Analysis of tracking and orbit estimation results of Korean space debris on LEO using the optical and the radar data

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ABSTRACT

Since 1992, 15 satellites on Low Earth Orbit (LEO) and nine satellites on Geostationary Earth Orbit (GEO) have been launched as Korean space asset into the Earth orbit. As of 2018, two satellites on LEO and four satellites on GEO are under operation. An optical tracking simulation results of Korean inactive satellites on LEO were analyzed in this research. And also the tracking and orbit estimation results were analyzed for the first Korean space debris, KITSAT-1, with the radar measurements. The orbit estimation results were compared with the Two Line Elements by Joint Space Operation Center of the United States. The optical tracking facility for the simulation was the OWL-Net (Optical Wide-field patroL-Network). The OWL-Net is a global optical tracking network for SSA in Korea. The radar data was provided from the LeoLabs radar network.

1 INTRODUCTION

In 1992, KITSAT-1 was launched for a collaborative research mission. KITSAT-1 was based on the modular microsatellite bus. An altitude of KITSAT-1 was designed by about 1300 km above the ground. It was a first Korean artificial satellite.

In 2019, among 43,931 registered space objects, 27 space objects are distinguished as Korean space assets. Except decayed object and rocket body, 23 space objects orbit around the earth [1]. Earlier launched Korean space objects on low earth orbit (LEO) had bigger semi-major axis. Therefore, almost Korean space debris on LEO have too high altitude to re-enter the ground in the near future. In case of inactive satellites of geostationary earth orbit (GEO), de-orbit process was done after the end of mission. Koreasat-1, 2 was de-orbit to the graveyard of the GEO.

In Tab. 1., summary of Korean space assets is described. The three space objects launched by the university were neglected. Among 12 LEO satellites, eight satellites are inactive now. Furthermore, some GEO satellites ready to close their mission.

Table 1. Summary of Korean space assets. Inactive satellites display as gray. Among 12 LEO satellites, eight satellites are inactive in 2019.

Name	INTLDES	Apogee (km)	Perigee (km)
STSAT 2C	2013-003A	528	259
KOMPSAT 3A	2015-014A	538	521
KOMPSAT 5	2013-042A	554	552
NEXTSAT-1	2018-099BF	591	571
STSAT 3	2013-066G	616	582

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KOMPSAT	1999-070A	666	661
KAISTSAT 4	2003-042G	686	670
KOMPSAT 2	2006-031A	698	673
KOMPSAT 3	2012-025B	694	681
KITSAT 3	1999-029A	722	705
KITSAT B	1993-061F	797	782
OSCAR 23 (KITSAT 1)	1992-052B	1318	1313
ABS 7 (KOREASAT 3)	1999-046A	35794	35778
KOREASAT 7	2017-023A	35793	35779
KOREASAT 5A	2017-067A	35793	35779
KOREASAT 6	2010-070B	35793	35782
GEO-KOMPSAT-2A	2018-100A	35789	35784
COMS 1	2010-032A	35787	35786
KOREASAT 5	2006-034A	35788	35787
ABS 1A (KOREASAT 2)	1996-003A	35937	35902
KOREASAT 1	1995-041A	35984	35932

The Optical Wide-field patroL-Network (OWL-Net) has been developed from 2010 for the tracking of Korean LEO satellites and the monitoring the GEO region. The OWL-Net consists of five global robotic telescopes. The main target of the OWL-Net includes not only the active LEO satellites but also the inactive LEO satellites to prevent the international space hazard by domestic space debris.

In this research, we analysed the visibility for Korean space debris on LEO by the OWL-Net. The orbit estimation results were analysed for KITSAT-1, first Korean space debris on LEO. A radar data from Leolabs was utilized for this work.

2 OPTICAL TRACKING FOR SATELLITES ON LEO

As we mentioned in previous section, the OWL-Net is global robotic telescope network. The OWL-Net has been installed in Mongolia, Morocco, Israel, the United States, and South Korea. Each station has weather sensor to decide the observability. The observation was performed by daily schedule from head-quarter in South Korea. All five stations are in northern hemisphere [2].

Figure 1. The location of the OWL-Net. Five stations are evenly distributed as longitudinal direction. However, the sites are only located in the northern hemisphere

The visibility study was done to find reasonable site location in 2011. We concluded that the location under +-30 degree of latitude was acceptable to track Korean LEO satellites. The stations were installed only in norther hemisphere as a result [3]. Currently, we found that there was seasonal condition of the visibility for last several years. In case of the optical tracking, the sun elevation condition and the lighting condition was required. There conditions make the observable period for LEO space objects.

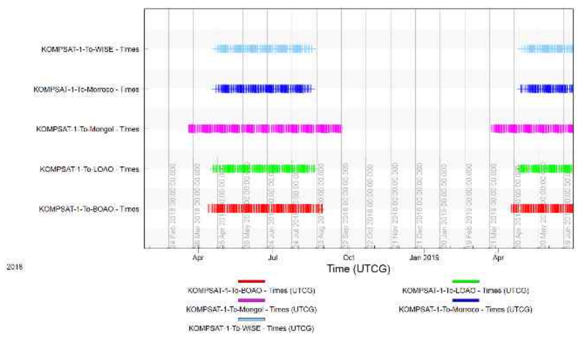

Figure 2. visibility of KOMPSAT-1 for the OWL-Net. The observation is only possible for several months in one year.

Fig. 1. shows the visibility of KOMPSAT-1 on five stations of the OWL-Net. The optical tracking is only possible from April to September. It is not temporary but periodic results. From April to September, KOMPSAT-1, STSAT-1 and STSAT-3 can be observed. From May to July, we have chances of the observation for KITSAT-3 and KOMPSAT-2 by the OWL-Net. However, KITSAT-1, KITSAT-2 and STSAT-2C can be observed by the OWL-Net all the year over.

Although the fast tracking and the orbit determination performance of the OWL-Net, the limit of the observation chance is obvious [4]. To track the space objects without the seasonal condition, other stations in the southern hemisphere are needed to add in the OWL-Net.

3 RADAR TRACKING FOR KITSAT-1 AND ORBIT ESTIMATION

LeoLabs is a commercial provider of tracking for LEO space objects. There are two radar stations of LeoLabs. The first one is the Poker Flat Incoherent Scatter Radar (PFISR) and the other one is the Midland Space Radar (MSR). These radars are phased arrays without tracking equipment. PFISR is a two-dimensional phased array and MSR is a one-dimensional phased array. These two radars can cover 95% of LEO satellite in the space catalogue [5].

We made the orbit estimation for KITSAT-1 with the radar observation data from the LeoLabs. Both radar stations' data were used in the orbit estimation process. We used the data from 1 January 2018 to 13 December 2018. For weekly orbit analysis, we separated the data in seven day increments. In 12th week, there was no data for KITSAT-1.

The orbit determination process was done using the sequential filter and smoother. Calibrated range and range-rate by LeoLabs were used to estimate the orbit. Because KITSAT-1 has altitude over 1300 km from the ground, we used CIRA 1972 atmospheric drag model. The gravity model, solar radiation pressure and third body effects also considered. We used two line elements (TLE) as a priori for the least square process. The forward sequential processing and backward smoothing processing was done with the results from the least square process.

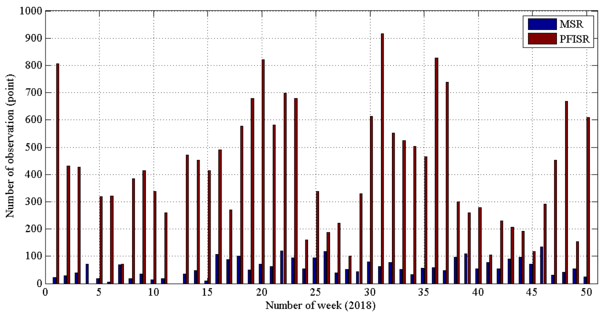

Figure 3. the distribution of number of observation for KITSAT-1 by Leolabs. PFISR has almost ten times much observations than MSR.

Fig. 3. shows the distributions of number of observation for KITSAT-1 by Leolabs. As we mentioned earlier, there was no observation data in 12th week. However, in fourth week, only MSR made observation. During the entire time, PFISR has almost ten times much observations than MSR. Larger field of view (FOV) and higher latitudinal position of PFISR would have made the condition for much observation data.

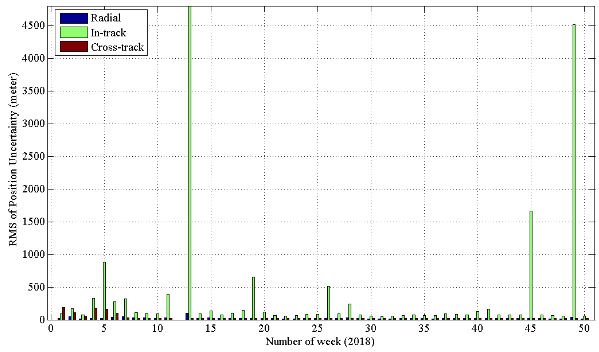

Figure 4. RMS of position uncertainty (meter) of weekly based orbit estimation process. Median value of In-track direction RMS of position uncertainty did not exceed 200 m.

Fig. 4 shows root mean square (RMS) of position uncertainty from the smoother process. Median value of RMS of position uncertainty for In-track direction is under 200 m. Almost radial and cross-track direction values are smaller than the In-track direction value.

However, 14th, 45th, and 49th weeks' results show greater values than others. It was caused by the leak of observation data, the error of a priori and unevenly distributed observation data. We used single TLE for a priori of each orbit estimation process. Each TLEs were published in the first day of the selected orbit estimation period.

These position uncertainty peaks were eliminated for yearly orbit estimation process. Although In-track direction position uncertainty was increased threefold during 12th week, it was caused by the leak of the observations. During the entire period, In-track direction position uncertainty was not exceeded 200 m.

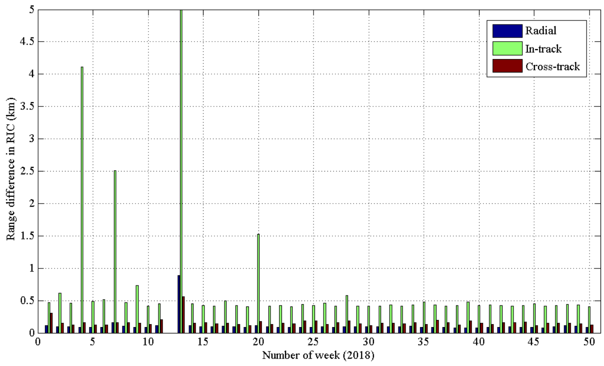

Figure 5. Range difference in RMS with consecutive TLEs in RIC (Radial, In-track, and Cross-track) frame. Smaller number of the observation in Fig.3. made bigger range difference in fourth, seventh week. In 13th week, abnormal two TLEs were used for comparison.

The estimated orbits were compared with consecutive TLEs. In case of KITSAT-1, sometimes TLEs were published twice a day. However, sometimes there was no updated for a week. Especially, during 12th and 13th week, three TLEs published and last two TLEs were used for comparison. However, those two TLEs were confirmed that inaccurate one by comparing the other TLEs. In Fig.4., the comparison result for 13th week was shown huge range difference than others. The bigger range differences for fourth and seventh week was caused by less observation data. Median range difference in RMS did not exceed 500 m.

However, yearly orbit estimation process shows constant range difference for a year except 12th and 13th week. The range difference in In-track direction did not exceed +-one km for other dates.

4 DISCUSSION

As the increasing number of space objects, safety of active satellites from collision with space debris is an urgent problem. Among about 20,000 space objects, only about 2,000 space objects is in active status. To avoid the collision between space objects, precise orbital information is needed.

The OWL-Net, optical tracking network, was developed for tracking Korean LEO satellites and monitoring GEO satellites. The main target of the OWL-Net includes eight Korean space debris on LEO. The OWL-Net consists five global stations which is evenly distributed in longitudinal direction. However, the visibility for Korean LEO satellites by the OWL-Net shows the seasonal changes. Therefore, more stations in southern hemisphere are needed for continuous tracking of Korean LEO satellites with the OWL-Net. On the other hands, radar system is not affected by the optical observation condition, therefore much observation chances are guaranteed.

We made the orbit estimation test for KITSAT-1, first Korean space debris on LEO, using the radar data from LeoLabs. The radar network consists of two stations in the United States. The orbit estimation test was done on a weekly basis. Median value of In-track direction RMS of position uncertainty did not exceed 200 m. The estimated orbits were compared with consecutive TLEs. As a results, range difference in RMS for In-track direction did not exceed 500 m for almost weeks. In yearly basis analysis, abnormal peaks for position uncertainty or range difference were eliminated. It indicated that the radar data can be maintained the orbital information for KITSAT-1 for a year.

The estimation target at lower altitude need to be utilized the orbit estimation for more representative results for LEO space objects. The atmospheric drag was a main perturbation for the space objects on LEO. And much objects on LEO orbits under 1000 km from the ground. And the additional analysis is needed for 12th week. During 12th week, there was no radar data and TLEs show huge errors. The analysis results can be used for analysis of the observation condition of radar system.

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Because KITSAT-1 has altitude over 1300 km from the ground,

6 FIGURES AND TABLES

Figures and tables can extend over two columns if required. Figure captions should be centred below the figures; table captions should be centred above the tables. Use full word 'Figure 1' or 'Table 1' in the caption. Use the abbreviation "Fig. 1" or "Tab. 1" in the text (even at the beginning of a sentence).

Figure 6. Space Debris 2009

7 REFERENCES

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7.1 Sample References

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