Orbit determination with angle-only data from the first Korean optical satellite tracking system, OWL-Net

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ABSTRACT

The optical satellite tracking data obtained by the first Korean optical satellite tracking system, Optical Wide-field patrol – Network (OWL-Net), had been examined for precision orbit determination. During the test observation at Israel site, we have successfully observed a satellite with Laser Retro Reflector (LRR) to calibrate the angle-only metric data. The OWL observation system is using a chopper equipment to get dense observation data in one-shot over 100 points for the low Earth orbit objects. After several corrections, orbit determination process was done with validated metric data. The TLE with the same epoch of the end of the first arc was used for the initial orbital parameter. Orbit Determination Tool Kit (ODTK) was used for an analysis of a performance of orbit estimation using the angle-only measurements. We have been developing batch style orbit estimator.

1. Introduction

Korea Astronomy and Space Science Institute (KASI) has been developing an optical tracking network named Optical Wide-field patrol Network (OWL-Net) since 2010. This optical network aim to track Korean domestic Low Earth Orbit (LEO) satellites and to monitor the Geostationary Earth Orbit (GEO) region. The optical network is under construction until this year.

OWL-Net has spread five overseas sites in Mongolia, Morocco, Israel, the U.S and South Korea. We selected this five sites with analysis to find suitable optical observation sites for 11 domestic LEO satellites [1]. It was validated by simulation with ground station grid and access frequency test for each target. Every site need to be calibrated and validate for achieved measurements to maintain the ephemeris of each target [2]. We have test observation with the LEO satellite with Laser Retro Reflector (LRR) to calibrate the angle-only metric data.

To calibrate process, we need to analyze the raw image files and observation result files including the observation time and determined metric data. The determined angle position from the raw images was matched with time tagging information by the ratio of streak length [3]. And it is required to correct false detection signal or mismatched data by blank signal [4].

Two OWL-Net sites are under construction now and we keep going on the calibration and validation process. We have been developing batch style orbit estimator to the analysis of the performance of the OWL-Net. As preliminary results, the orbit determination results by using the Orbit Determination Tool Kit (ODTK) is presented with the very dense observation case.

2. Data Reduction and calibration

As we mentioned earlier, the OWL-Net is consist of five optical observatories. And headquarter has been operating on Korea Astronomy and Space Science Institute (KASI). The observation targets are imported by headquarter. Each site get the observation schedule from headquarter. The headquarter makes the observation schedule with the priority for each target. After observation of each night, the site operation system sends the observation results including the time and metric observation as text files.

Fig. 1. Locations of the OWL-Net observatories. The first site in Songino, Mongolia, the second one in Qokaimeden, Morocco, third site in Wise observatory in Israel and fourth and fifth sites are under construction in Mt. Lemmon observatory, the Unite States and Mt. Bohyun observatory, South Korea, respectively.

Park et al. [3] are described the data reduction process of the OWL-Net system. The OWL-Net system's backend consists of 1) Filter Wheel (B, V, R and C), 2) Time tagger system, 3) chopper system to chop long streak as streak-let and 4) CCD detector. We can get the metric data from each image. The coordinate of each image is corrected with WCS (World Coordinate System) solution with the star catalog. This metric information is matched with recorded time from time tagger.

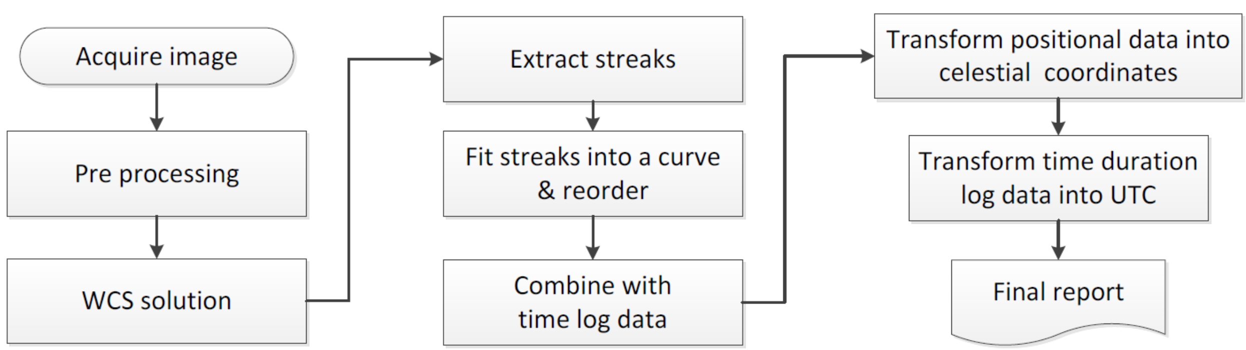

Fig. 2. Data reduction flow of the OWL-Net. From acquired images, the positions of each streak-let are calibrated with the star catalog and matched with the recorded time by time tagger system.

The chopper system makes short streak-lets from satellite's trajectory streak. Four blades rotate to cut long streak with maximum speed 50 Hz. We can get hundreds of angular position information form only one image by this system. And observation time for each streak-let is matched with its position on CCD and recorded time by time tagger system. This process can make errors due to indirect matching process. The error sources are 1) Time server synchronization, 2) measured position and time mismatching and 3) skipped or duplicated streak-let mismatching. From these errors, Park et al. [4] dealt with skipped or duplicated streak-let mismatching problem.

The site operating system has an NTP server and synchronizes the operation time with GPS clock. The detector sub-system also maintains its time with the NTP server. But we need to consider the time mismatch errors for the reason by software or hardware system.

The observation metric information includes the time and topo-centric right ascension and declination. This angular information used J2000 coordinate same as used star catalog. For analyzing the angular measurement, we need to consider some corrections like 1) light travel time from observer to satellite, 2) annual aberration and 3) diurnal aberration.

3. Orbit determination analysis

We processed calibration and validation test for the OWL-Net system. Test observation was done by the OWL-Net facility in Israel. The target of test observation was Cryosat-2. This satellite has LRR system and International Laser Ranging Service (ILRS) provide comparable ephemeris. The specification of Cryosat-2 was described below.

Table 1 Specification of Cryosat-2

SATCAT ID	36508
Launch mass	720 kg
Dimensions	4.6 by 2.3 meters
Perigee	718 km
Apogee	732 km
Inclination	92.03 degree

The test observation in Wise observatory in Israel was made for six days. We got five pass observations for six days. Although we can’t get the observation from rising and set of satellite for each pass, it is very dense observation case. The maximum chopper speed was 50 Hz. The skipped and duplicated detection was corrected with the image and recorded time. After correction, we got totally 3602 metric pairs for five passes. The observation duration of each pass was about one to two minutes.

Table 2 Observation summary of Cryosat-2

Pass number	Number of shot	Number of data	Date and Time (UTC)
1	11	869	31 May 2016 00:37:01.61 ~ 31 May 2016 00:39:40.98
2	11	866	02 Jun 2016 00:34:47.695 ~ 02 Jun 2016 00:36:33.483
3	5	578	02 Jun 2016 23:44:46.720 ~ 02 Jun 2016 23:45:44.878
4	7	594	04 Jun 2016 00:32:22.475 ~ 04 Jun 2016 00:33:28.656
5	7	695	06 Jun 2016 00:29:47.398 ~ 06 Jun 2016 00:30:54.714

We used the ODTK software to estimate orbit with the angular metric data and also used Two Line Elements (TLE) as a priori. The ODTK run with sequential type filter and smoother. We considered several perturbations for this orbit estimation test as geopotential gravity (EGM96), air-drag (NRLMSISE 2000), third-body gravity and solar radiation pressure. This test observation results show well separated and dense case for the optical tracking. We got five pass observations among 6 days and the number of points of each observation exceeds five hundred. Fig. 3. shows the orbit determination results for test observation. The smoother result was compared with the consecutive

TLEs with backward propagation for 6 days. We got bigger difference for in-track direction against radial and cross-track direction difference. It might be concerned with time system and its error sources. The calibration and validation process keep going for multisite orbit determination accuracy for next step.

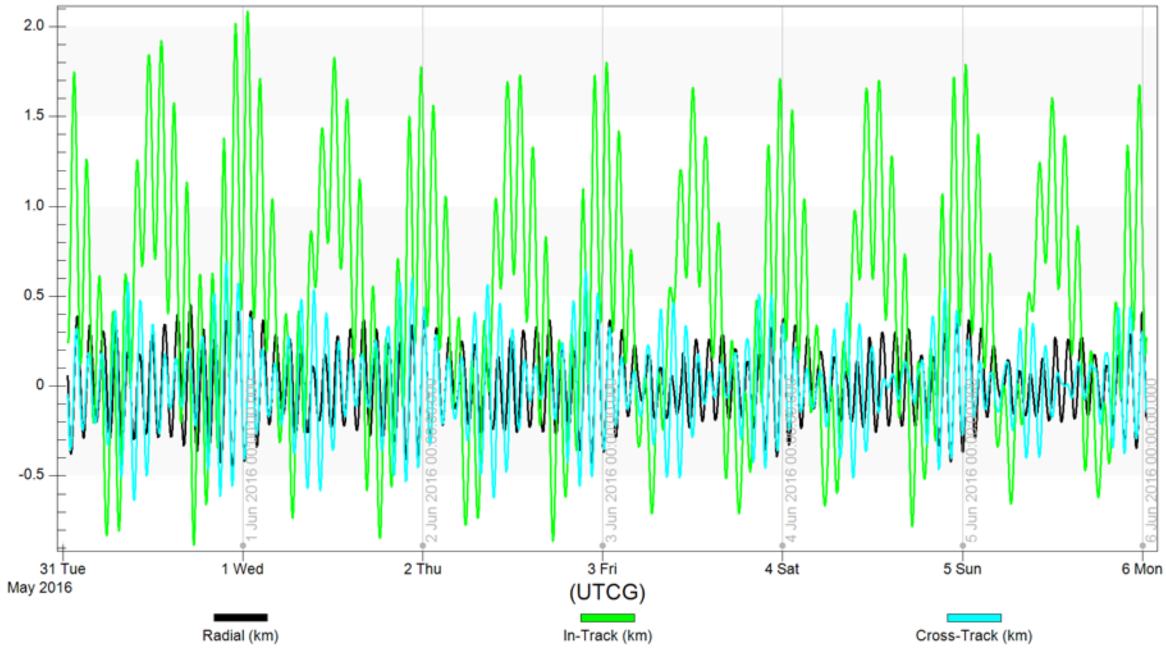

Fig. 3. Orbit determination results for test observation of Cryosat-2. The smoother result was compared with the consecutive TLEs for 6 days.

4. Batch style orbit estimator development

The ODTK has been used for the operation of the OWL-Net system. But we also have been developing the batch style orbit estimator for validation of system and research purpose. The design concept of Goddard Trajectory Determination System (GTDS) was referred for software structure. We used the Matlab software as development tools. Table 3 shows the basic information of the estimator under construction. Its integrator results were validated with HPOP propagator in System Tool Kit (STK).

Table 3 basic information of batch orbit estimator

Integrator	RKF 78
Gravity	EGM2008
Drag	NRLMSISE 00
3rd body gravity	Sun, Moon, solar planets
SRP	Sphere type
Estimation	Weighted least square

The measurements from the OWL-Net is comparatively dense optical data. And due to the limit of the optical tracking like weather condition and illumination condition, the observations are made sporadically. The batch estimator aims to operate stably with this optical observation cases. This estimator also can be used to calibrate and validate the tracking system performance.

5. Summary

The OWL-Net tracking network has been developing since 2010. Test observation for calibration and validation was made with LRR satellite, Cryosat-2 at Wise observatory in Israel. We used the ODTK to estimate its orbit for system calibration. The estimated results were compared with consecutive TLEs. The difference for in-track direction might be concerned with time record system. We also have been developing the batch style estimator for validation of the OWL-Net system and related research. Full force models were applied to its integrator after comparison with HPOP. The batch style estimator will be used to research using angular measurement and system validation.

6. REFERENCES

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