Development of a Reduction Algorithm of GEO Satellite Optical Observation Data for Optical Wide Field Patrol (OWL)

Sun-youp Park¹†, Jin Choi¹², Jung Hyun Jo¹², Ju Young Son¹², Yung-Sik Park¹, Hong-Suh Yim¹, Hong-Kyu Moon¹, Young-Ho Bae¹, Young-Jun Choi¹², Jang-Hyun Park¹
¹Space Situational Awareness Center, Korea Astronomy and Space Science Institute, Daejeon 34055, Korea
²Korea University of Science and Technology, Daejeon 34133, Korea

An algorithm to automatically extract coordinate and time information from optical observation data of geostationary orbit satellites (GEO satellites) or geosynchronous orbit satellites (GOS satellites) is developed. The optical wide-field patrol system is capable of automatic observation using a pre-arranged schedule. Therefore, if this type of automatic analysis algorithm is available, daily unmanned monitoring of GEO satellites can be possible. For data acquisition for development, the COMS1 satellite was observed with 1-s exposure time and 1-m interval. The images were grouped and processed in terms of "action", and each action was composed of six or nine successive images. First, a reference image with the best quality in one action was selected. Next, the rest of the images in the action were geometrically transformed to fit in the horizontal coordinate system (expressed in azimuthal angle and elevation) of the reference image. Then, these images were median-combined to retain only the possible non-moving GEO candidates. By reverting the coordinate transformation of the positions of these GEO satellite candidates, the final coordinates could be calculated.

Keywords: GEO satellite, data reduction, algorithm, optical, wide field

1. INTRODUCTION

A geostationary orbit (GEO) satellite or geosynchronous orbit satellite is a satellite that orbits around the Earth with the same period as the Earth rotation. Therefore, it appears on the same position from the viewpoint of a ground observer. However, in reality, it very slowly moves naturally or by human-designed operation, and the movement should be monitored by a ground station to keep the satellite properly operating. Several attempts have been made to observe GEO satellites by optical methods (Choi et al. 2009; Choi et al. 2010; Choi et al. 2011; Lee et al. 2004; Montojo et al. 2011; Nikolayev et al. 2011), but most of these methods are done by manual observations and manual data reduction. The optical wide-field patrol (OWL) system is capable of automatic observation using a pre-arranged observation schedule (Park et al. 2013); thus, if a method of automatic data reduction of GEO satellites is available, a fully automated GEO satellite monitoring would be possible.

In this paper, Section 2 describes the test observation for data acquisition to be used in a data reduction algorithm. Section 3 explains the details of the reduction algorithm. Section 4 provides the results and their discussion. Section 5 presents the summary.

2. TEST OBSERVATION

2.1 Site, Telescope and Detector

The test observation was performed at the testbed site located in the Korea Astronomy and Space Science Institute.
(KASI), Daejeon, Korea. Table 1 lists the summary of the test environment information and the observation system specification.

2.2 Test Observation

Table 2 lists the summary of the test observation run. All pointing directions of the telescope are within one square degree in the horizontal coordinates (expressed in azimuthal angle and elevation) because the target is just one GEO satellite, which is assumed to stay apparently fixed on the sky from the viewpoint of a ground observer. The observation sequences consist of “actions,” which include from six to nine images with just 1-s exposure time. The reasons for taking only 1-s exposure time are the following:

1. The night sky in the observation site is too bright; thus, the target and the stars are easily absorbed in the background noise.
2. With short exposure time, the number of available images can be increased.

Because of weather conditions, the rate of successful world coordinate system (WCS) solution varies daily. If one image fails in the WCS solution, it is excluded for further reduction steps.

3. DATA REDUCTION

The sequence of the data reduction steps is described as follows:

1. WCS solution calculation
2. Reference image selection
3. “Object” image generation using SExtractor
4. Image transformation to match the reference image
5. Transformed image combination
6. GEO detection in the combined image
7. Detection of the points nearest the GEOs in the original images

3.1 WCS Solution Calculation

The X and Y positions of the objects in the image pixel units should be expressed in celestial coordinate values. The coefficients of the transformation equation are WCS solution (Calabretta & Greisen 2002; Greisen & Calabretta 2002). The detailed method of calculating these values is similar to the definition given by Park et al. (2013).

Obtaining the positions and brightness of the objects in the image using SExtractor (Bertin & Arnouts 1996; Bertin 2006).

Retrieving the stars in the corresponding sky area from the Guide Star Catalog (GSC) 1.1 (Jenkner et al. 1990; Lasker et al. 1990; Russel et al. 1990).

Matching the SExtractor output with the GSC stars using the triangle pattern matching algorithm (Groth 1986) with CCXYMATCH and CCMAP tasks in the Interactive Data Reduction and Analysis Facility (IRAF) (Valdes 1984).

Mapping the matched objects and calculating the solution.

3.2 Selecting the Reference Image

Before creating a combined image, a reference image should be selected first. The rest of the images in an “action” are geometrically transformed to match this reference image in the horizontal coordinate system (expressed in azimuth and elevation). The condition for the reference image is described as follows:

1. Its WCS solution calculation is successful.
2. The seeing, expressed in the mean full width at half maximum (FWHM) value of the stars in the image, is the smallest among those of all the images in the “action.”
3.3 Generating “Object” Images Using SExtractor

In the WCS solution calculation step, a quick photometry of the celestial objects in the image is performed using SExtractor to obtain the X and Y pixel positions and brightness values. SExtractor can also generate additional “check image.” This check image can be any “object,” “background,” “original–background,” and so on. To make the pixel values equal to zero except for the area of possible GEOs in the median-combined image, the “object” check images are generated in the SExtractor execution step. The resultant “object” image is an image that has detected celestial objects in their positions and with zero pixel values in the sky background area (Figs. 1 and 2).

3.4 Transforming Images to Match the Reference Image

Before combining the “object” check images, they must be geometrically transformed to match the reference-object check image to compensate the slight displacement and rotation due to time difference and telescope-pointing error. Because the purpose of the combination is to retain only the GEO candidates, the transformed and the reference images should have the same horizontal coordinate system (expressed in azimuthal angle and elevation). The steps of this procedure are described as follows:

1. We generate equally spaced grid points on the object image. In this case, 7 × 7 = 49 grid points located at every 512 pixels are used (Fig. 3).
2. Using the WCS solution of the object image, we obtain the J2000 right ascension and declination coordinates.
3. We convert these coordinates to geocentric (CIRS)
position at the observation date and time.
4. We obtain the topocentric azimuthal angle and
elevation at the observation date and time from step 3.
5. We calculate the right ascension and declination at the
date and time of the reference image from step 4.
6. From step 5, we obtain the J2000 right ascension and
declination.
7. Using the WCS solution of the reference image, we
calculate the $X$ and $Y$ coordinates of the grid points
transformed to match the reference image.
8. Now, we have 49 mapped ensemble pairs of \{(X, Y)$_{\text{object}}$, $(X, Y)$_{\text{reference object}}\}. Using these pairs, we calculate
the geometric mapping formula. In this step, the GEOMAP
task of IRAF is used.
9. We transform the image using the GEOTRAN task of
IRAF (Valdes 1984).

In the above steps, a traditionally developed code that
uses functions of the International Astronomical Union
Standards of Fundamental Astronomy (IAU SOFA) library
(version 11, Nov. 2013) is applied in steps 3 and 4 for
coordinate transformation and correction of precession and
nutation.

3.5 Combining Transformed Images

The geometrically transformed check images, including
the check image of the reference image, are median-
combined to a single image. This combined image has the
same coordinate system as the reference image, but all have
zero pixel values except the area of the possible GEO objects
(Fig. 4) because all other background stars are in different
positions due to sidereal movement.

3.6 Detecting GEOs on the Combined Image

The positions of geostationary objects are extracted using
SExtractor. The resultant positions are possible GEO objects
detected in the reference image. Using the WCS solution of
the reference image, the J2000 equatorial right ascension and
declination coordinate values of the possible GEO objects at
the time the reference image is taken are calculated.

3.7 Detecting Points Nearest to the GEOs in the Original
Images

The positions of the GEO candidates on the combined
image are the same as those on the reference image. Now
reversing the coordinate conversion procedure from steps
2 to 7 in Section 3.4, the positions of the GEO candidates on
the images other than the reference image can be calculated.
For each image in one action, the quick photometry results
are already waiting. Using these results, the nearest points
to the GEO candidates are selected. The final results are
arranged in the text format of observation time and right
ascension and declination expressed in degrees.

4. RESULTS AND DISCUSSION

The final reduced product is a sequence of UTC time
and J2000 right ascension and declination. Table 3 lists
the summary of the observation and reduction results.
Figs. 5-9 show the time series plots of the GEO objects
observed during the campaign. In both right ascension and
declination plots, the celestial positions with observation
times of all three GEO objects (including the COMS and
two Japanese GEO satellites) are detected and traced. The
equinox of the right ascension and declination is 2000.0, in
reference to the GSC catalog.

The weather condition on August 29, 2014, was worst
among the five nights of observation. The automatic
observation system of OWL cancels the schedules during
bad weather; thus, only a few data points were produced
(24 images were taken, 22 images were successful for WCS
solution calculation, and 66 data points were contained in
four actions). The four visible packs of data points represent

<table>
<thead>
<tr>
<th>No.</th>
<th>Obs. Date (UTC)</th>
<th># image</th>
<th>Action #</th>
<th># image / action</th>
<th>WCS success</th>
<th>Detected points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aug 28 2014</td>
<td>24</td>
<td>4</td>
<td>8</td>
<td>22</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>Aug 30 2014</td>
<td>138</td>
<td>23</td>
<td>6</td>
<td>138</td>
<td>282</td>
</tr>
<tr>
<td>3</td>
<td>Aug 31 2014</td>
<td>132</td>
<td>22</td>
<td>6</td>
<td>131</td>
<td>393</td>
</tr>
<tr>
<td>4</td>
<td>Sep 01 2014</td>
<td>106</td>
<td>18</td>
<td>6</td>
<td>97</td>
<td>212</td>
</tr>
<tr>
<td>5</td>
<td>Nov 10 2014</td>
<td>80</td>
<td>9</td>
<td>9</td>
<td>80</td>
<td>240</td>
</tr>
</tbody>
</table>

Fig. 4. (Left) Geometrically transformed image and (right) the combined image. The background stars are removed, and only the GEO candidates are visible in the combined image.
four observation actions. Three bad points between 14:50 and 14:55 and one bad point at about 15:21 UTC were observed, which appeared to be false detections and were excluded in the orbit determination.

In the night of August 30, 2014, the three detected GEO objects (including the COMS) were faint, and their...
brightness varied with time. Therefore, not all the images detected the three GEO objects. Among the 23 actions, 18 were successful, and the failed five actions did not detect any GEO objects. In the night of August 31, 2014, all 22 actions detected at least two GEO objects. In the night of September 1, 2014, the result shows similar behavior that on August 30, 2014. Out of the 18 actions, 16 detected at least one GEO object detected. The weather condition was the best at November 10, 2014. All actions of nine images detected three GEO objects (only one point was not detected).

5. SUMMARY

An algorithm to automatically extract the coordinate and time information from optical observation data of GEO satellites has been developed. As a test observation campaign, the COMS1 satellite was observed for five nights from August to November 2014 with 1-s of exposure time and 1-min of interval. These images were grouped and processed into “action,” and each action was composed of six or nine successive images. Using coordinate transformation and combining all images in one action, the possible GEO candidates, including the COMS, were detected. The output shows that this data reduction algorithm can be used for full automation of the monitoring of GEO satellites by optical observation using OWL. However, this method suffers from the limitations of detectable brightness of the targets as well as from bad weather conditions.

ACKNOWLEDGEMENTS

This work was supported by the National Agenda Project "Development of Electro-optic Space Surveillance System" funded by Korea Research Council of Fundamental Science & Technology (KRCF) and the Korean Astronomy and Space Science Institute (KASI).

In this work, software routines from the IAU SOFA collection were used. Copyright © International Astronomical Union Standards of Fundamental Astronomy (http://www.iausofa.org).

REFERENCES

Bertin E, SExtractor v2.5 User's manual, (Institut d'Astrophysique & Observatoire de Paris, France, 2006).


