IDEA THE PROJECT FOR IN-SITU DEBRIS ENVIRONMENTAL AWARENESS

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ABSTRACT

Kyushu University has initiated IDEA the project for in-situ debris environmental awareness. This project aims at a prompt and clear understanding of the current and future micron-size debris environment in the low Earth orbit region. Orbital debris, even smaller than 1 mm, may cause a fatal damage on a spacecraft because of a high relative velocity at impact. Micron-size debris could be one of major threats against safe and secure space development and utilization for humankind. However, the current micron-size debris environment has not been defined well because measurements are quite limited in terms of orbital regimes and not continuously available yet. Thus, the IDEA project proposes to deploy a group of micro satellites, those conduct in-situ and near real-time measurements of micron-size debris, into any orbital regimes to be monitored. This paper briefly introduces the IDEA project and micron-size debris modeling to define and dynamically update the current environment using measurements continuously acquired through the IDEA project.

1 INTRODUCTION

Since Suptnik-1 launched in 1957, humankind have launched many rockets and inserted many satellites into many orbits. Such space development and utilization have provided humankind with conveniences, new knowledge, and technologies. Space is limited in spatial extent, however. Now space debris represents a significant threat against safe and secure space development and utilization for humankind, with over 95 % of the more than 16000 cataloged objects in orbit being debris [1]. It may be noted that the cataloged objects are equal to or greater than 10 cm in size.

Objects in the low Earth orbit (LEO) region are traveling at a speed of approximately 8 km/s. Therefore, space debris, even smaller than 1mm, may cause a fatal damage on a spacecraft not sufficiently protected. For example, as reported in [2], a simulated debris particle with a size of approximately 0.2 mm fractures power cables on a spacecraft. This kind of damage might be the cause of loss of power, which happened to ADEOS-2 spacecraft in October 2003[3]. Impacts on spacecraft by micron-size debris in space are not new in these days. In fact, Endeavour and Atlantis have received flesh scars caused by micron-size meteoroid or debris impacts on their radiator panels [4,5]. Another example is micron-size meteoroid or debris impacts on Window 2 of the Cupola module of the International Space Station during check-in. Therefore, micron-size debris could be one of major threats against safe and secure space development and utilization for humankind.

Knowledge on micron-size debris should be incorporated in design of spacecraft. However, the current micron-size debris environment has not been defined well because measurements are quite limited in terms of orbital regimes and not continuously available yet. The latest knowledge on micron-size debris from recent major breakups such as Chinese anti-satellite missile test using Fengyun-1C in January 2007 and US Iridium 33 and Russian Cosmos 2251 accidental collision in February 2009 may not be enough to understand the current environment. Knowledge is necessary to be dynamically updated based on measurements of micron-size debris in the actual environment.

Kyushu University has initiated IDEA the project for in-situ debris environmental awareness, aiming at a prompt and clear understanding of the current and future micron-size debris environment in the LEO region. The IDEA project proposes to establish an in-situ and near real-time measurements network to monitor micron-size debris using a group of micro satellites. This paper briefly introduces the IDEA project and micron-size debris modeling to define and dynamically update the current environment using measurements continuously acquired through the IDEA project.

2 IN-SITU DEBRIS ENVIRONMENTAL AWARENESS

The following subsections describe IDEA the project for in-situ debris environmental awareness on-going at Kyushu University, Japan.

2.1 Why micro satellites?

The IDEA project aims to build an in-situ measurement

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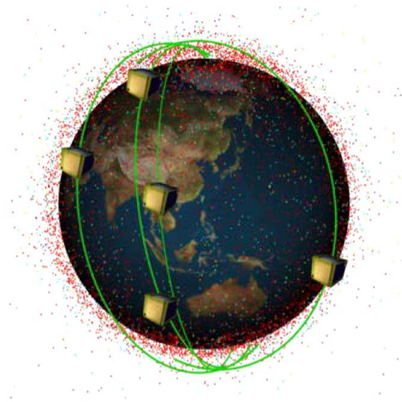

Figure 1. In-situ measurements network by IDEA satellites

network using a group of micro satellites. Each micro satellite can detect debris impacts on their surfaces facing the ram and downlinks measurements to the ground in near real-time. Fig. 1 illustrates a future vision that the IDEA project expects as a novel system. Large massive satellites may be able to gaurantee a large sensing area to acquire more measurements. However, their research and development time may become long to cost much. In addition, their launch cost may be also expensive. Thefore, it is near impossible for large satellites to build a in-situ measuremetns network. In contrast, micro satellites may require shorter reaech and development time to cost less in comparison to large massive satellites. The micro satellites can be lauched as secondary payloads to reduce their launch cost and to find out launch opportunities with ease. Therefore, micro satellites are suitable to build a constellation.

2.2 IDEA-1 satellite

With the aforementioned background, the first micro satellite named IDEA-1 is under development at Kyushu University, Japan. The IDEA-1 satellite is supposed to conduct the following two missions:

1) Technology demonstration of the IDEA-1 satellite through its entire life cycle from launch to de-orbit, and
2) Detection of impacts by micron-size debris with information on size, time and location to be transmitted to the ground in near real-time.

Mission 1 is judged by whether or not the system of the IDEA-1 satellite succeeds in keeping connection with a ground station through its entire life cycle from launch to de-orbit. Mission 2 is evaluated by whether or not the IDEA-1 satellite succeeds in transmitting the mission data continuously more than two years.

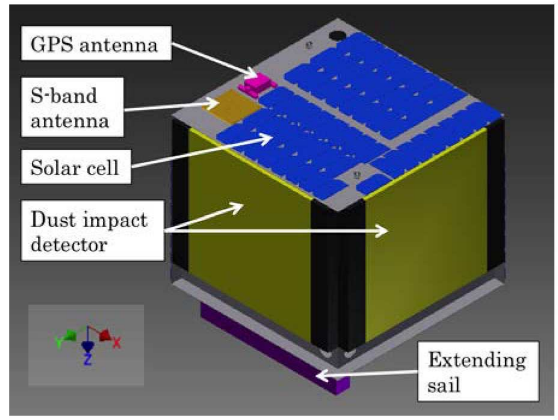

Figure 2. Outer structure of the IDEA-1 satellite

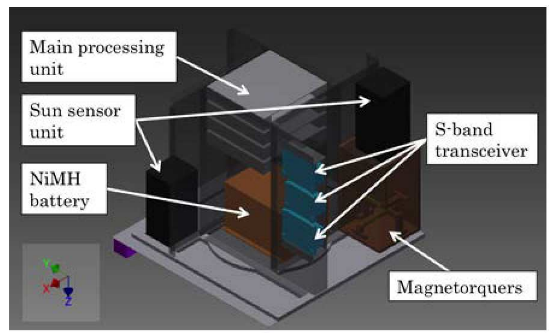

Figure 3. Interior structure of the IDEA-1 satellite

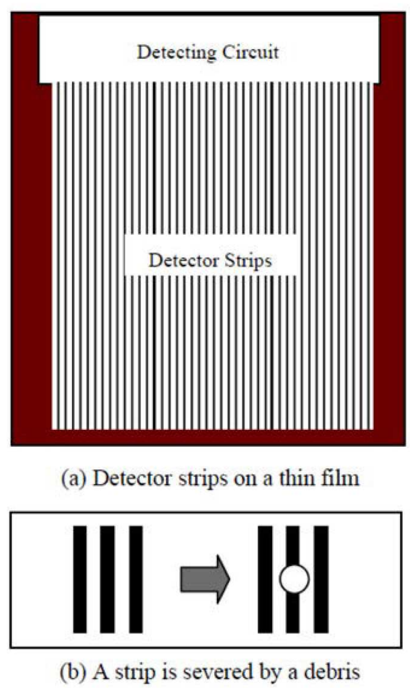

Figure 4. Concept of the dust impact detector[6]

Figs. 2 and 3 illustrate outer and interior structures of the IDEA-1 satellite, respectively. A dust impact detector adopted for the IDEA project is under development at JAXA based on the patent jointly submitted by IHI Corporation and Institute for Q-shu Pioneers of Space[6]. The dust impact detector has a thin film where recognizes impacts caused by debris and a pair of circuits on both edges. A sheet of an impact detector consists of 3500 conductive lines with a width of 50 μm, which are equally spaced on a non-conductive film with a gap of 50 μm, as schematically illustrated in Fig. 4. The effective sensing area on the film is approximately 0.12 m^2 (0.35 m by 0.35 m).

A debris particle punches out a hole on the film at impact to break some conductive lines on the film, so that the impact can be detected by periodically confirming the continuity of the conductive lines on the film. Beside, the size of the hole on the film is substantially the same as the size of the debris impacted. One can estimate the size of the debris impacted using the number of the conductive lines without the continuity. The location at impact can be also estimated by confirming the continuity of the conductive lines. Therefore, the impact detector can record debris size, time and location at impact. However, a single impact detector cannot measure the impact velocity. Overlaying two impact detectors will be capable of measuring the impact velocity further.

3 APPROACH

One of advantages is that the IDEA-1 satellite can transmit the measurement data to the ground in near real-time. This advantage enables to dynamically update the space debris environment. It is necessary to perform the estimation on how it is plausible that the micron-size debris is distributed around the Earth orbit for generating the debris flux obtained on the orbit where the IDEA-1 satellite exists. This study refers to the existing space objects catalogued by Space Surveillance Network as possible orbits of micron-size debris. Among the catalogued objects, objects whose orbit may intersect with a given mission orbit of the IDEA-1 satellite are extracted because they may potentially contribute to flux to the IDEA-1 satellite. Tab. 1 summarizes the mission orbit of the IDEA-1 satellite being planned at present.

Let a, e and i denote the semi-major axis, eccentricity and inclination. Let P and A denote perigee and apogee altitudes, respectively, whereas let subscripts O and I represent a cataloged object and the IDEA-1 satellite, respectively. Objects that may intersect with the IDEA-1 satellite can be extracted by the following criteria (see also Fig. 5):

1) When the apogee altitude of the IDEA-1 satellite is higher than the perigee altitude of a catalogued object, or
2) When the perigee altitude of the IDEA-1 satellite is higher than the apogee altitude of a catalogued object.

Thus,

$$A_I \geq P_O \text{ or } P_I \geq A_O$$

4 RESULT AND DISCUSSION

Figs 6, 7, and 8 depict orbital features of catalogued objects that may contribute as impacts on the IDEA-1 satellite. Fig. 6 shows the apogee and perigee altitudes distribution of possible contributors. Most of possible contributors distribute below 1500 km altitude. Even if these contributors are broken up into pieces, the majority of fragments distribute near the parent object's orbit. Because most debris that may be potentially measured by the IDEA-1 satellite exists below 1500 km altitude, the measurement space of the IDEA-1 satellite is defined as less than 1500 km altitude.

Fig. 7 shows cumulative eccentricity distribution of possible contributors. Although a great portion of eccentricity is 0.1 or lower, there also exists at a range of 0.5 and 0.8. When an object with a high eccentricity fragmentizes, the great majority of fragments are also in highly elliptic orbits similar to the orbit of the fragmented object. Therefore, objects with higher eccentricities may be unable to be disregarded.

Table 1. Mission orbit of the IDEA-1 satellite

a (km)	e	i (deg)
7178.000	0.0000000	98.6000

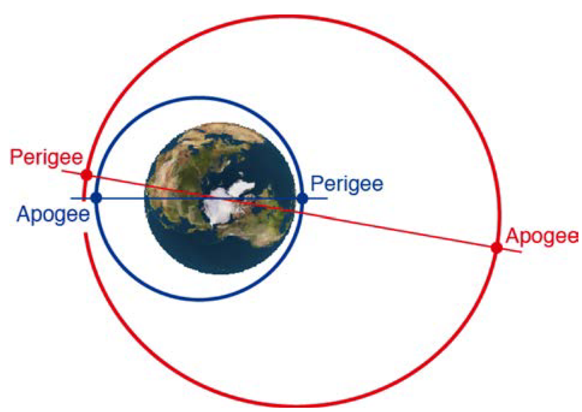

Figure 5. Apogee-perigee filter

Fig. 8 shows right ascension of the ascending node and inclination distribution of possible contributors. The objects are distributed evenly over right ascension of the ascending node, but they are concentrated at 98 degrees of inclination. Thus, the objects that may be measured by the IDEA-1 satellite are focused on sun-synchronous orbits.

5 CONCLUSIONS

This paper described the necessity of micron size debris environmental model, and then simply introduced IDEA the project for in-situ debris environmental awareness and the IDEA-1 satellite. Finally, this paper described orbital features of catalogued objects that may encounter with the IDEA-1 satellite. Micron-size debris still can cause a fatal damage on a spacecraft to be a major threat against safe and secure space development and utilization for humankind. Uncertainties are remaining in micron-size debris environment because of lack of measurements. Thus, the existence and behaviour of micron-size debris are not well revealed yet. The IDEA project aims to build an in-situ measurement network using a group of micro satellites. For as such things happen, it is possible to development a dynamical environmental model taking the IDEA-1 satellite's advantage. Now, towards micron-size debris modelling, it is under examination on how to utilize the actual measurement data acquired from the IDEA-1 satellite. Possible orbits of micron-size debris that may be detected by the IDEA-1 satellite are investigated using existing catalogued objects. It is revealed that the IDEA-1 satellite should be inserted into a Sun-synchronous orbit to effectively measure micron-size debris environment. It is also revealed that micron-size debris in highly elliptical orbits, not incorporated in the existing models, should be taken into account.

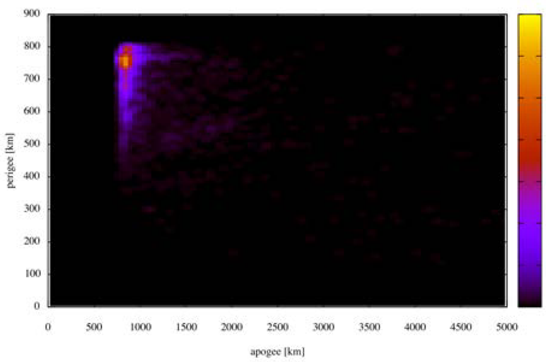

Figure 6. Apogee-perigee distribution

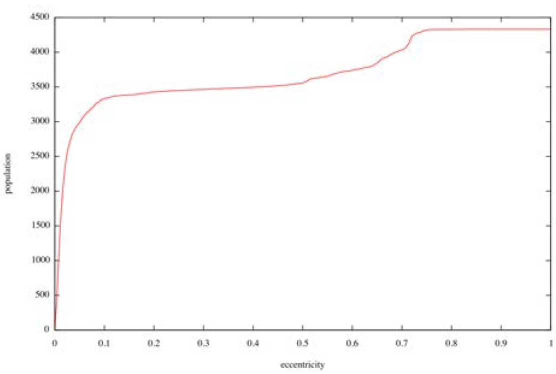

Figure 7. Cumulative eccentricity distribution

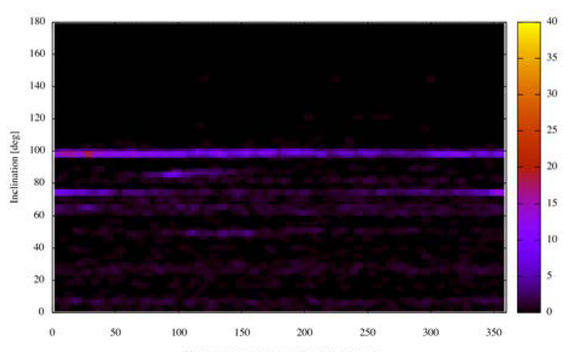

Figure 8. RAAN-inclination distribution

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