デブリ観測・防御技術の研究開発動向
Research and Development of Space Debris Observation and Protection Technologies

○柳沢俊史, 東出真澄 (宇宙航空研究開発機構)
○Toshifumi Yanagisawa and Masumi Higashide (JAXA)

In order to cope with the space debris problem, improvements of observation and protection technologies must be considered. The main concern is that there is a gap between observable size (10cm) and protectable size (a few mm). Burying this gap by enhancing both observation and protection technologies will greatly contribute to solving the problem. I would like to outline what is currently going on the areas of space debris observation and protection in the world and introduce our activities in JAXA on these area.
Abstract

In order to cope with the space debris problem, improvements of observation and protection technologies must be considered. The main concern is that there is a gap between observable size (10cm) and protectable size (a few mm). Burying this gap by enhancing both observation and protection technologies will greatly contribute to solving the problem. This talk outlines what is currently going on in the areas of space debris observation and protection in the world and introduce our activities in JAXA on these areas.
Improving Space Surveillance Network (SSN) to Space Fence System is underway. Space objects of about 10 times will be tracked. Joint Space Operations Center (JSpOC) is providing the conjunction assessment services to satellites’ operators since 2009.

NASA is collecting GEO debris data using 61cm MODEST telescope in Chile under the collaboration with Michigan University since 2001. From 2011, 6.5m Magellan Telescope which can carry out spectroscopy is being used.

Meter Class Autonomous Telescope is being constructed in Ascension Island. The telescope will be able to observe GEO and LEO with photometry and spectroscopy mode. It will also contribute SSA.

3.8m UKIRT Telescope for IR photometry and spectroscopy is also available.
NASA is monitoring LEO environment using Haystack radar and Haystack Auxiliary (HAX) radar in Lexington. Although they can’t determine orbits of detected objects, it can detect LEO objects of a few mm in size.

AGI established Commercial Space Operation Center (ComSpOC). By using world wide optical and radar sensors, ComSpOC provide satellites with variety of SSA services including conjunction analysis. Up to 100x reduction in uncertainty dramatically reduces the number of false alarms and warnings.
International Scientific Optical Network (ISON) started in 2005 has been adding new telescopes every year. Currently, 80 telescopes in 15 countries are joined. The main objective is GEO monitoring, but LEO observations are also planned. Most of the telescopes are ranging from 20cm to 40cm.

Europe

Future SSA radar system 1m telescope in Tenerife TIRA radar

ESA started SSA program which will be funded 0.8 billion dollars in 10 years from 2009.

ESA is conducting GEO, GTO, MEO surveys using the 1m telescope in Tenerife. LEO environment is continuously monitored by TIRA radar. The data obtained both sites are reported in IADC every year.

Envisat rotation was investigated using radar and optical data. Rotation rate was jumped up to 3.5 degrees/s in 2013 from 0.4 degree/s in 2012.
A lot of light curve observations were carried out to investigate rocket bodies’ attitude in LEO region. Laser ranging toward space debris are being conducted using high power laser to get accurate orbital information.

Two small satellites, NEOSSat for NEO observation and SAPPHIRE for GEO debris observation, were successfully launched. Ground-based optical automated observatories were constructed using 4 40cm-telescopes.
FPGA board for image-processing and CMOS sensor for detection of LEO objects were developed. Space based optical sensors for GEO debris are being considered. GEO and LEO are being monitored with both a phased array and optical telescopes in Japan.

FPGA board for image-processing and CMOS sensor for detection of LEO objects were developed. Space based optical sensors for GEO debris are being considered. GEO and LEO are being monitored with both a phased array and optical telescopes in Japan.
Optical Observational Facility of JAXA at Mt. Nyukasa

Overview of the facility

Observational equipment:
35cm telescope and 2K2K CCD camera

Telescope: Takahashi C-350
D: 355mm f:1248mm (F/3.6)
Equatorial mount: Shoda fork-type 25EF

CCD camera: N说服 CCD42-40
chip: 2K2K back-illuminated (a2v)
cooling: panther device (−30°)
FOV: 1.27 × 1.27°
Data analysis process I: Stacking method

The stacking method uses multiple CCD images to detect very faint objects that are undetectable on a single CCD image.

Concept of the stacking method

Sub-images are cropped from many CCD images to follow the presumed movement of moving objects. Faint objects are detectable by making the median image of these sub-images.

Many asteroids were discovered by the method.

Development of the new algorithm

The algorithm is installed to the FPGA board for reducing analysis time.

Analysis time is reduced one 1200th.

280 hours → 14 minutes
Remote observation in Australia

Remote observations using small telescope at Australia are being carried out. Weather condition there is much better than Japan.

Brightness distribution of detected GEO objects using 50cm telescope in Taiwan (red) and 18cm telescope in Australia (blue).

Optical Fence System for LEO objects

About 40 optical sensors are installed to one site. 2 regions of the sky are monitored to get long arc. 2 consecutive passes should be observed for accurate orbital determination. For this reason, 2 longitudinally separated sites are considered.
Detection abilities

Result of 16 days’ survey

About 30 cm LEO objects are detectable
About 15% of detected objects are un-cataloged

Future Works

CMOS sensor for LEO observation. Readout time is 60 times faster than that of CCD

Diffuse reflection with 90-degree phase angle and albedo 0.1

Aim to detect about 10 cm LEO objects

Improve equipment: CMOS sensor will be used for the LEO survey observation
Improve analysis method: Linear Motion Detection Algorithm → Stacking method
DebrisSat Project

Design and fabricate a 60-cm/50-kg class satellite, including MLI and solar panels, to be representative of modern payloads in LEO
Perform hypervelocity impact test with sufficient kinetic energy to completely breakup DebrisSat

Fragments were collected with foam panels
The collected fragments are characterized the physical properties
Analyze the data to improve NASA satellite breakup models

Risk Assessment of Satellite Internal Structure

Fraunhofer EMI conducted as a part of EU FP7 project P2ROTECT
Estimate satellite internal structure damage by using a triple-wall ballistic limit equation
Investigate damage of electronics boxes from impact experiments

ESABASE2

MMOD impact risk assessment tool developed by ESA
Analyze impact risk against a satellite 3D model
**China**

**Spacecraft Breakup Model**
Research by Hypervelocity Aerodynamics Institute of China Aerodynamics Research & Development Center

Develop the breakup model based on impact experiment results of dummy spacecrafts made of aluminum plates, filled with some simulated electronics boxes with a circuit board as the actual payload.


**Density-grade Bumper Shield**
Research by China Academy of Space Technology

Develop new bumper made of density-grade material, Ti/Al/Mg/nylon and Al/Mg


---

**Japan**

**Protect spacecraft from space debris impacts**

**Investigate debris impact vulnerability of spacecraft components**
- Honeycomb sandwich structures
- Wire harnesses
- MLI etc.

**Propose debris bumper shields**
- Light weight bumpers (CFRP, Porous metal)
- Flexible bumpers (High-strength fiber fabric) etc.

**Develop tools to help space debris protective design**
- Impact risk assessment tool (TURANDOT)
- Impact experiment & numerical simulation database
Conclusion

The trend of research and developments on space debris observation and protection in the world was outlined. JAXA’s activities on this field were also introduced. Strengthening observation and protection abilities against space debris is fundamental to solve the problem. We would like to bury the gap between observation and protection limit and contribute to solving the problem under the collaboration of other nations.