INTEGRATED ANALYSIS SYSTEM FOR RE-ENTRY RISK ASSESSMENT

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ABSTRACT

The purpose of this study is to design the Integrated Analysis System (IAS) for re-entry risk assessment, as part of the research and development of national space situational awareness system.

The key technologies for risk analysis of space objects re-entry into the Earth are divided into four stages; the cataloguing/database of re-entered space object identification, the prediction of life cycle and trajectory, breakup fragment survival modelling after re-entry and prediction of multipole debris distribution, and the impact probability on the ground.

In this study, we investigated the technology research and key elements for the re-entry risk assessment and conducted a basic analysis to find the core requirements for the determination of the re-entry risk due to the ground collision. Also, we propose a technique and algorithm that can be used as a basis for judging the risk due to the re-entered space objects. It will be uses as part of the IAS for national Space Situational Awareness (SSA) system.

1 INTRODUCTION

The threat posed by outer space has become one of the important global issues and Space Situational Awareness (SSA) is also emerging as a new agenda of space development. A SSA is invariably linked to threats and hazards, but SSA can also provide opportunities to both mitigate or reduce the hazards, and even to benefit from the potential resources present in both man-made and natural space objects [1]. In particular, SSA has been recognized to be an essential prerequisite for the safe conduct of space activities. Because the high-level SSA objective 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 services [2][3][4][5].

In May 2014, Korea established the preparedness plan for space hazards according to the space development promotion act which is amended to take action with respect to hazards from space. Under the plan, the Korean space situational awareness system is now proceeding. This plan is composed of three main items such as System, Technology and Infrastructure [6]. System includes the establishment and management of national space hazards headquarters at risk situation. National Space Situational Awareness Organization (NSSAO) was given the task of managing and developing for the measurement system and research for SSA system. Technology for SSA implies the importance which is to develop the system that can detect, predict and assess the risk to life and property due to potential impacts of re-entries of man-made space objects as well as potential impacts of Near-Earth Objects (NEOs).

The conceptual design of SSA system consists of two main segments such as space objects monitoring system and Integrated Analysis System (IAS) as Fig. 1 [6]. For observation system, OWL-net (Optical Wide-field patroL Network), one of Korean space situational awareness facilities using optical system, and planned observation sensors such as optical telescopes, all-sky camera, and radar system are included. For risk assessment, the all provided data from the acquired data through the international cooperation and public data are used. In this paper, the integrated analysis system for re-entry risk assessment of artificial space objects will be summarized.

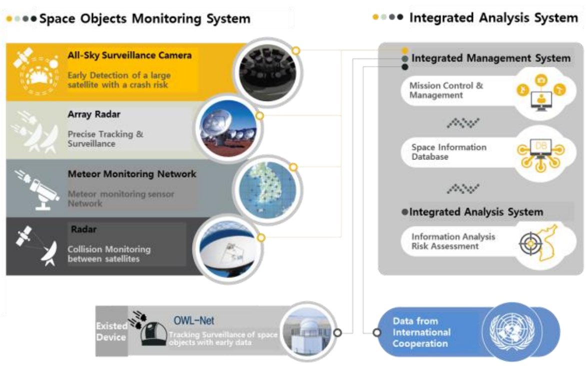

Figure 1. Configuration of Space Objects Monitoring System and Integrated Analysis System [6]

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2 RISKS OF SPACE OBJECTS

Artificial space objects are all man-made space objects caused by human activities such as satellites and space debris resulting from the launch vehicle or satellite. Since the launch of Sputnik I, space activities have created an orbital debris environment that poses increasing impact risks to existing space systems. Currently, according to the box score of the Satellite Situation Report issued on April 10, 2017, 42,489 objects have been registered as orbiting the Earth, of which 18,401 are in Earth orbit and 24,088 objects have already burned up in the atmosphere. Fig. 2 displays a summary of all objects in Earth orbit officially catalogued by the U.S. Space Surveillance Network as object and region type [7]. “Fragmentation debris” includes satellite breakup debris and anomalous event debris, while “mission-related debris” includes all objects dispensed, separated, or released as part of the planned mission.

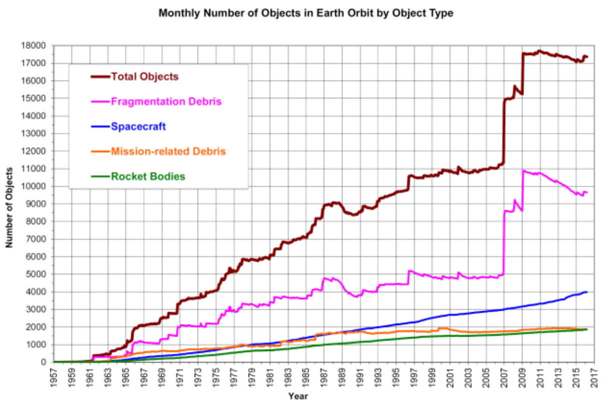

Figure 2. Number of Catalogued Objects in Earth Orbit by Object Type [7]

The risks of artificial space objects can be broadly defined in two categories: collision between artificial space objects and re-entry into the Earth of a large inoperable satellite. As the number of satellites and space debris increases, the likelihood of collisions between flying objects in space also increases. The most active and endangered region is between the altitudes of 500~1,200 km in LEO, and even without any new launches, this region is highly unstable. Objects larger than 10 cm in diameter in LEO, softball size or larger, can be routinely detected and tracked and are known as the catalogued data. These objects travel at a speed of up to 8 km/s, which means even the smallest particles are capable of causing catastrophic damage to any satellite they encounter. To protect the space infrastructure and predict on-orbit collisions accidentally or intentionally, a SSA system is becoming more critical to enable conjunction assessment with subsequent collision avoidance.

There is also a great risk of a major disaster caused by the re-entry of a nuclear-powered or a large inoperable satellite. A re-entry is when an artificial space object comes back into the atmosphere. Approximately 57.3 % of the number of registered objects fell to the Earth. Fig. 3 shows the number of re-entries for the entire space age [8]. Typically, there are 200 to 400 objects big enough crashed into the Earth each year [8]. The re-entry of space objects may be broken into many pieces of debris at an altitude in the range of 75~85 km. Generally, most of the debris is burned just go away decay, but the surviving fragments can cause great hazards to persons and buildings on the ground. There are two kinds of re-entry: controlled and uncontrolled. For controlled re-entries, the re-entry target zone can be chosen to avoid populated areas on the Earth. However, in case of uncontrolled re-entries, it is very difficult for the prediction of the re-entry location and epoch to achieve the required prediction accuracy [9]. Especially, the re-entry of a large inoperable nuclear-powered satellite has caused the risk of disaster. On 24 January 1978, Cosmos 954, a Soviet maritime reconnaissance satellite crashed in the northwestern Canada. This crash scattered numerous components contaminated with radiation from the nuclear reactor that powered it [10]. The important point is that the satellites with on-board nuclear reactors of the same model are still in the Earth orbit. That is why we need to continue to monitor them.

Recent event of uncontrolled re-entries that gained a lot of public interest include the Progress M-27M, Russian cargo spacecraft with a planned 6-hour rendezvous profile to the International Space Station (ISS). The Progress M-27M carried 2,357 kg of food, fuel and supplies for the six members of the ISS. However, the spacecraft was out of control and its orbit would eventually decay to fall back into Earth’s atmosphere on 8 May 2015. Although the hazards posed by re-entering spacecraft or debris are extremely small, the re-entry of space objects must be considered with a number of legal and safety aspects.

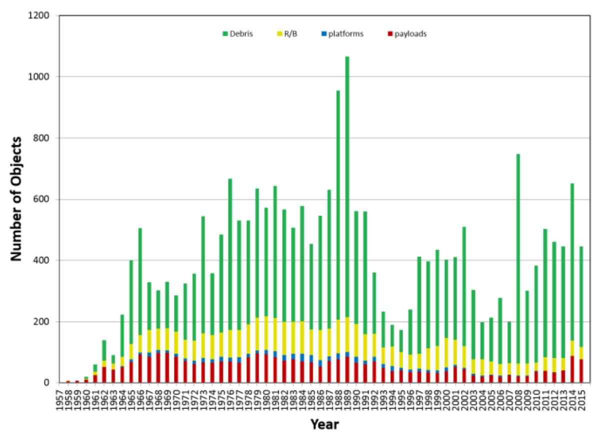

Figure 3. The number of re-entries for the entire space age [8]

3 INTEGRAGED ANALYSIS SYSTEM

Integrated Analysis System (IAS) performs the functions for management of observation system and for analysis of risk assessment. Fig. 4 describes the architecture design of IAS [6]. In particular, the design of space objects database for national SSA system is carried out as part of the IAS. The data policy for the national SSA system is required to deal with the space objects data collected by various routes, such as space objects surveillance information of foreign partners, calculated data and information of space surveillance observation equipment and data provided by domestic space observation system. Therefore, the data management is the most important function for IAS to manage the obtained data from the observation and catalogued data. IAS includes the functions for risk assessment. Crash risk analysis predicts the re-entry time and location and analyse the impact time and location. The re-entry risk assessment processes a comprehensive risk evaluation function and generates the mission priority.

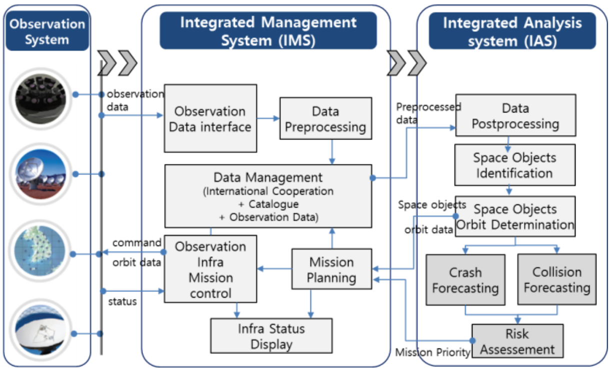

Figure 4. Architecture Design of Integrated Analysis System [6]

4 RE-ENTRY RISK ASSESSMENT

Since the decay of the Sputnik 1 launch vehicle on December 1957, 24,088 catalogued orbiting objects (issued on April 10, 2017) have re-entered the Earth's atmosphere. And still, about one object re-enters each day. Generally, a mass fraction between 5%~40% of satellite is able to survive re-entry and the actual percentage for a specific object depends on the weight, number and component survivability [11].

NASA standard 8719.14 defines the guidelines to minimize the risk to human life and property on the ground. Especially, re-entries must have the human casualty expectancy lower than 1:10,000 [11][12]. The human casualty risk can be divided both the possibility of a direct hit of people and potential debris impact leading to indirect human casualties, such as building, vehicle and high risk industrial plan, and so on.

In order to evaluate the hazard and ground risk due to re-entered space debris, total casualty probability is given by the summation of the terms obtained by multiplying casualty area, probability of debris impacting area and population density at ground.

· Total Casualty Area:

$$A_c = \sum_{i=1}^{n} \sqrt{A_h} + \sqrt{A_i})^2 = \pi \sum_{i=1}^{n} (r_i + r_h)^2 \tag{1}$$

A_i : Cross Section area, A_h : Human Risk Cross-section

· Probability of Debris Impact Area:

$$\sigma_i(\delta, \phi) = \frac{1}{2\pi^2 R_e^2 (\sin^2\phi - \sin^2\delta)^{1/2}} \tag{2}$$

δ : Latitude of Impact Location, ϕ : Reentry Inclination angle

· Total Casualty Probability :

$$E = \sum_{i=1}^{n} \rho_i \sigma_i A_{ci} \tag{3}$$

ρ_i : Population Density at Ground

To get the final total casualty probability, the re-entry object's detailed information must be secured first; TLE (Two Line Element) and characteristics of space objects. Therefore, in order to treat the re-entry risk assessment, it is necessary to have the database of space objects and the capability for prediction of lifetime and the atmospheric re-entry prediction.

The key technologies for re-entry risk assessment of space objects are divided into main four steps as Fig. 5. : 1) The cataloging/database of re-entered space object identification, 2) The prediction of lifetime and trajectory, 3) Break-up fragment survival modeling after re-entry and prediction of multiple debris distribution, 4) the impact probability on the ground.

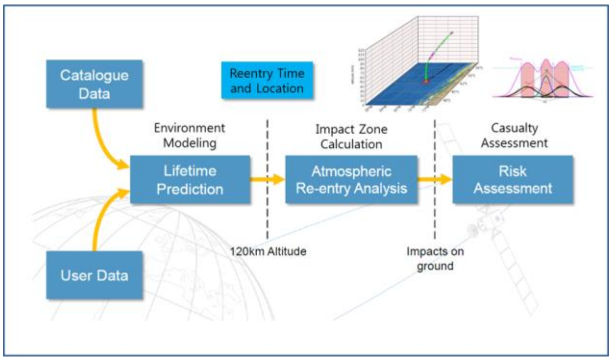

Figure 5. Key technologies for re-entry risk assessment

As a first step, we have developed the database of space objects based on space-track TLE information and OWL-Net observation data. The main objective of the OWL-Net is to get orbital information of Korean LEO and GEO satellites using optical telescopes and to maintain their orbital elements. Currently, OWL-Net is calibration and validation phase. The database uses the operation status and provided data from OWL-Net. The process for space cataloguing includes the data processing of measurement data and orbit determination.

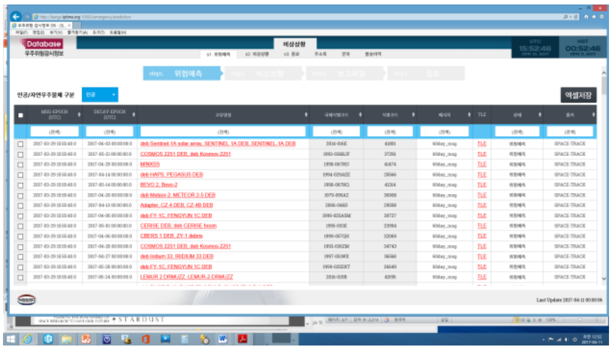

Figure 6. Database for space objects and Prediction Information for re-entries using Space-Track

Lifetime prediction algorithms included in the re-entry window can calculate the expected time and trajectories for space objects to re-enter the atmosphere. However, it is not certain. And in practice, starting a few days before the satellite re-enter from orbit, the nominal predicted trajectory is modified. Also, before the event of break-up of re-entering space object, it is necessary to analyse and predict how many break-ups could survive during the atmospheric re-entry phase. Finally, total casualty probability is calculated based on the trajectory and the distribution as a function of a time.

5 CONCLUSION AND FUTURE WORKS

The present paper outlines the integrated analysis system for re-entry risk assessment, which is used by the National Space Situational Awareness Organization (NSSAO) to predict the risk assessment for re-entry event. The Integrated Analysis System (IAS) and the key technologies for re-entry risk assessment have been described in this paper. This system can manage the space objects data and provide key algorithms for calculating the re-entry risk assessment.

According to the preparedness plan for space hazards, Korean space situational awareness system is currently building to prepare for space risks to human and property due to re-entries of space objects. The designed architecture and algorithms for the re-entry risk assessment will be used as key part for national SSA system and can provide powerful support for preparing space risks.

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