SURVEY AND TRACKING SYSTEM FOR UN-CATALOGED LEO OBJECTS USING CMOS SENSORS

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ABSTRACT

JALESS (JAXA LEO Survey System) has being developed to carry out the survey for LEO objects, the tracking observation, the orbital determinations and the maintaining the orbits automatically. Two remote observation sites using CMOS sensors have been established for JALESS in Australia. Some of un-cataloged LEO objects detected in the site located on east side of Australia were successfully tracked at other site located on west side of Australia after one cycle of the orbit. The precise orbital determinations were carried out using the data from both sites. The determined orbits were propagated to the future and confirmed that the orbits are accurate enough to redetect the objects next a few days. We also tested the persistence of the orbits determined using a few days' data. One of un-cataloged objects with the size of 20cm in altitude of 900km was successfully redetected about 50 days later by using the orbits

1 INTRODUCTION

In recent years, the space environment has been rapidly polluted by debris generated by orbital destruction experiments, collisions between satellites and mega constellations. The situation in low Earth orbit particularly is becoming serious year by year. The debris problem is an important issue that must be resolved in order to continue space activities. In order to protect active spacecraft, it is necessary to constantly monitor these debris. Currently, the US radar observation network plays this role, but the size of low Earth orbit objects that can be observed is 10 cm, and it is not sufficient to protect spacecraft that can be devastated by debris of even a few milli-meters. In addition, the orbit information obtained using these observation data (so-called two line elements (TLE)) is not sufficiently accurate, which is an obstacle to collision approach analysis. In light of these circumstances, there is a need to improve the low Earth orbit debris observation capability.

Figure1. Two remote observation sites of JAXA in Australia. One is in Siding Spring Observatory and the other is in Zadko Observatory

There are two main methods for observing low-orbit debris. One is radar observation, and the US radar observation network is a good example. The advantage of radar observation is that it allows observation 24 hours a day, all year round, but the disadvantage is that it requires huge costs to build, maintain, and operate radar observation facilities. The other method is optical observation. Optical observation of low-orbit debris has the weakness of being dependent on solar illumination conditions and weather, but has the advantage of significantly reducing the cost of building a system. Recently, high-sensitivity, high-speed optical sensors such as CCD and CMOS and high-speed computing resources have become available at low cost, and by efficiently combining these, it may be possible to build an observation system comparable to radar observation. In addition, optical sensors have the advantage of being much more accurate at determining the position of detected objects (with an accuracy of a few arc seconds) than radar, which works in favour of orbit determination.

JAXA is developing optical observation technologies. JALESS is the system to detect, track, calculate orbits and maintain the orbits of un-cataloged LEO objects using optical sensors and GPU machines for analysis of the data. JALESS succeeded in detecting un-cataloged LEO objects, tracking, determining the orbits and maintaining them in 2024.

In Section 2 and 3, observation equipment and data analysis of JALESS are described. The concept of the orbital determination of JALESS and the related experiment are explained in Section 4. The future perspectives are discussed in Section 5.

2 OBSERVATION EQUIPMENT

We installed observation equipment consisting of a

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Figure 2. The sliding roof (left) and the observation equipment installed to Siding Spring Observatory.

small telescope and a large CMOS sensor to two remote observation sites, Siding Spring Observatory(SSO) and Zadko Observatory(ZDK) in Australia as shown in Figure 1. Figure 2 shows the sliding roof and the observation equipment installed to Siding Spring Observatory.

The small telescope is the Takahashi ε-180ED. It has an aperture of 18cm, F2.8, a hyperbolic primary mirror, and a two-element correction lens with ED glass convex lens, achieving perfect aberration correction that exceeds that of a Schmidt camera. It has high imaging capabilities over a wide range of focal planes (image circle φ44mm).

The CMOS sensor is the Bitran BH-60M-KAI. It is equipped with a 35mm film size, a low-noise Canon CMOS element, 35mm FHD XSM with a large 19µm pixel size, and a. It is equipped with an interval shooting function that is advantageous for low-orbit debris survey observations and a function to add GPS time information to the image header. The field of view when attached to the aforementioned ε-180ED is 4.4 x 2.5°.

The mount is a Mathis Instruments MI-500 fork-type equatorial mount. The four observation units are each oriented horizontally in the right ascension direction to a different field of view.

These devices are controlled remotely from Japan.

3 DATA ANALYSIS

JAXA is developing technology to efficiently process multiple images to detect dark moving objects that are buried in noise in a single image[1-3]. We have achieved many results so far, including the discovery and orbit determination of uncatalogued geostationary orbit debris, and the discovery of near-Earth objects. Please refer to other literature for details, but we will provide an outline here. The top of Figure 3 shows a very dark object moving through the image. For these images, by assuming a large number of shift amounts and creating a median image (bottom of Figure 3), when the assumed shift amount happens to match the movement amount of the moving object, the signal-to-noise ratio improves and the moving object that would have been buried in noise in a single image can be made to stand out. Figure 4 shows an example of moving object detection using this technology. The left side of Figure 4 shows one observed image, and the right side shows the final image obtained using this technology. It can be seen that one moving object (asteroid) has been detected. This object is present within the yellow dashed circle in the left of Figure 4, but is barely visible. This method had the drawback of requiring an enormous amount of calculation time to detect moving objects, but it was found that by binarizing the image and adding instead of using the median, it was possible to obtain almost the same calculation results and significantly reduce analysis time. In addition, by implementing the algorithm itself on a GPU computer, it became possible to further increase the speed. The CMOS sensor used for low-orbit debris observation captures several tens of images per second, and it is possible to analyse these images in real time.

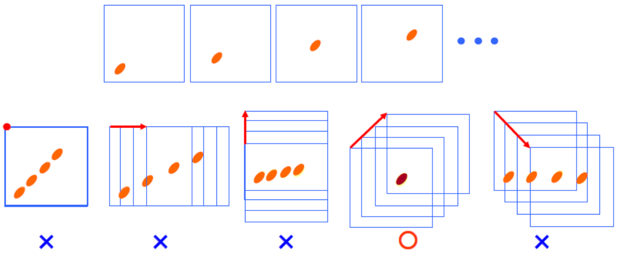

Figure 3. The image processing technology for detection of faint moving objects

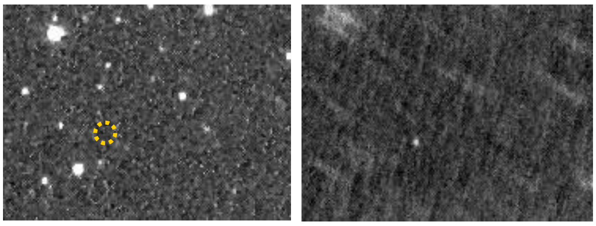

Figure 4. The example of moving object detection using the technology

Test observations were carried out to verify the effectiveness of the data analysis method described above. One area on the celestial sphere was observed for six hours over two days using one set of the observation unit shown in Figure 2. The CMOS sensor used its interval function to continuously capture 32 images with an exposure time of 10 msec, at two-second intervals. The image data obtained was analyzed sequentially using the data analysis method. Figure 5 shows the brightness distribution of objects detected in this test observation. Blue indicates objects that are listed in the catalog of the Space-Track, and red indicates uncatalogued ones. The size of several magnitude classes is shown in the figure, assuming an orbital altitude of 1000 km, diffuse reflection, phase angle of

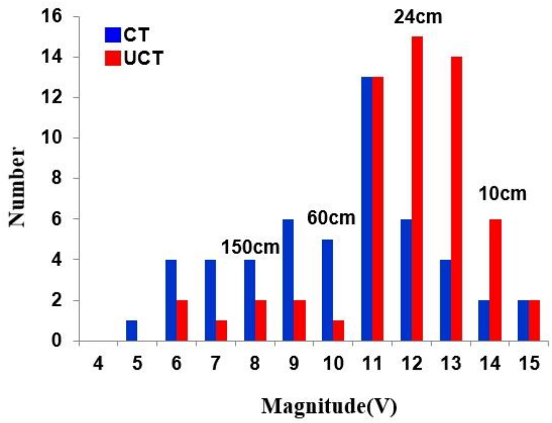

Figure 5. brightness distribution of detected objects. Blue indicates objects that are listed in the catalog of the Space-Track, and red indicates uncatalogued ones.

90°, and reflection coefficient of 0.1. Of the 109 objects detected, 58 objects, more than half, were uncatalogued objects. It can be seen that many uncatalogued objects were captured in the 10-20 cm range. These results show that optical observation system for LEO objects (JALESS) that JAXA is currently developing could make a significant contribution to understanding the situation of low-orbit objects of about 10 cm in size that are not captured by the current mainstream radar observation network.

4 ORBITAL DETERMINATION OF UN-CATALOGED LEO OBJECTS

Regarding orbit determination for LEO objects, past research has shown that it is possible to determine the orbit with a certain degree of accuracy by using position information obtained by two consecutive optical observations of the same object[4]. JAXA is conducting research and development by installing observation equipment at two locations separated in the longitude direction, as shown in Figure 1. The idea is that a low-orbit object detected by the eastern system is re-detected by the western system after one orbit. This makes it possible to obtain the position information of two consecutive passes, allowing orbit determination with a certain degree of accuracy. The two stations should be installed longitude-wise apart by the angle of the Earth's rotation (approximately 25°) caused by the time that a LEO object to make one orbit (approximately 100 minutes). The longitude difference between Siding SSO and ZDK, where we installed our observation equipment, is approximately 33°. The orbit determination is performed using the following procedure. At SSO on the east side, the observation equipment described in Section 2 is pointed toward the zenith, and survey observations are carried out as described in the latter half of Section 3. Since the observation data is analyzed in quasi-real time, the identification of detected objects is also carried out almost simultaneously. If an object is identified as an uncatalogued object, the coordinate values on the sensor where the object was detected are converted to coordinate values on the celestial sphere using the positions of the background stars, and the circular orbit of the object is determined using these coordinate values. In this case, the SGP4 algorithm is used for orbital propagation.

An experiment to determine the orbit of an uncatalogued LEO object was carried out using the procedure described above. As a result, an uncatalogued LEO object with an orbital altitude of 870 km and a size of 20 cm, detected by SSO on July 3, 2024, was successfully tracked and observed on its next orbit at ZDK. Orbit determination was carried out using data from both sites, and tracking observations were also successfully carried out the next day and the day after using that orbit. During tracking observation, the object passed almost at the center of the sensor. This demonstrated that it is possible to determine the orbit of an uncatalogued LEO object with a certain degree of accuracy by two-pass continuous observation. Furthermore, an orbit was determined using three days of data, and by propagating that orbit with the SGP4 algorithm, the object was successfully recaptured 54 days after it had been invisible. Although this is only one case, it was found that the orbit determined using three days of data maintains enough accuracy to be recaptured even without observation for more than a month. In the future, we would like to conduct similar experiments to verify the orbit determination accuracy and the possibility of recapture after a long period of invisibility for each type of orbit.

5 FUTURE PERSPECTIVE

In Section 4, we found that by using two consecutive passes of optical observation data from two stations separated in the longitude direction, it is possible to determine an orbit with a certain degree of accuracy, and that it is possible to recapture the same object even after a long period of invisibility. Therefore, as shown in Figure 6, by constructing an observation network that uses multiple sensors at each station to widely cover two locations on the celestial sphere in a fence-like manner, it will be possible to detect many known and uncatalogued objects in low earth orbit, and to determine and maintain their orbits. By operating such a system for four months, it will be possible to determine the orbits of approximately 45% of the cataloged objects. Furthermore, based on the results of the test observation, it will be possible to determine the orbits of even more uncataloged objects. The orbital plane of the objects whose orbits have been determined will change due to perturbations of the J2 term, and they will become

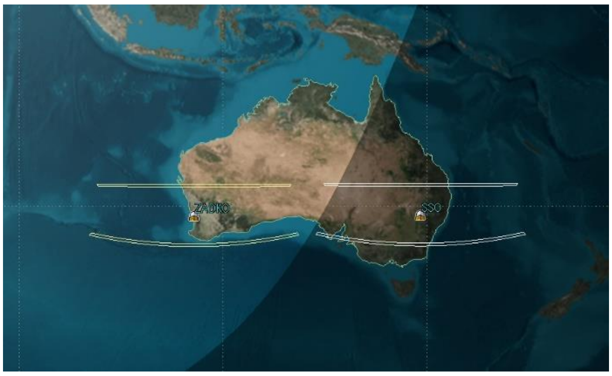

Figure 6. Observation network for space objects

unobservable after a while. From the experimental results in Section 4, it is expected that it is possible to recapture an object even after a period of invisibility, but from the viewpoint of orbit determination accuracy, it is better if there are no periods of invisibility. Continuous tracking observations can be made possible by setting up observation sites in the polar regions. Since observations are not possible during the midnight sun in the polar regions, it is necessary to prepare such tracking observation facilities in both polar regions. Since tracking observation facilities observe objects whose orbits are known, there is no need to prepare a large number of sensors required to construct an observation network such as that shown in Figure 6. By establishing such a large-scale observation network in the future, it will be possible to establish a system that can maintain and manage the orbit information of many cataloged and uncataloged objects.

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