Orbit determination with the angle-only measurement from the optical tracking network, OWL-Net

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ABSTRACT

The Optical Wide-field patrol-Network(OWL-Net) have been developed by Korea Astronomy and Space Science Institute for last six years. The optical tracking stations were installed in Mongolia, Morocco, Israel, United States and South Korea. The OWL-Net system uses the chopper and fast mount system to acquire dense optical measurements. By the end of 2016, five overvea optical tracking stations were under test observation phase. During the test period, various LEO objects including the domestic LEO satellites were observed for several weeks. We analysed system error modelling by back-end system for observed space objects. The orbit determination process was done with batch least square orbit estimator. We attempted to compare orbit determination results with Two Line Elements and CPF files to analyse the overall system. This results can be used to predict the performance of the OWL-Net operations. The OWL-Net also can be used as a space debris optical tracking system.

1 INTRODUCTION

Korea Astronomy and Space Science Institute (KASI) has developed an optical tracking network to observe artificial satellites from 2010. The optical tracking network was named the Optical Wide-field patrol – Network (OWL-Net). The OWL-Net aims to maintain orbital ephemeris of Korean domestic satellites. Eleven domestic Low Earth Orbit (LEO) satellites are registered as Korean space asset now. Six Geostationary Earth Orbit (GEO) satellites will also be monitored by using the OWL-Net [1].

The OWL-Net is consisted of 5 overseas sites and one headquarter in South Korea. Fig. 1 shows the location of OWL-Net sites. Five sites have been constructed in Mongolia, Morocco, Israel, United States and South Korea. The headquarter send observation schedules for 5 sites and also save the observation results from each sites. The observation schedules are made by Target Ephemeris Generation System (TEGS) with priority registered in Target Management System (TMS). The observation is automatically performed with the environmental sensors. After the end of observation, data reduction system conducts angle-only measurements with millisecond accuracy time information. The time and metric data are sent to the headquarters to analyse the angle-only measurement and orbit determination.

In this study, we analyse the orbit determination result of the OWL-Net. The orbit determination was done with a batch estimator and the sequential filter in the Orbit Determination Tool Kit (ODTK) software. The observation results and data reductions are also described before the orbit determination results.

Figure 1. Locations of OWL-Net

2 OBSERVATION AND DATA REDUCTION

The astronomical charged coupled device (CCD) was used in the OWL-Net. It provides good linearity of detected signal, but also needs few seconds for read out time. Therefore, a chopper system was adopted to cut long streak in one shot image. Park et al. shows structure of the OWL-Net back-end system [2]. Fig. 2 shows structure of back-end system of the OWL-Net and single observed image. The OWL-Net back-end system is consisted of four main parts to make plenty of angle data of target LEO satellite.

1) Filter Wheel – B, V, R, and C (default: R)
2) CCD detector – 4096 by 4096 CCD
3) Time tagger – time count equipment
4) Chopper – four blade to make streak

Position measurements of background stars in single shot should be corrected using World Coordinates System solution (WCS) with catalogued positions of

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each stars. GSC 1.2 catalogue is used as star catalogue. The astrometric signals of satellite look like chopped streak-let. Each position of the streak-let are determined with the Source Extractor software. The determined positions of every streak-let are filtered with linearity test to detect single satellite trace.

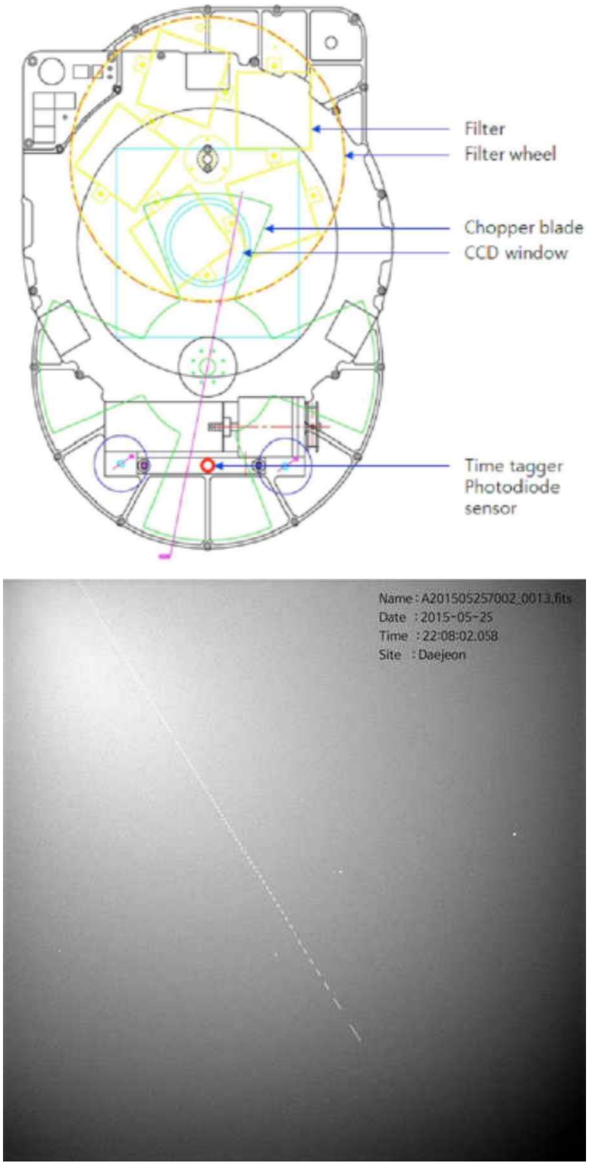

Figure 2. Back-end system of OWL-Net and single observed image

The final determined position data of satellite are matched with the recorded time data. The time information of the OWL-Net is kept NTP time synchronization with GPS signal. The time of each streak-let are determined with the time tagger system. The determined metric data and matched time can include uncertainty and errors [3]:

1) Time server synchronization off-set
2) Time information recording delay
3) Measured position and time tagging information mismatching
4) Skipped streak-let mis-matching.

The determined time has another systematic correction term. The time tagging system records time with signal from photodiode sensor at center of the CCD. Therefore, we need to correct delay time of passing the chopper from detected position to center of the CCD. When the delay time is calculated, rotation of the CCD also considered. The upward direction of the CCD is always kept to northern pole with the de-rotator. But de-rotator's move during observation are ignored for its short exposure time.

The observational model also should be considered for the orbit determination. The correction terms for the OWL-Net angle only measurements are listed below [4]:

1) Light travel time effect
2) Annual Aberration
3) Diurnal Aberration

The target for validation test was selected among the satellite providing precise orbit information. The satellites with the LRR (Laser Retro Reflector) were considered as target with its brightness and observation window from the OWL-Net ground station. Cryosat-2 shows good observability and stabilized brightness. Tab. 1 describes a detailed physical specification of the Cryosat-2.

Table 1 Specification of Cryosat-2

COSPAR ID	2010-013A
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 OWL-Net station in Israel was performed test observation for the Cryosat-2. The observation was successfully takes 3 pass for 3 days from 1 to 3 June 2016. Tab. 2 shows observation summary.

Table 2 Observation summary of Cryosat-2

Pass number	Number of shot	Number of data	Pass duration
1	5	710	51.3 sec
2	4	930	55.7 sec
3	5	868	42.1 sec
4	4	774	42.6 sec
5	4	820	54.2 sec

3 ORBIT DETERMINATION

The orbit determination and validation was done with the batch estimator and the ODTK and System Tool Kit

(STK). The orbit determination results were compared with the CPF data from CDDIS of NASA [4]. We used Two Line Elements (TLE) information as *a priori*. The white noise set from "seeing" condition of each observation for 5 arc seconds. And we considered full perturbation, non-geopotential gravity (EGM 2008, 70 by 70), luni-solar gravity, air-drag (JB2008) and solar radiation pressure. Fig. 3 shows the position uncertainty of estimated orbit by sequential filter and smoother of ODTK and position difference between CPF and estimated orbit. In-track direction uncertainty is three times bigger than radial and cross track uncertainty. This can be caused by time synchronization delay or detection error.

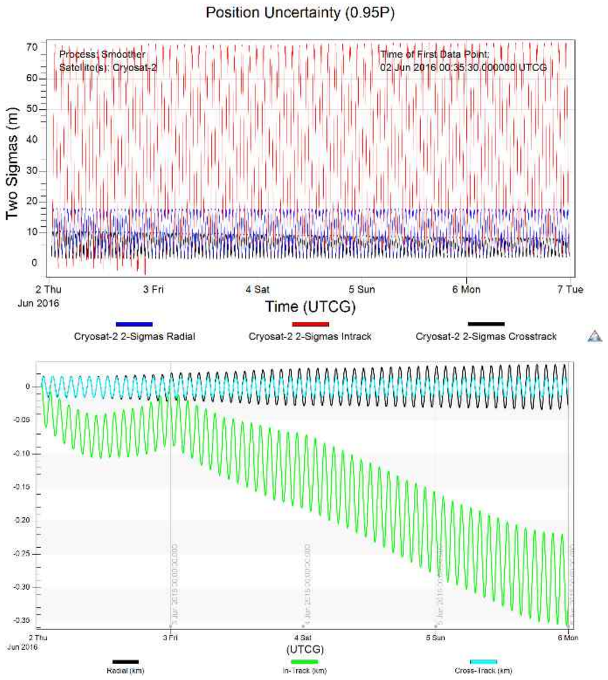

Figure 3. Position uncertainty of smoother result and position difference between CPF and estimated orbit using ODTK

The batch style estimator has been developed for system calibration/validation and Space Situational Awareness (SSA) research. The Goddard Trajectory Determination System (GTDS) was referred as overall concept. Internal integrator was designed with special perturbation theory and numerical propagation method. SOFA library was utilized for time and coordinate transformation. Tab. 3. shows the description of developed batch style estimator.

Table 3 basic information of batch orbit estimator

Integrator	RKF 78
Gravity	EGM2008
Drag	JB2008
3^{rd} body gravity	Sun, Moon, solar planets
SRP	Sphere type
Estimation	Weighted least square

We compared the estimation using the batch estimator with the CPF file from NASA. Consecutive TLEs for the Cryosat-2 has oscillated difference of in-track direction for 1.2 km with 1day period. Fig. 4 shows the position difference between CPF and estimated orbit by batch estimator. In-track position difference from batch estimation shows 0.5 times bigger than TLE with CPF data. As we mentioned in session 2, it is needed to check time error, positioning error and match problem for those two information.

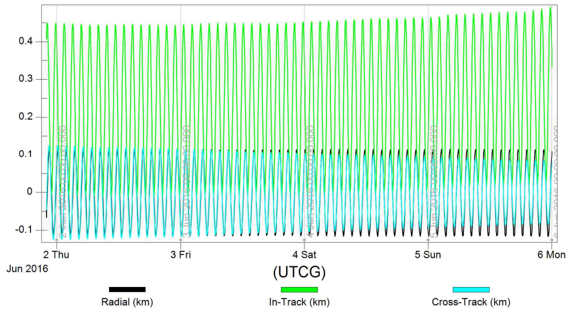

Figure 4. Position difference between CPF and estimated orbit by batch estimator

The angle-only data from the OWL-Net is comparatively dense and short-arc optical data. And optical observation condition can be given very sporadically. For more stable orbit estimation analysis, multi-arc and multi station observation are required. Furthermore, time synchronization should be kept very precisely.

4 SUMMARY

We performed orbit estimation with the sequential filter by ODTK and the batch style in-house estimator for LEO satellite, Cryosat-2. Its results were compared with the CPF data from NASA. The batch style estimation results show maximum 0.5 km in-track direction difference with the CPF data for six days with one site observation. Additional time and position detection error analysis should be analyse for estimation and observation accuracy.

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