Development of Space Surveillance Tracking and Orbit Determination Program

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ABSTRACT

Space Surveillance Tracking is the process of detecting, orbit determination and tracking, identifying, and cataloging orbital debris. In particular, the process of orbit determination of orbital debris includes a core algorithm that can perform preprocessing of observation data, observation modeling by optical or radar system, and system parameter estimation related to the observation system. This paper presents an overview of space surveillance tracking and orbit determination (SSTOD) program, as well as validation and verification results using actual observation data such as optical and radar data. This program can provide an integrated solution of orbit determination for several activities related with space surveillance tracking scenarios

1 INTRODUCTION

Major advanced space development countries, including the U.S., Europe have already been pursuing policies and development on Space Situational Awareness (SSA) in order to ensure the safety of space assets and protect them. The high-level objective of SSA is to provide to the users dependable, accurate and timely information in order to support risk management on orbit and during re-entry and support safe and secure operation of space assets and related service. Therefore, to predict and assess the risk to humans and property on ground due to the re-entries as well as on-orbit collisions or explosions, SSA system implies the importance of the detection and tracking of space objects. The mission of this system focuses on the ability to view, understand, and predict the physical location of space objects in orbit around the Earth. In particular, the space surveillance and tracking segment is responsible for the detection and prediction of the movement of space object in orbit. This is considered as a system based on the data coming from one or several sensors, typically optical or radar. The core performance of this system can be evaluated by the ability to detect a new space object, to continuously maintain the latest orbit element after detecting a new space object, and the ability to precisely determine the position and velocity of the observed space object.

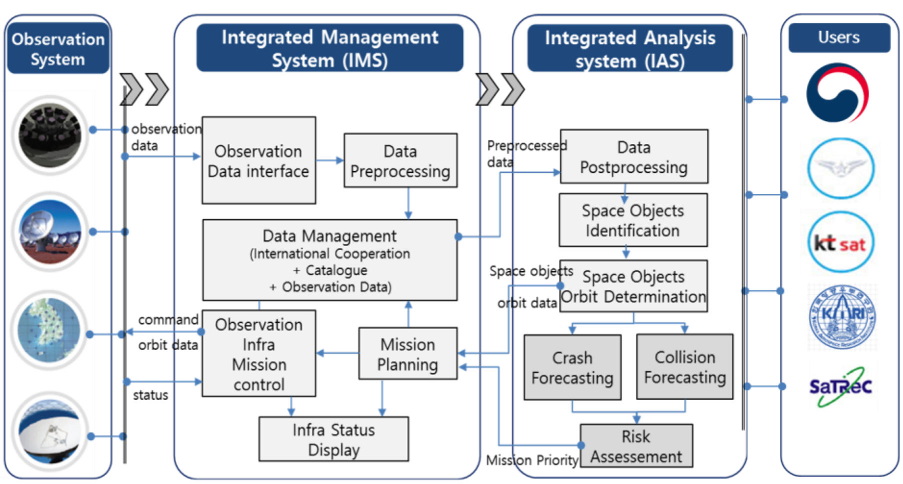

Fig. 1. Overall architecture of Integrated Analysis System [1]

In Korea, National SSA Organization (NSSAO) carries out the role as specialized institute for SSA and secures the strategic capability to assess the space risk. Furthermore, additional technical studies and required technology developments are in progress by NSSAO. The conceptual design of SSA system consists of two main segments such as space objects monitoring system such as optical and radar and integrated analysis system, as shown in Fig. 1 [1]. For observation system, OWL-Net (Optical Wide-field patrol Network), one of Korean space situational awareness facilities using optical system, and the planned radar system are included. For integrated analysis system performs the functions for management of observation system and for analysis of risk assessment.

Throughout this research, the space surveillance tracking and orbit determination program has been developed for orbit determination and prediction of space objects based on the data coming from actual observation system. The orbit determination is based on dynamic perturbation models for the space object, the observation models like right ascension and declination or range and range rate observation, and the weighted lest squares batch filter. This paper described the space surveillance tracking and orbit determination (SSTOD) program was developed in this research. And the results of the orbit determination using actual optical and radar observation data from OWL-Net optical system and LeoLabs radar system. The accuracy of orbit determination was verified using the precision orbit ephemeris of the KOMPSAT-5 satellite, of which the position accuracy is 20cm (1 σ) in position and 0.3 mm/s (1σ) in velocity [2].

2 SPACE SURVEILLANCE TRACKING AND ORBIT DETERMINATION (SSTOD)

There are many orbit determination tools available for each space agencies, including commercial products. SSTOD is an integrated solution developed to determine the orbit of space objects using actual optical and radar observation data. The design of SSTOD is strongly motivated by accuracy and performance of sensor. SSTOD provides the function of preprocessing as optical or radar observation data. In this research, two sensors such as OWL-Net and LeoLabs are used. Fig. 2 shows how this program is organized. This program can be divided into three main modules; observation data preprocessing, orbit determination and analysis including result visualization.

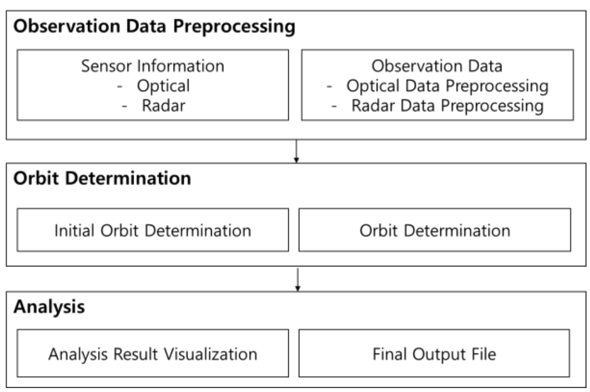

Fig. 2. Space Surveillance Tracking and Orbit Determination (SSTOD) functional diagram

2.1 Observation Data Preprocessing

The observation data preprocessing supports the two different observation data via optical and radar. In particular, this program provides for the preprocessing of optical observation data consisting of right ascension and declination and preprocessing of radar data consisting of range and range rate. In this paper, Optical wide-field patrol network (OWL-Net) and LeoLabs, Inc. observation data preprocessed as representative of optical and radar sensor data.

The Optical wide-field patrol network (OWL-Net) is ground-based optical tracking system of space objects developed at the Korea Astronomy and Space Science Institute (KASI). There are five observatories around world, in Mongolia, Morocco, Israel, USA, and Korea. The OWL-Net observation data were provided in form of report files, which include the location of the observatory, exposure time, time-tagged data points [3].

The LeoLabs' network consists of two radars, the Poker Flat Incoherent Scatter radar (PFISR) and the Midland Space Radar (MSR). LoeLabs provides raw measurements including calibrated range and range-rate measurements, including correction values and uncertainty estimates. Fig. 3 shows the user interface of observation data preprocessing module.

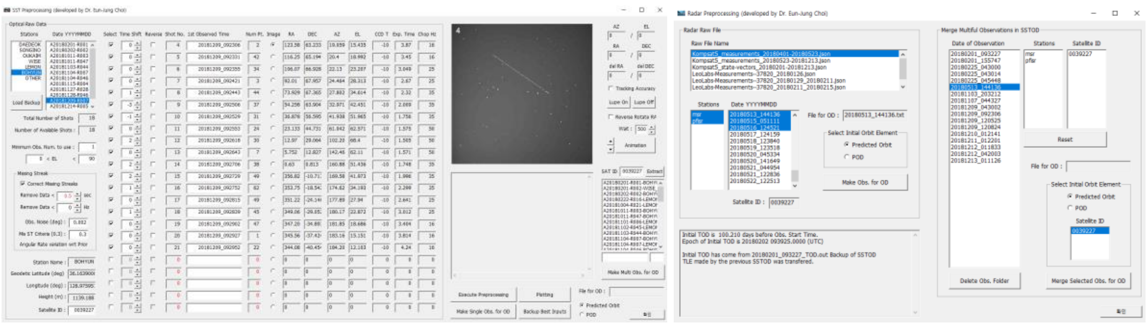

Fig. 3. Preprocessing of optical (left) and radar (right) sensor

2.2 Orbit Determination

The orbit determination adopts the conventional dynamic parameter estimation concept that consist of the precise dynamic models of satellite, the observation models in J2000 coordinates, and the weighted least squares batch filter. The precise dynamic models are applied as the equations of motion and variation equations of satellite which are integrated numerically using Adams-Cowell 11^{th} order predictor-corrector method. The perturbations such as geo-potential, the gravity of the Sun and Moon, slid Earth tides, ocean tides, solar radiation pressure, and atmospheric drag are modeled [4][5][6]. In particular, this program can estimate parameter related to observation such as angle and angle timing bias, range and range timing bias, TEC scale factor for ionospheric delay, and zenith delay parameter for tropospheric delay. Furthermore, the parameters related to dynamic such as position and velocity, drag coefficients, and solar radiation pressure can be estimated.

The initial orbit determination produces an initial estimation of state vector using the Gauss algorithm [7]. It is based on a limited set of raw observation data with no prior knowledge of position and velocity of space object. In case of initial orbit ephemeris, the osculating orbit data, TLE, or initial orbit determination data can be used. That is, the initial orbit determination technique can be used as a priori states.

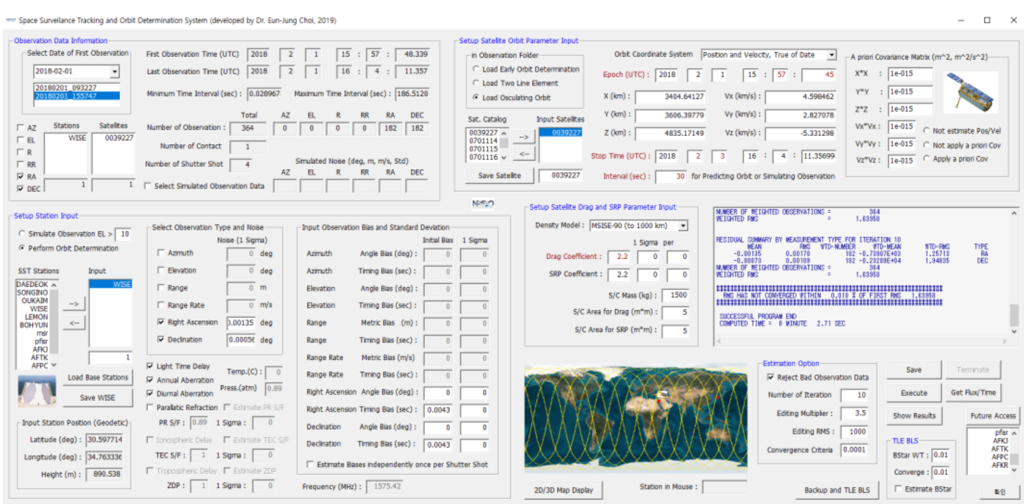

Fig. 4. Orbit Determination (OD)

2.3 Analysis Visualization

The results of the orbit determination can be shown graphically in graphs and text files as Fig. 5. This module consists of text mode and graph mode. Text file includes all calculated information and graph modules include the observation residual part and estimated orbit state and observation bias part.

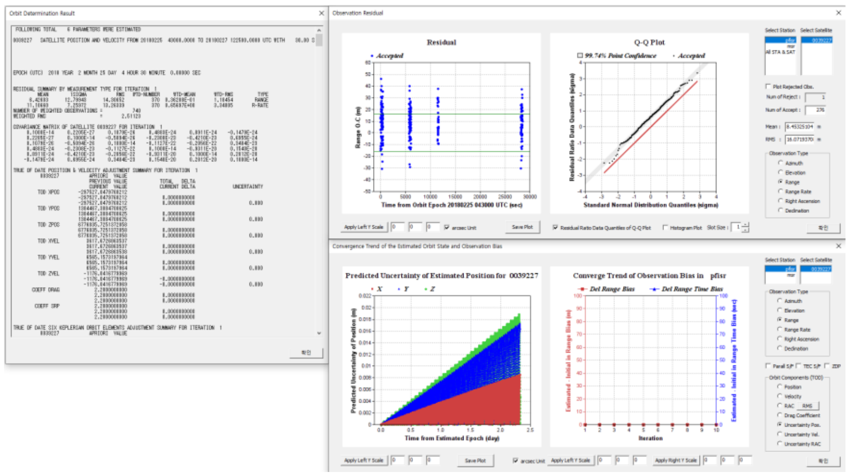

Fig. 5. Orbit Determination Result Visualization

3 RESULT

For the purpose of the verification for SSTOD, the orbit determination was performed using actual KOMPSAT-5 satellite observation data of OWL-Net and LeoLabs. The KOMPSAT-5 satellite carries a dual frequency GPS receiver, thus making it possible to have independent orbital comparisons. The KOMPSAT-5 satellite has the precision orbit ephemeris, which is the accuracy of about 20cm (1 σ) in position and 0.3mm/s (1 σ) in velocity. In this paper, sample results of the orbit determination are described.

The optical observation data with right ascension and declination of the KOMPSAT-5, which were observed for about 6 minutes from 1 February 2018 09:32:27 UTC at Bohyun station of OWL-Net, were used. The observation data was pre-processed by the optical observation data preprocessing module. Fig. 6 shows the residuals of right ascension and declination and their RMS were 2.39 and 1.17 arcseconds, respectively. Fig. 7 shows the predicted uncertainty of estimated position.

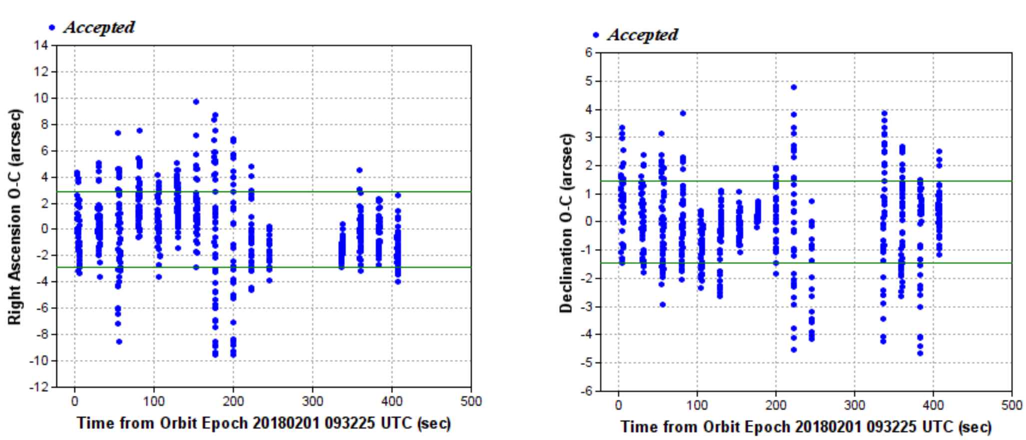

Fig. 6. Residuals of the orbit determination of KOMPSAT-5 observed at OWL-Net Bohyun station

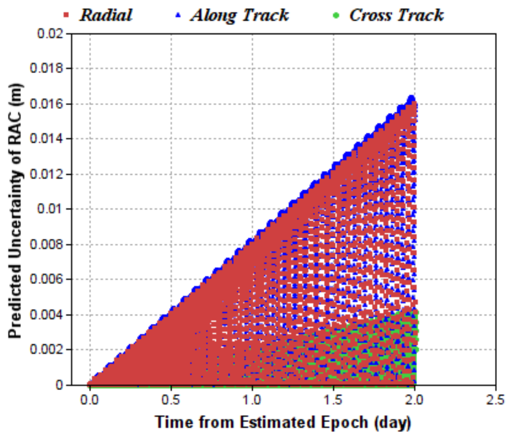

Fig. 7. Predicted uncertainty (square root of covariance) of radial, along track, and cross track position

The radar observation data with range and range rate of the KOMPSAT-5, which were observed between 25 February 2018 04:54:48 to 14:18:00 UTC at PFISR of Leolabs, were used for the verification of orbit determination using actual radar data. During the observation, there were two contact time and 127 range and range rate data. The observation data was pre-processed by the radar observation data preprocessing module. As a result, Fig. 8 shows the residuals of range and range rate and their RMS were 12.17 m and 3.84 m/s, respectively. Fig. 9 shows the predicted uncertainty of estimated radial, along track, and cross track.

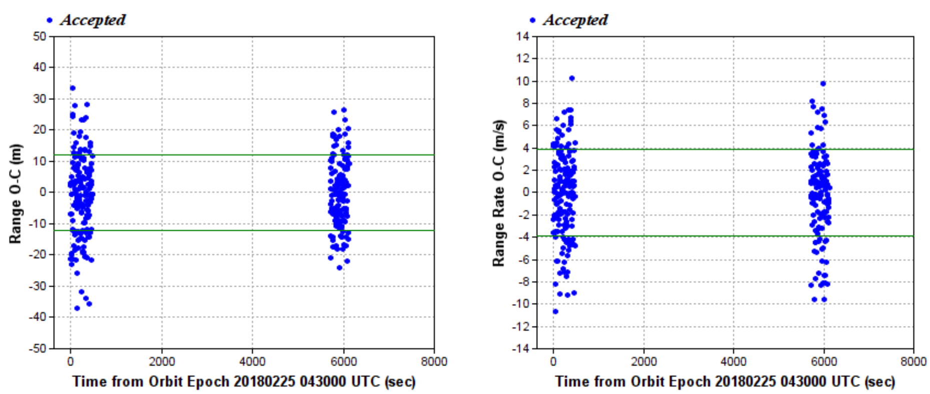

Fig. 8. Residuals of the orbit determination of KOMPSAT-5 observed at LeoLabs' PFISR station

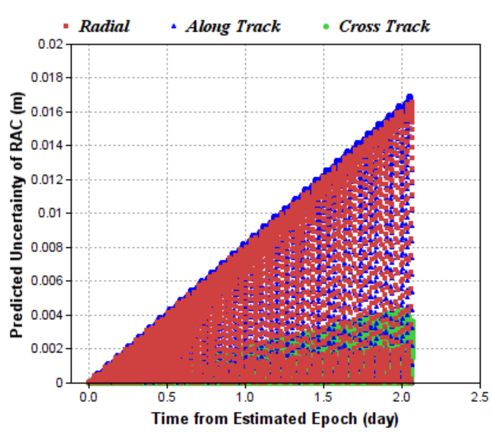

Fig. 9. Residuals of the orbit determination of KOMPSAT-5 observed at LeoLabs' PFISR station

4 CONCLUSION

Space Situational Awareness (SSA) requires the ability to detect a new space object, to continuously maintain the latest orbit element, and to observe the space objects periodically and track them exactly. In particular the space surveillance tracking and orbit determination, which is to accurately determine the ephemeris of an space object from the observed data, is required for the most important factor in evaluating the performance of the SSA system. With that goal in mind, in this research, the SSTOD program was developed to improve the capability for national SSA system. This paper has presented the overall architecture and functions of the SSTOD. The developed SSTOD program will provide the observation data preprocessing of optical and radar system and orbit determination results using graphically user interface. This solution will be able to be used as a national SSA system and can be used for almost the whole observation network for space object tracking.

5 ACKNOWLEGEMENTS

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