Report on Space Debris Related Activities in Japan
(For UNCOPUOS/STSC February, 2010)

1. Overview

The research relating to space debris in Japan, mainly conducted in JAXA and Kyusyu University, has been rather concentrated on following topics.

The main objective of the JAXA R&D strategy is to find a solution or countermeasures to the debris issue according to the following categories.

- **Category-A: Mission Assurance**

  Mission assurance to provide benefit from space activities shall have the highest priority.

  [Tactics: Observation and modeling, Risk assessment and management, Protection design, Monitoring of debris and Collision avoidance, etc.]

- **Category-B: Preservation of Environment and Safety Assurance on ground**

  Ensure sustainable development of space activities, and ground safety from objects fallen from orbit.

  [Tactics: Debris mitigation management, Estimation of future debris population, Safety control for re-entry objects, Monitoring re-entry objects, etc.]

- **Category-C: Improvement of Orbital Environment**

  To prevent chain reaction of debris generation by collision among orbital objects, remove disposed objects from densely populated orbital regions.

  [Tactics: Removal of existing large objects by international corporation]

Here in COPUOS/STSC, Japan would like to introduce some topics among several R&D items defined by above strategy.

## 2. Research on Observational technologies for Space Debris in GEO

The innovative technology research center of JAXA is developing observation technology for GEO objects in order to deal with the space debris problem. The center has run a space debris observation facility at Mt. Nyukasa, Nagano since 2006. The facility contains two telescopes and two large CCD cameras.

The main objective of the facility is to establish technologies for detecting un-cataloged GEO debris and determining their orbits. The stacking method, using multiple CCD images to detect very faint objects that are undetectable on a single CCD image, has been developed since 2000. The only weak point of the stacking method is the time required to analyze the data when detecting an unseen object whose movement is not known, because a range of likely paths must be assumed and checked. Although space debris whose movements can be estimated in some way is an easy target to detect, finding un-cataloged space debris is time-consuming work and not really practical. In order to reduce analysis time of the stacking method, we are developing a FPGA (field programmable gate array) system. The most time-consuming part of the stacking method is calculating median values of each pixel from the sub-images. As FPGA is a kind of electrical circuit, it shows its power in simple calculations. A more sophisticated and simplified algorithm is required for FPGA. We discovered that binarization of the sub-images with a proper threshold and calculating the sum of the binarized sub-image instead could derive almost the same consequence of the original algorithm of the stacking method. Fig.1 represents the difference between the original algorithm and the new algorithm. Calculating the sum is much simpler than calculating the median, and very suitable for FPGA. Moreover, binarization itself reduces amount of data to one-sixteenth, which greatly helps to reduce analysis time. We developed FPGA boards executing this algorithm. Fig.2 shows the FPGA board, which is H101-PCIXM manufactured by Nallatech. The FPGA board was shown to be able to reduce analysis time to about a thousandth. This is a big progress. The FPGA board will be installed in the facility and used for actual observation in the near future.

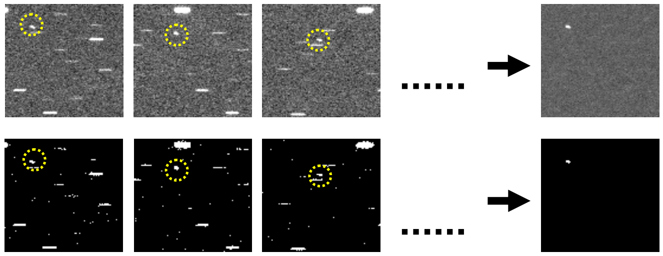

**Fig.1. Difference between the original algorithm of the stacking method (upper) and the new algorithm using binarized images.**

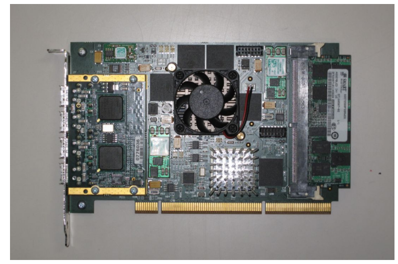

**Fig.2. FPGA board H101-PCIXM manufactured by Nallatech**

## 3. New Type Sensor for In-Situ Space Debris Measurement

The importance of measuring large debris particles (larger than 100 µm) has increased, especially from engineering viewpoints (e.g. space system design and operations). However, it is difficult to measure the impact flux of these large particles because of the low spatial density of large particles (larger than 100 µm). Sensor systems to monitor these sizes must have a large detection area, while the constraints of a space environment deployment require that these systems be low in mass, low in power, robust and have low telemetry requirements. The in-situ measurement data are useful for:

1) verifications of meteoroid and debris environment models,
2) verifications of meteoroid and debris environment evolution models,
3) real time detection of unexpected events, such as explosions on an orbit (Ex. ASAT: Anti Satellite Test).

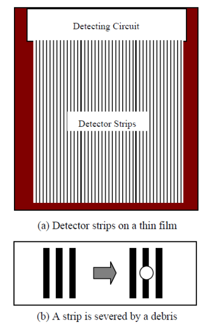


Fig. 3 Concept of the detector
(a) A pattern of parallel, thin detector strips formed on a layer of thin film of nonconductive material.
(b) When debris with diameter larger than or around the spatial pitch of the detector strips impacts the sensor, one or more of the strips are severed and become nonconductive.

JAXA has been developing a simple in-situ sensor to detect dust particles ranging from a hundred micrometers to several millimeters. Multitudes of thin, conductive strips are formed with fine pitch on a thin film of nonconductive material. A dust particle impact is detected when one or more strips are severed by the impact hole. The sensor is simple to produce and use and requires almost no calibration as it is essentially a digital system. The authors have developed prototypes of the sensors and performed hypervelocity impact experiments. As a result, prototype models have been manufactured successfully and the projectile diameter (debris diameter) is able to be estimated from the number of broken strips.

## 4. Collision Risk Monitoring

JAXA has monitored close approaches of other space objects to ALOS, a large-size earth observation satellite, since 2008. Orbital information of space objects are received from the US Space Surveillance Network (SSN) and provided in the Two-Line element (TLE) format. The automated collision risk assessment is performed daily with 7-day predictions and the result is sent via emails. When the conjunctions that meet established criteria are detected, JAXA considers radar observation, if observable, in order to receive more accurate orbital information of risk objects. When collision risks are still determined to be high by the precise conjunction assessment, ALOS conducts a collision avoidance maneuver.

JAXA developed the conjunction assessment tool in 2007. In order to conduct the assessments efficiently, a sequence of processes, as described above, are all performed by this tool. The tool has a 3D visualization function and helps our intuitive understandings of how two objects approach each other.

ALOS has experienced one collision avoidance maneuver so far. JAXA will continue collision risk monitoring into the future.

## 5. Active Debris Removal System

JAXA is studying an active space debris removal system. Conceptually, this consists of a small spacecraft (a micro-satellite capable of piggyback launch with other payloads) that transfers large debris objects that occupy useful orbits to a disposal orbit. EDT (Electro-Dynamic Tether) technology is being investigated as a high efficiency orbital transfer system for this concept. An EDT package could be used to lower the orbit of the debris removal system without the need for propellant. [See Annex-A]

Annex-A

# Research and Development of Active Space Debris Removal System in JAXA

Shin-ichiro Nishida, Satomi Kawamoto, Yasushi Ohkawa and Shoji Kitamura
Aerospace Research and Development Directorate (ARD), Japan Aerospace Exploration Agency (JAXA)

## Overview

The JAXA's Aerospace Research Directorate is studying an active space debris removal system. Conceptually, this consists of a small spacecraft (a micro-satellite capable of piggyback launch with other payloads) that transfers large debris objects that occupy useful orbits to a disposal orbit. EDT (Electro-Dynamic Tether) technology is being investigated as a high efficiency orbital transfer system for this concept. An EDT package could be used to lower the orbit of the debris removal system without the need for propellant.

Capture is necessary for the retrieval of large space debris. It is common for large debris objects to tumble, since angular momentum may have remained in their attitude control systems when failure occurred. Active compliance of each joint of the capture arm and a flexible boom are therefore proposed to relieve loads at the time of capture.

## Active Removal System

The removal from orbit of rocket upper stages and satellites that have reached the end of their lives has been carried out only in a very small number of cases, and most remain on-orbit. Explosions of residual propellants and collisions between satellite remnants or rocket upper stages can generate large quantities of smaller debris, which greatly increases the probability of further debris collisions by a cascade effect. Due to such cascade collisions, it is estimated that the amount of space debris will increase at an ever-greater rate from now on and will eventually jeopardize near-Earth space activities. The following countermeasures are therefore being considered for reducing the amount of space debris.

a. Designing space systems so that they do not become space debris; that is, positive end-of-life processing of satellites and the establishment of proper disposal procedures for rocket upper stages.
b. Processing existing debris that has no self-removal capability; that is, removing large-size satellite remnants from economically and scientifically useful orbits to disposal orbits.

For the disposal of rocket upper stages, a promising approach is for the stage to decelerate by re-starting its engine using fuel remaining after the payload has separated. Research and development of systems to remove large-sized satellite remnants from useful orbits is also in progress.

## Method for Removing Satellite Remnants

Earth-orbiting satellites typically occupy either low Earth orbits (LEO) or geostationary orbits. Satellite remnants and rocket upper stages in LEO may be removed within 25 years by lowering their altitude to 650km or less, from where they will eventually re-enter the atmosphere and burn up.

## Target for Retrieval / Removal

In LEO, the influence of the Earth's geomagnetic field is strong, and so use of an electro-dynamic tether to generate thrust to lower the orbit is practicable. Low Earth orbits effective for Earth observation (especially sun-synchronous orbits) have the greatest risk of debris collision, and so measures to reduce the number satellite remnants or rocket upper stages in such orbits are a priority. In consideration of this, JAXA is studying a system with the emphasis on the retrieval and removal of satellite remnants from sun-synchronous low Earth orbits.

## Strategy

A large number of satellite remnants remain near such orbits from past launches, and it is considered possible for a debris removal satellite to be able to retrieve and remove debris objects by transferring them to lower orbits. A removal micro-vehicle will remove an object by capturing it using a robot arm then de-orbiting, taking the debris with it. The concept is shown in Figures 1–3.

The following concepts for a retrieval/removal system were studied, concentrating on methods that can be realized in the near term.

a. Piggyback launch of debris removal micro-vehicles alongside new Earth observation satellites into sun-synchronous orbits useful for Earth observation.
b. Use of EDT to generate thrust for lowering orbit.
c. A capture mechanism as the other end of the tether.
d. The vehicle body itself as the tip mass of the tether.

## Debris Removal System Concept and Missions Scenario

The mission profile of the conceptual LEO debris removal system, named SDMR (Space Debris Micro Remover), is described below (see Figure 2).

a. Rendezvous with a debris object (target) and measure its motion.
b. Fly around the target, and make a final approach to capture it.

c. Capture the target using an extensible folder arm.
d. Extend an EDT fixed at the base of the arm.
e. Autonomously control tether inclination to regulate thrust and avoid tether instability.

Remover Vehicle Composition

The SDMR vehicle has the following features:

a. Compact shape and low mass to allow a piggyback launch with an Earth observation satellite using the surplus payload capability of the launch vehicle.
b. Simple rendezvous navigation system consisting of a GPS receiver, a star tracker and vision sensors.
c. Small thrusters for maneuvering between orbits.
d. Extensible light robot arm for debris capture.
e. Debris removal by an EDT package incorporated into the base of the robot arm.

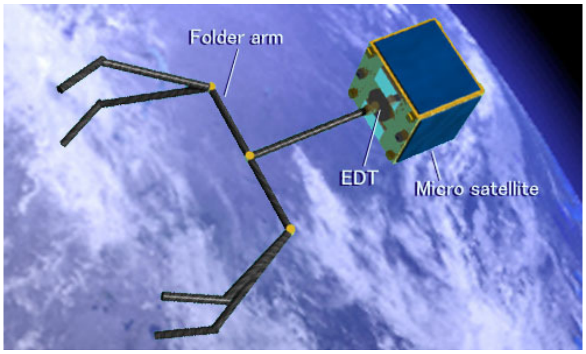


*Figure.1 Space debris micro remover satellite*

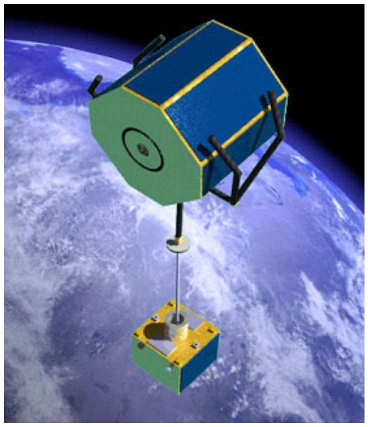

*Figure 2 LEO debris removal concept*

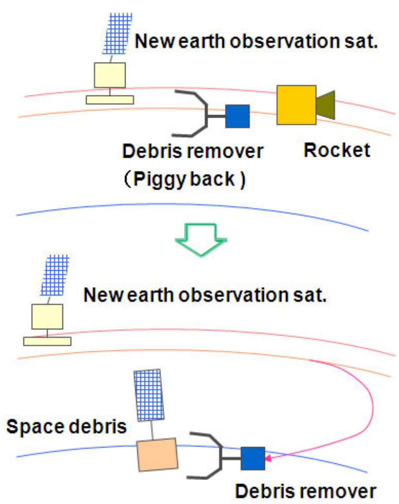


*Figure 3 Concept of the Debris Remover*

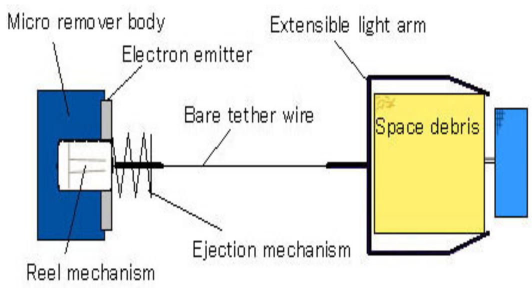


*Figure 4 Configuration for debris removal using an EDT*