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Development of Space Traffic Management System: ZIRCON †

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Abstract: In near future, commercial companies have proposed to launch the extreme large constellation of small to medium-sized satellites over new 20,000 satellites in orbit. As a result, satellite operators will face a new challenge and have to prepare some solutions to mitigate huge potential collision risks. Under current practices, operators receive collision warning messages (Conjunction Data Messages: CDMs) generated by the Combined Space Operations Center (CSpOC). It is possibly to receive huge conjunctions that exceed warning threshold control each day but many of them are false conjunctions because the result of a combination of inaccuracies in the sensor measurements, predicting error and especially inadequacy of satellite information (e.g., GPS data and satellite size) To reduce the false CDMs and effectively mitigate the potential risk in time, space traffic management system can minimize the problems. The key system capabilities are able to automatically screen potential risky objects and provide an analysis tool to decide effective maneuver planning. As a result, GISTDA initiates the project to develop the space traffic management system known as "ZIRCON" to monitor and mitigate the risk of GISTDA's satellites and future satellites (e.g., THEOS2 project). This paper presents the operational collision avoidance process and algorithm analysis of space traffic management system. The accuracy of analysis results is validated by comparing the analyzed results of CSpOC and Space Data Association (SDA) serving the commercial space sector to monitor and provide warning message for membership. The last section describes the future development planning and services for satellite operators.

Keywords: space traffic management; space debris; Collision avoidance maneuver; ZIRCON; close approach; mitigation and conjunction risk assessment

1. Introduction

In the first space era, space sector mainly serves science, security applications and space exploration. Today, it is becoming more commercial and the participation of private sectors to build economic growth, risk mitigation and new innovation. Multiple commercial companies (SpaceX, OneWeb, Theia, Boeing, etc.) propose to launch small satellites in megaconstellations. The expected growth of space object population results in huge close encounters or Conjunction Data Messages (CDMs). This issue is forecasted to significantly grow in the near future. Space traffic management (STM) is essential for the global space community [1] to detect and prevent possible on-orbit collisions between space objects. In this reasons, Geo-Informatics and Space Technology Development Agency (GISTDA), which operate Earth observation mission known as "Thaichote", awares of the issue.

GISTDA purposes to develop in-house STM systems to enhance the safety, stability and long sustainability for current and future satellites of GISTDA in the space environment.

This paper presents the space traffic management process known as "ZRICON" in Section 2. Section 3 presents the validation results and ZIRCON features. Then, Section 4 describes the conclusion and future development planning.

2. Space Traffic Management System Process

In Figure 1, the system automatically downloads Two Line Elements (TLEs) of all space objects from the US Strategic Command (USSTRATCOM) through www.space-track.com and satellite ephemeris from satellite mission control. The potential collision risk of space objects is automatically screened in advance 7 days. If the threshold control of miss distance is less than 1 km, collision probability is analyzed. Then, the data are summarized in term of a conjunction report for the operators. An operator analyzes the geometry of conjunction and collision probabilities. If the collision probability is over threshold control, an operator examines the conjunction by using the risk assessment tool to analyze the conjunction geometry as shown in Figure 2 and decide the planning of the collision avoidance maneuver.

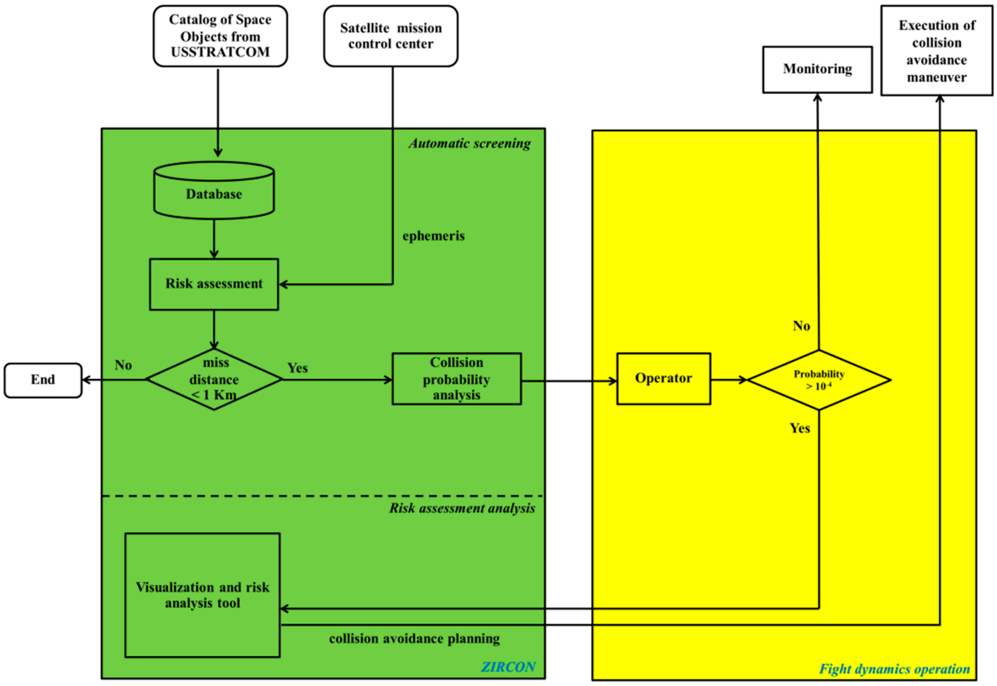

Figure 1. Space traffic management system process: ZIRCON.

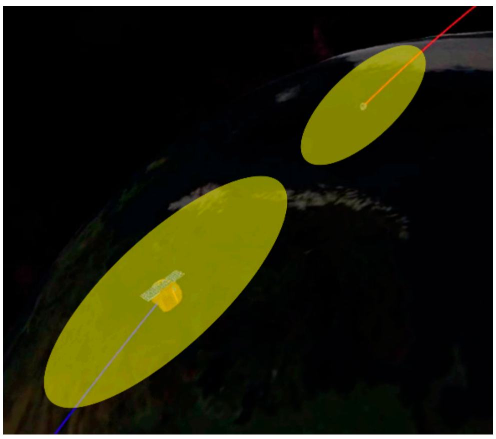

Figure 2. 3D Visualization of risk assessment analysis tool: ZIRCON.

3. Risk Assessment Algorithm and Validation

3.1. Orbital Dynamics

Based on GISTDA's experiences that success to develop and implement in-house flight software dynamics known as "EMERALD" [2–9], the accuracy of orbital prediction consists of 2 main factors in order to high accuracy to define TCA and miss distance. Firstly, perturbation forces in ZIRCON are decided to consider gravitation potential, third body perturbations (the sun and moon), solar radiation pressure and atmospheric drag. Secondly, the propagation is used numerical integration to solve the ordinary differential equations. These are implemented in ZIRCON for high accuracy of orbital propagation.

3.2. Collision Proability

The collision probability is to evaluate the potential collision risk. In the general method, the collision probability is expressed in the integral of the three-dimensional probability density function (PDF) and both primary and second objects are simplified to be sphere. For the short encounter, two objects are assumed to move along straight lines and position uncertainty during the encounter is assumed to be constant. Under these assumptions, the collision probability onto the projected covariance ellipsoid or b-plane resulting in the probability that calculate in the two-dimensional probability is given as:

$$P_c(r, xm, ym, \sigma x, \sigma y) = \frac{1}{2\pi\sigma x\sigma y}\int_{-r}^{r}\int_{-\sqrt{r^2-x^2}}^{\sqrt{r^2-x^2}} e^{-\frac{1}{2}\left[\left(\frac{x-xm}{\sigma x}\right)^2+\left(\frac{y-ym}{\sigma y}\right)^2\right]} dydx \quad (1)$$

where r is the combined object radius, x lies along the minor axis of error covariance ellipse, y lies along the major axis of error ellipse, σx and σy are the corresponding standard deviations, xm and ym are the respective coordinates of the projected miss distance. In case of the worst case conjunction scenario, the maximum possible collision probability described in [10] is implemented in ZIRCON.

3.3. Validation

The analyzed results of ZIRCON is validated by comparing with the conjunction data message of the space Data Association (SDA), which is a membership-based organization of satellite sharing satellite ephemeris data in member for more accurate and up-to-date closet approach. Table 1 shows examples of the comparison of ZIRCON and SDA collision analysis by screening threshold control at miss distance < 1km that shows the small difference of TCA miss distance. The comparison results therefore present high accuracy of closest approach events.

Table 1. Comparison analyzed results between SDA and ZIRCON.

Primary/Secondary	**Time of Close Approach (UTC)**		**Miss Distance (km)**	
	SDA	**ZIRCON**	**SDA**	**ZIRCON**
THEOS (33396)/FENGYUN 1C DEB (30116)	01/05/2019 15:35:40:806	01/05/2019 15:35:40:807	8.7527	8.7526
THEOS (33396)/COSMOS1275DEB (18592)	10/05/2019 07:13:36:168	10/05/2019 07:13:36:168	5.8118	5.8118
THEOS (33396)/METEOR1-27 DEB (31890)	04/06/2019 19:23:07:280	04/06/2019 19:23:06:281	1.2225	1.2225
THEOS (33396)/NOAA 16 DEB (41214)	06/06/2019 01:49:17:035	06/06/2019 01:49:17:051	0.6022	0.6023

4. Conclusions and Future Work

This paper presents the process and risk assessment analysis algorithm of space traffic management system (ZIRCON) developed by GISTDA. The closest approach analysis of ZIRCON is reliable and high accuracy by comparing with SDA. Currently, the system can perform full automatic screening of the potential risk of space objects and automatically providing the conjunction summary report. However, to maintain a safe operating environment and enhance full ZIRCON's capabilities, the future development planning consists of 2 phrases. Firstly, the new STM capability will be developed and implemented such as autonomous maneuver planning, radio-frequency interference and coordination with other satellite operators Secondly, the system can provide space weather information, support mega-constellation and monitor conjunction analysis of sub-orbital, launching and reentry. Then, the collision warning message will be the first service for Thai satellites in near future.

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