Space objects photometry using Optical Telescope Array

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Abstract: This paper summarizes the recent analysis work on space objects photometry using optical telescope array. With this work, we can understand the accuracy of the data better, and correct the data to make it available for application.

Key words: space target photometry, optical telescope array, accuracy, availability

1 Background

Earth orbit is limited non-recyclable resource, its usability is closely related to aerospace industry. Because of the increasing number of launched artificial satellites, and the effect of collision and disintegration, it’s more and more crowded in earth orbit, this greatly affects the safety of normal aircrafts, and brings more other problems. Nowadays, there are about 20000 objects larger than 10cm in catalogue state, and much more objects smaller than 10cm cannot be observed. These objects are mainly in orbit under 2000km, semi-synchronous orbit and synchronous orbit. These make the space craft safety problem more serious than ever, the US-RU satellite collision in 2009 is a warning. So it’s very important to trace the space objects as many as possible.

The traditional space object observation is based on position-time measurements. It’s a direct and effective way to trace the space objects. Use a proper kinematic model to catalog all the observation data, and use catalog parameter to predict the object’s position, this is the basic operation mode. However, in practical work many other factors are involved, target recognition, data matching, track association. And in some kind of work we have to know more about the space targets, such as spin characteristics, size, long term evolution etc. So, more information than position need to be used, target’s luminosity is the most important one, we can derive many characteristics from luminosity series, and it’s easier to get because of the widely use of CCD in modern observation.

Photometry is commonly used in astrophysics research. However, in space target observation, most telescopes are not well designed for photometry, such as shutter system, color system, etc. So, special reduction is needed. This article will take Optical Telescope Array as an example to show the space target photometry result and its analysis on special equipment.
2 Equipment

Optical Telescope Array (short for OTA), is a kind of large sky area space objects survey device, its main scientific objectives is discovering uncataloged objects. It’s composed of several large field optical telescopes which point at fix positions in the sky, mainly low elevation. Usually OTA covers two or three complete annuluses of sky, and acquires digital images as many as possible. This makes it could capture all moving targets across the sky, also the capability of outputting large amount of ccd image series. The photometry is based on these digital images.

Each OTA-1 telescope covers 50 square degrees of sky; each OTA-2 telescope covers 120 square degrees of sky. For the reason of observation depth, there is no filter, and all cameras are KAF series full frame CCD without shutter. The telescope takes 1 frame per 1.5 second with 50~200ms exposure time while the condition is proper, this is why there is no shutter.

3 Data

Figure 1 Image of OTA-2
Figure 1 is part of one frame of the OTA-2 image. The green polygons mark out all the targets found in the Full Field Scanning, and the red circle marks out the moving target, the latter process is based on three consecutive frames using the algorithm called consecutive frames track association.

Notice that every target has vertical smear comes through the whole image, this is the effect of full frame CCD without shutter, CCD exposes continuously while reading and flushing. During the Full Field Scanning, first stage is to reduce the smear effect; second, calculate the noise of every row separately because of the residue of smear; then mark out the signal points beyond the noise row by row and do the domain connection test to extract all the visible targets. Finally, calculate the all the basic parameters of every target, such as center, aspect ratio, inclination, counts, background and so on.
Figure 2 is the mag distribution histogram of a series of images. Left figure is the matched stars and right figure is the catalogue stars cover the observed sky but larger. The figure shows that the mag limit of OTA-2 can up to 13 in some case.

4 Analysis

In order to analysis the photometry accuracy of OTA, we use stars data because there is complete star catalogue. We mainly use wcstools and tycho-2 catalogue to match the stars, and V mag data for photometry, some comparison data comes from USNO-A2.0 catalogue. The analysis is based on a specific series of images, we use wcstools to match all the stars in these images and do the statistics to find factor that affects the photometry accuracy on OTA.

We mainly consider 3 factors. Color system, there is no color filter in OTA optical system because the prime design want to get the maximum observation depth to find as many targets as possible. But in differential photometry, the catalogue mag we use commonly the V mag or R mag, so the calibration star’s color index may bias the final result. Also, the absorb curve of telescope and CCD response curve can bias the result between OTA-1 and OTA-2. If we want to use all the observation data together, color system must be considered; Vignetting, in order to cover the sky as much as possible, the telescope’s field of view is so large that the vignetted cannot be ignored. The counts in the center will be higher than in the edge for a fixed source. Atmospheric extinction, at low elevation, 11 degree height difference will bring significant extinction difference.

Figure 3 Mean Error

Figure 3 is the mean error of stars with different brightness, here error means the difference between the catalogue value and measured value for every measurement. From the figure, we
can see that the error rising as the target getting fainter. The abnormal of 14 mag value is because that the samples are too little. With this, it’s easier to find the equipment limit for the specific research.

Figure 4 Zero-Color Relationship
Figure 4 shows the mean photometry zero point for different color stars. Two edge abnormal values come from the too little data for statistics. From the diagram, we can infer that the color system of calibration star will bring large variance, in common situation, choose a group star of specific color for calibration will be effective, because in OTA situation, there are enough stars for calibration. Usually we choose 0.65 ± 0.2 because the satellite always reflect the sunshine whose color index is 0.65.

Figure 5 Vignetting Relation
Figure 5 shows the relationship of vignetting, the difference between center star and edge star is 0.1 mag for this telescope, and this difference is relative easy to correct. Figure 6 shows the error of all stars and only center stars, the peak of error is lower when only use center star.
Figure 6 Error Distribution Contrast

Figure 7 Air Mass Coefficient

Figure 7 is the extinction coefficient of air mass term relationship with color index, means the air absorption in different wavelength is different. The air mass $X$ comes from the equation 1.

$$X = \frac{1}{\cos z + 0.50572 (0.07995z + 90 - z)^{1.6984}}$$

Equation 1 Air Mass

5 Results

We select some samples from the OTA-1 archive data to verify the feasibility of OTA photometry. The most direct way is mag distribution and light curve. The former one shows the long term statistical characteristic while the latter one shows the short term variation characteristic. All data has been normalized, both phase angle and slant range.
Figure 8 Mag Distribution In 4 Years

Figure 8 is a target 4 years data. From the diagram, we can see that the mag distribution matches well as in 4 years observation, including the very bright peak, like a flash. This shows the observation stability in certain accuracy range.

Figure 9 One Night Light Curve

Figure 9 is one night light curve with blank removed. It’s a schematic diagram to show the obvious periodicity of the target light curve. And the data is available for spectrum analysis.

6 Conclusion

These are the basic reduction and analysis of OTA photometry system. From this work, we can infer that OTA optical system can do some specific photometry work. Although the accuracy is not high enough and there are also some other flaw, because of the survey feature and the large amount of data, the OTA’s photometry work is still very useful. Especially, to form a large space targets luminosity database for reference, and to select certain target for further research. In future work, we will try more to improve the photometry accuracy and the cataloging method.

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