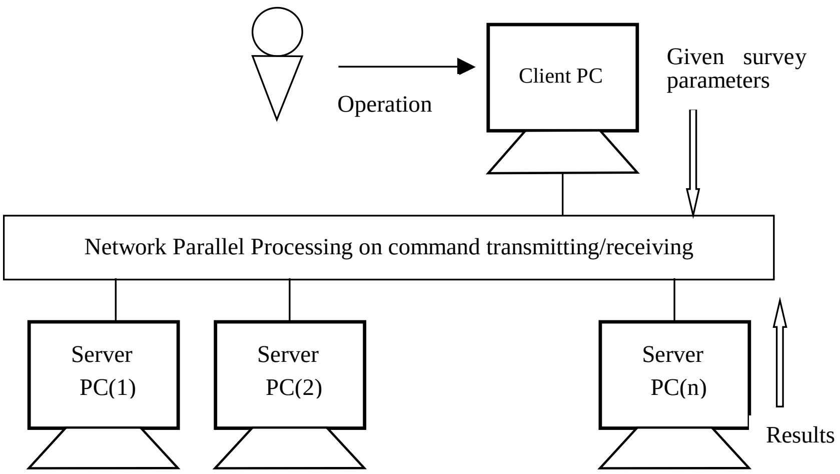


Fig.3 Parallel Processing Subsystem at First Survey Mode

(4-2)Parallel Processing Example(1)

To evaluate the parallel processing capability, the longitude 110 deg. east area was surveyed. At this region, 7 geostationary satellites are operational. The exposure time is 10 sec. and 20 images are used. The observation start time is 2007.06.11 14:53:25(UT) and the stop time is 2007.06.11 15:00:46(UT), then the time interval between them is 441 seconds. The shift values are given as –30X to +30X pixels and 0Y to +300Y pixels with every 4 steps. The maximum calculation movements of GEO satellites and debris are given as 30 pixels/441 sec., which is equivalent to 0.153 arc sec./sec.(= 67.5/441) for east-west direction and 0.765 arc sec./sec. for south direction(from north to south one way). The repeated search counts are1216. In case of one PC processing, the calculation time is 10 hours and 38.25 minutes. On the contrary, the calculation time is decreased to 1 hour and 29.3 minutes by using 8 server PCs. Each PC has the same characteristics, then the calculation loads for each server PC are the same. Client and server PCs are OPTIPLEX GX620(DELL Co.).

(4-3)Parallel Processing Example(2)

The GEO debris with some orbital inclinations cross the equator in the direction of north-south, which is given as a dominant Y-direction shift with small X-direction shift values. The FOV center of the surveyed area, as an example 2, was AZ=167°55'43.4" and EL=47°12'49.2". In this region, MTSAT-2 GEO satellite is operational. The first survey shift values for each direction are chosen as X=±50 and Y=±400, then the search count becomes 5226 times. The observation started from 2007.03.20 19:38:05 (UT) and ended to 19:43:19(UT). 14 images were exposed during 314 sec. The calculation time covered those movements by the parallel processing is 3 hours 46.7 minutes.

For more efficient surveying, the calculation time can be more decreased by limiting the survey area and binning processing. For example, when the shift values are limited as X=±20, Y=-20 and Y=+250 and 4x4 binning processing, the first surveying calculation time is only 2.3 minutes.

(5) Second Survey

The second survey process picks up debris candidates. Through this process, shift value tuning and grouping are conducted. Fig.4 shows the example screen of the second survey results for the parallel processing example(2) as described above. One GEO satellite MTSAT-2, is operational and 2 debris passed through the FOV from north to south direction. These three objects are detected by this software, automatically. The sub-screen in the figure shows the detected stacking image of the equator crossing debris. Three images shown in the left side expressed the movement of the detected debris. These images are used for the checking of the stacking image.

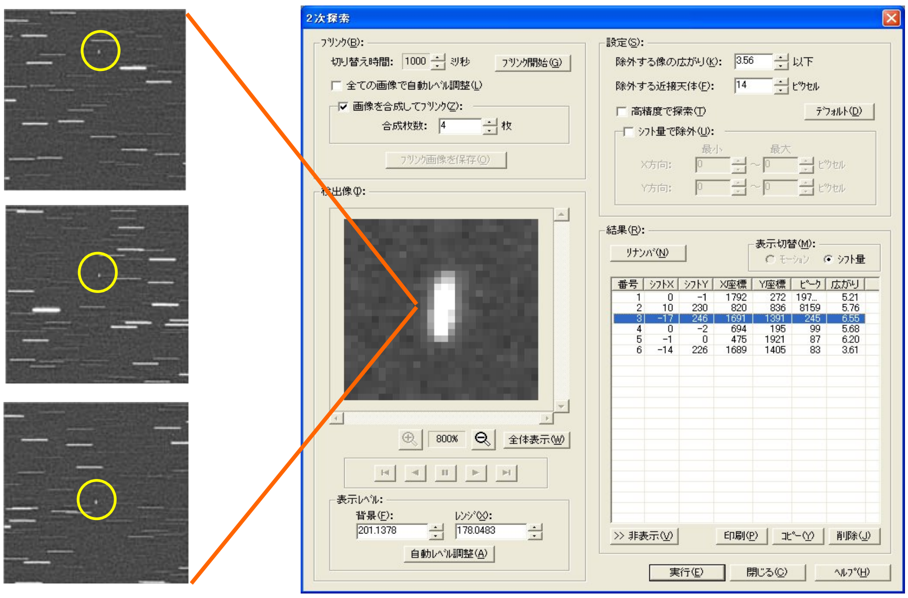


Fig.4 Second Survey Results of Example 2

(6) Mapping

After the determination of the position and brightness on the detected objects, they are mapped on the star chart and also identified with satellites whose orbits are given as TLE data, otherwise, they are categorized as unknown object. Fig.5 and Fig.6 show the traces of the objects for the examples 1 and 2. In Fig.5, 7 GEO satellites, which are controlled their orbits, are shown with slight movements. Some of them are shown in a magnified scale. Fig.6 shows the movements of the detected objects for the example 2 as described before. During the exposure, FENGYUN 1C debris passed through the FOV.

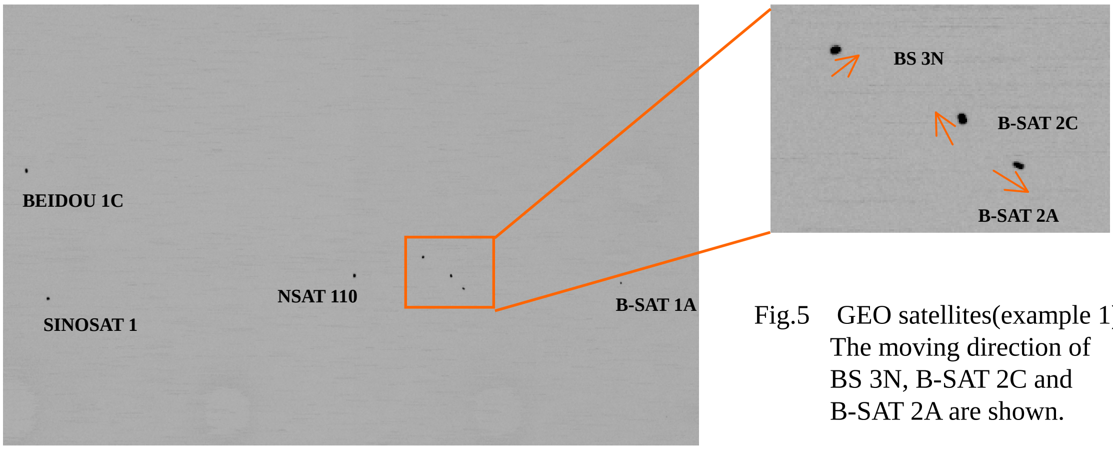


Fig.5 GEO satellites(example 1)
The moving direction of BS 3N, B-SAT 2C and B-SAT 2A are shown.

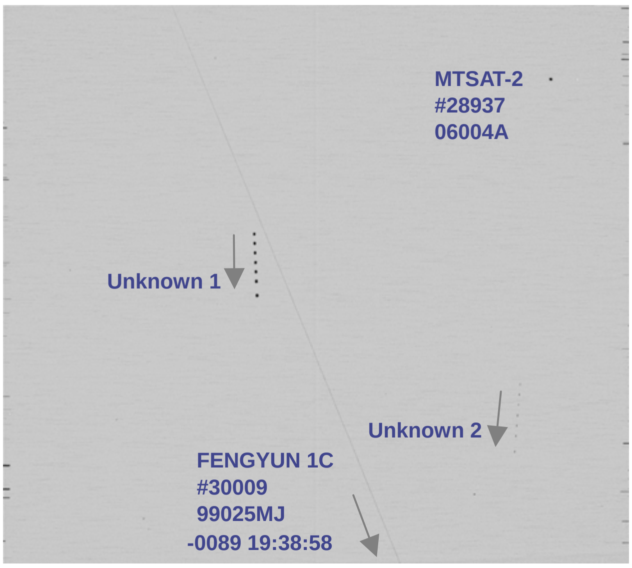
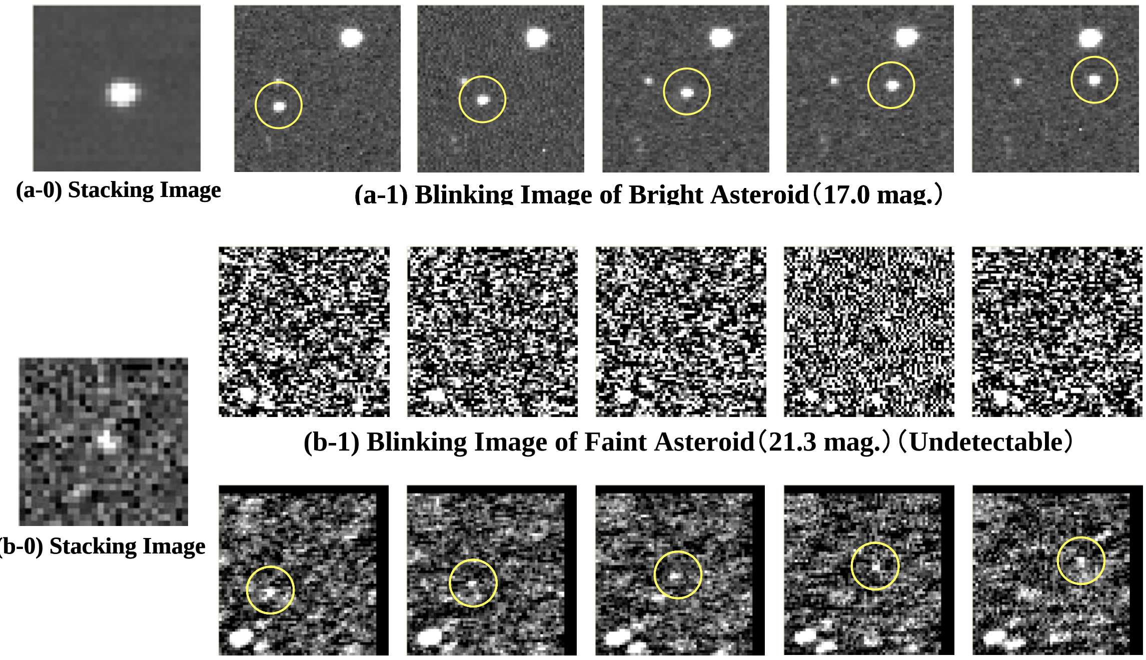


Fig.6 GEO satellite and debris(example 2)

3.2 Evaluation of the stacking Method

For the evaluation of the proposed stacking method, moving objects detection software, which has almost the same algorisms as shown in Fig.2, is demonstrated in this section. As examples, the stacking images of bright and faint asteroids are shown in Fig.7(a-0) and (b-0), respectively. The both images are clear and have enough S/N, then they are recognized as asteroids. For the further confirmation of the existences, blink checking is usually used. For bright asteroid, as shown in (a-1), it can be seen apparently and confirmed. On the contrary, for faint asteroid, which is over limiting magnitude for 35cm telescope, it can't be seen in (b-1) because of its noise-level low signal. In (b-2), it can be seen by applying the stacking blink method.

From these examples, it was proved that the stacking method can improve the detection capability. About 2 magnitudes will be improved for asteroid detection application. For debris detection, it will be expected to have the same improvement.



(a-0) Stacking Image

(a-1) Blinking Image of Bright Asteroid (17.0 mag.)

(b-0) Stacking Image

(b-1) Blinking Image of Faint Asteroid (21.3 mag.) (Undetectable)

(b-2) Stacked Blinking Image of Faint Asteroid (21.3 mag.)

Fig.7 Asteroid Detection Capability Improvement by Stacking Method

4. CONCLUSIONS

Nyukasayama observatory, space debris and asteroids optical observation facility of IAT/JAXA, was introduced. By using the data obtained from this observatory, automatic debris detection software has been developing and improving. For faint debris detection, stacking method, known as shift-and-add method, is useful. For the decrease of the calculation time, parallel processing function was added to the developing software and evaluated. By using 8 server PCs, the calculation time takes about 14 %, compared to that time used only one PC. From the result, it was proven that the parallel processing reduces the first surveying time drastically. For more decreasing the calculation time, survey area and other parameters should be limited to an adequate value for individual debris populations.

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