宇宙デブリ除去システムの技術開発

○西田信一郎、河本聡美（JAXA）

地球周回低軌道では、すでに軌道上にある宇宙デブリ同士の衝突により宇宙デブリの数が自然に増加していく「デブリシンドローム」が起きつつあると、解析されている。従って、新たな宇宙デブリを発生させない防止策だけでは不十分であり、すでに軌道上にある宇宙デブリの除去が必要となっている。本講演では、宇宙デブリの軌道上からの除去に必要となる軌道変換・対象接近制御や宇宙デブリの制動・捕獲などの宇宙ロボット作業技術の現状と今後の開発方針について述べる。

宇宙デブリ除去システムの技術開発

Technology Development of Space Debris Removal System

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Space Debris W/S2010@Chofu
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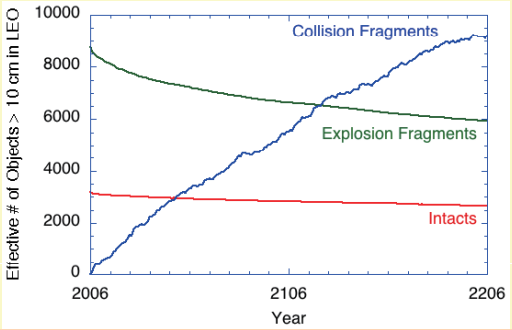
Introduction

- Mitigation measures such as break-up prevention and end-of-mission de-orbit may not be enough to preserve space environment because of mutual collisions between existing debris.
- Active Debris Removal (ADR) as soon as possible is needed.
- To realize ADR
  - Technological feasibility
  - Reasonable cost
  - International cooperation

  will be needed.



Effective number of objects predicted by LEODEEM
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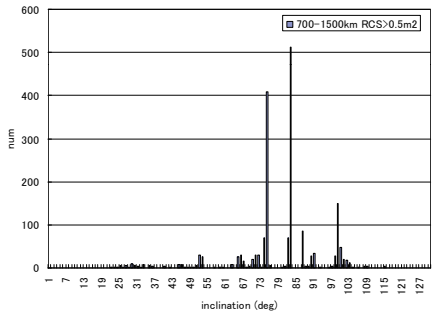
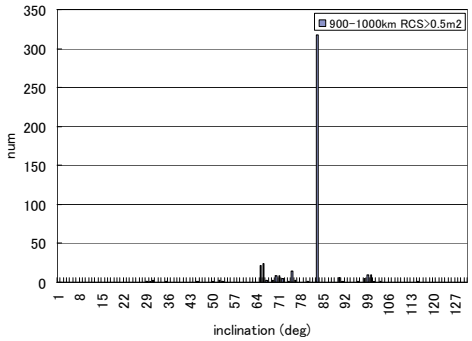
Strategy for Active Debris Removal

Target orbits for removal

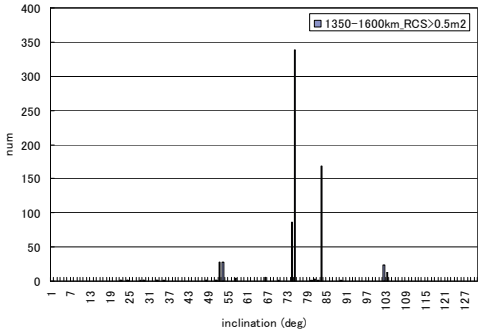
- Some crowded regions exist
  - SSO (98-100deg)
  - 82-83deg : 900-1000km
  - 74-75deg, 83deg, 52deg : 1500km



700-1500 km



900-1000 km



1350-1600 km

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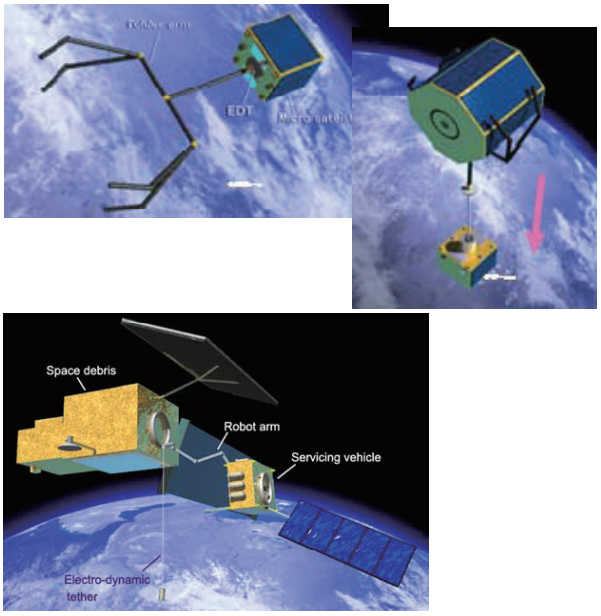
Strategy for Active Debris Removal

JAXA is studying systems with the emphasis on the removal of satellite remnants from sun-synchronous low Earth orbits.

- 1st step: “Micro-Remover”
  a piggyback satellite to dispose of one debris object
- 2nd step: A dedicated debris removal satellite, which carries several EDT packages and rendezvous with debris in crowded orbits to attach an EDT package for de-orbit



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Remover Vehicle Composition

The MSDR vehicle has the following features:

- Compact shape and low mass to allow a dual launch with an Earth observation satellite.
- Simple rendezvous navigation system consisting of
  - GPS receiver
  - Star tracker
  - Vision sensors
- Force controlled robot arm for debris capture.
- Debris removal by an EDT package attached by the robot arm.

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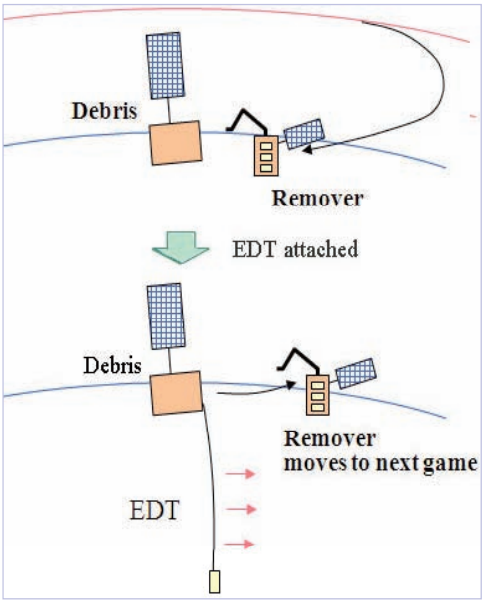
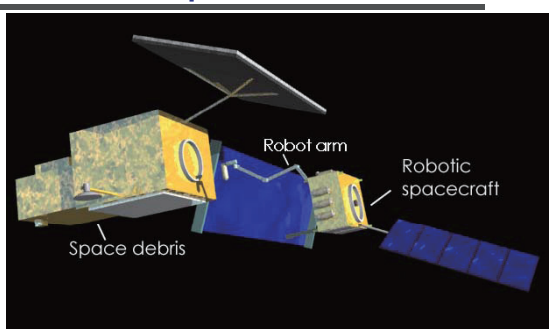
Remover Vehicle Composition

Conception for operation





Specifications

Item	Specification	Remarks
Dimensions	1800×1800×1000mm	
Weight	1000kg	Fuel: 250kg
Power	500W	Average
Attitude control	3-axis control	3 wheels
Thrusters	1N×8, 20N×8	
Rendezvous Sensors	GPS receiver & antenna Star tracker Stereo vision	

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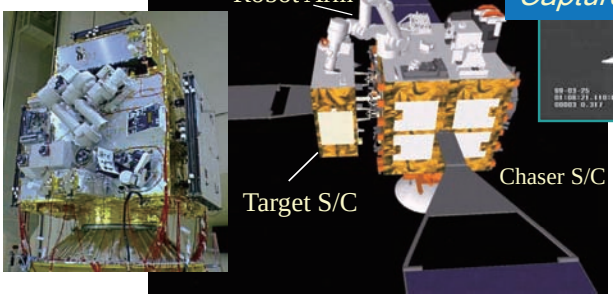
ETS-VII Flight Demonstration on 1998-1999

■Autonomous Rendezvous/Docking experiments and autonomous target capture experiments have been conducted successfully on the ETS-VII satellites for the case of a handle equipped to facilitate grasping by a robot arm.

■Visual feedback control and force control function were applied to the robot arm. And they worked very good.



The rendezvous technology was utilized for the HTV

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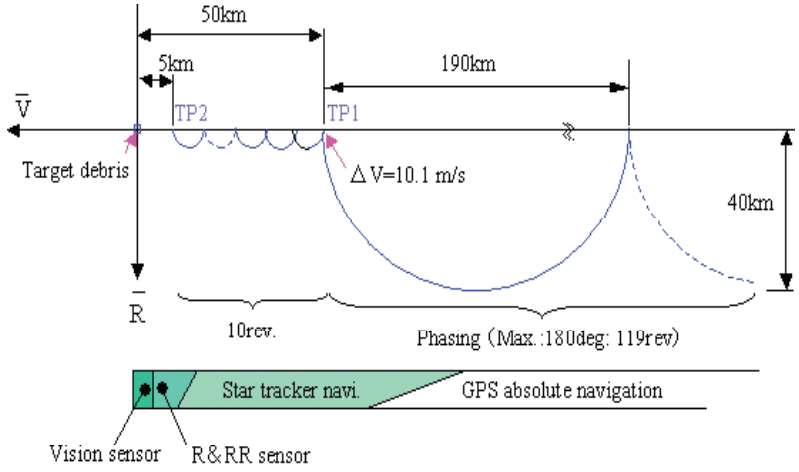
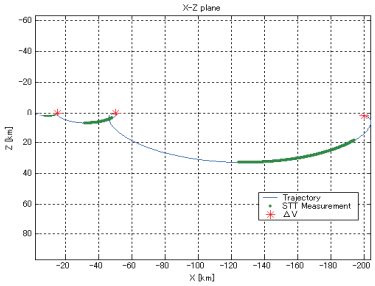
Rendezvous sequence with a debris

Rendezvous sequence with a space debris object

- Rendezvous with the target by using GPS-receiver, Star-tracker and Laser-Range-Finder (IR-CCD-type)
- Fly around the target, and make a final approach to capture it





Rendezvous with debris using star tracker navigation.

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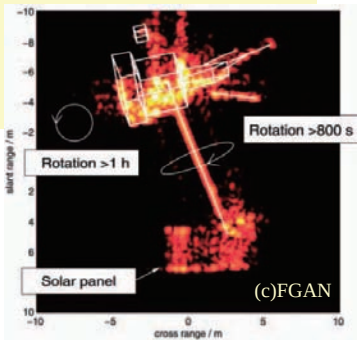
Capturing of a debris

Debris capture by a robot arm

- Capture is an essential process for the retrieval of large space debris objects by other spacecraft.
- It is common for large debris objects to tumble, due to angular momentum that remained in their attitude control systems when failure occurred.
- For example, the ADEOS is tumbling in rotating rate around 0.3deg/sec.



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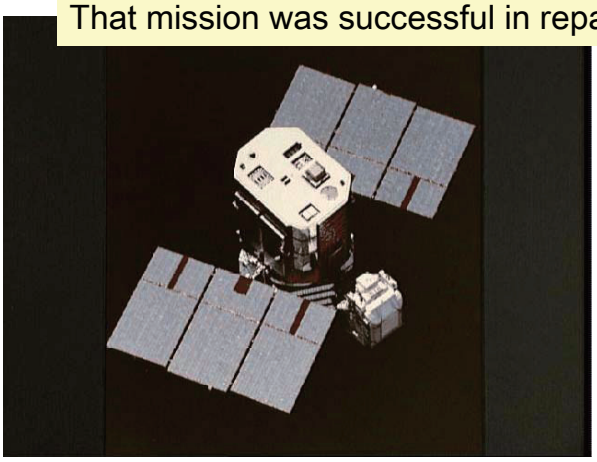
Capturing of a debris

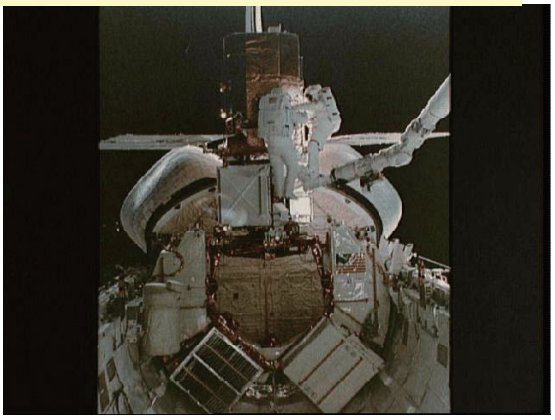
In-orbit Repair of SMM by STS-41 in 1984

The SMM was rotating faster than the rate that SRMS can capture.

Therefore, the crew flying with SMU slowed down the spacecraft rotation by tapping its solar array with his glove.

That mission was successful in repairing and re-orbiting of the SMM.





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Strategy for capturing of a debris

- The target rotating rate can be presumed by the observation from the ground in advance.
- A scenario is chosen as shown in lower table according to the target rotating rate.

Table Scenario for capturing according to the rotation

Case	Rotational rate	Scenario for capturing
A	High (w>30deg/s)	It is not game.
B	Medium	Braking by brush before capture
C	Low (w<3deg/s)	It can be captured easily.

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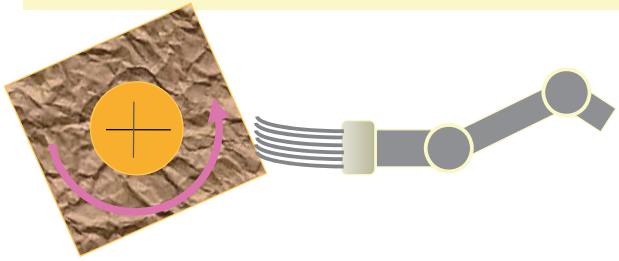
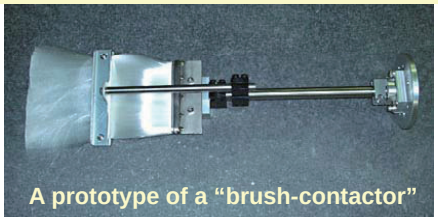
Strategy for capturing of a debris

- Tapping and rubbing of a target's surface are best for slowing its rotation if the SMM retrieval mission is taken into consideration.

- "Brush-contactor", a robot arm end-effecter , is suitable for braking of tumbling of a debris because of its elasticity and good fitness for object form.

- A prototype of a "brush-contactor" made of PTF fibers is shown in the following figure.





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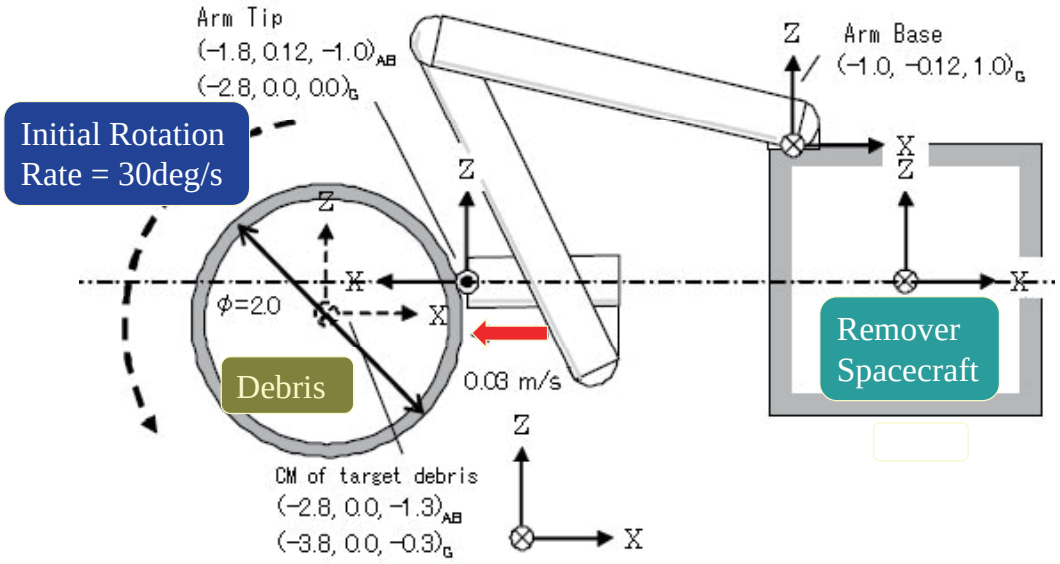
Dynamical simulation of debris de-rotation

Layout of the simulation model



S.Nishi

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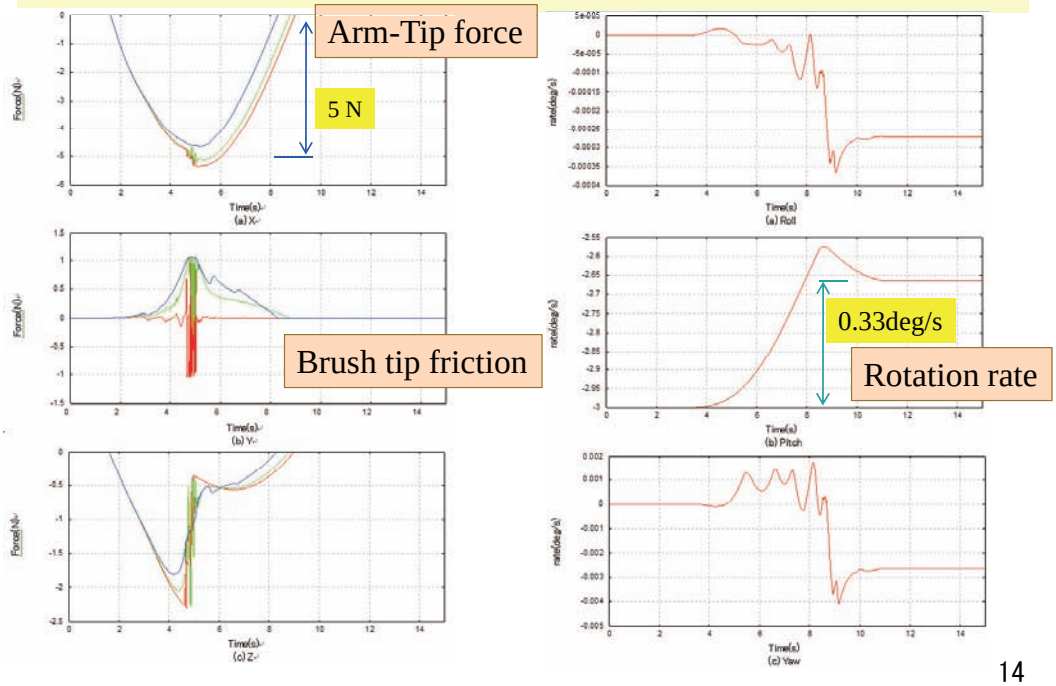
Dynamical simulation of debris de-rotation

Dynamical simulation results of target rotation braking by tapping with brush contactor



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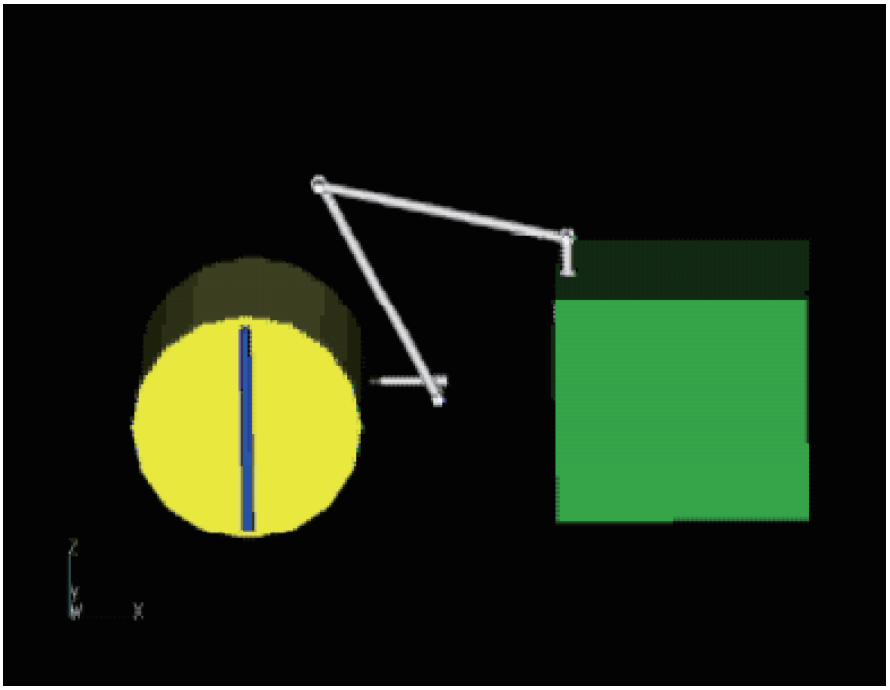
Dynamical simulation of debris de-rotation



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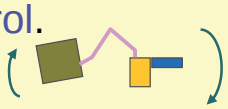
Strategy for capturing of a debris

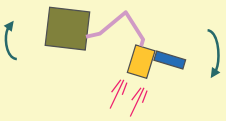
Scenario for target capture

(1) The chaser observes the target's attitude and motion via stereo vision sensing and begins tracking of a point to be grasped.

(2) The target is grasped by the robot arm. Impact loads due to rate difference/position gap at the time of capture are relieved by means of arm force/torque control.



(3) De-rotation of the target and the chaser is done using RCS of the remover.



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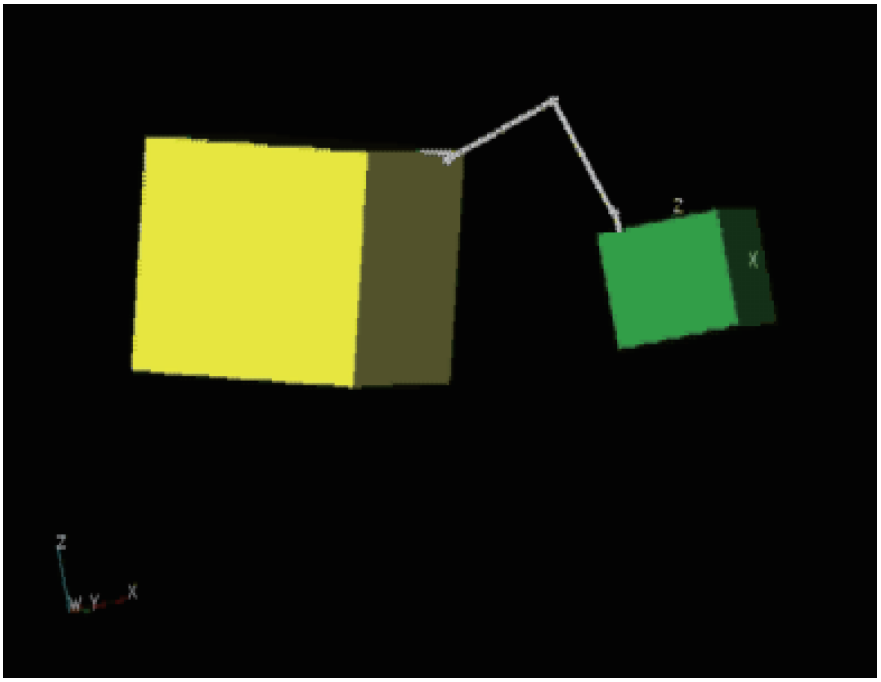
Strategy for capturing of a debris



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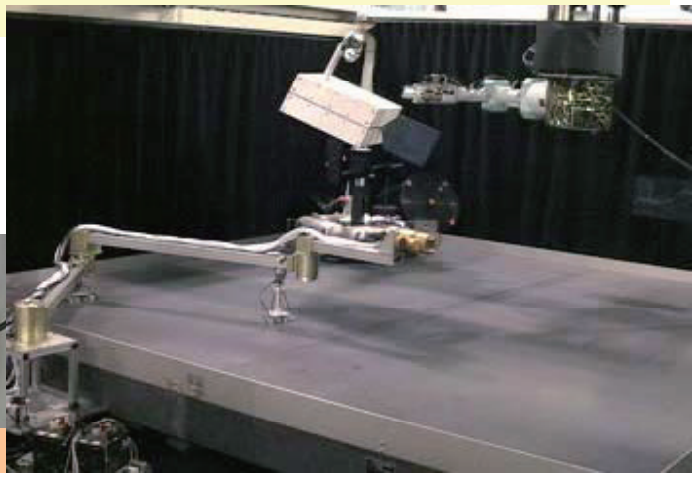
Strategy for capturing of a debris

Debris capture by a robot arm

■As a control system of a robot arm to buffer and braking residual motions of space debris at the time of capture, joint virtual depth control and joint mechanism with torque sensor have been developed.

New joint mechanism & torque sensor



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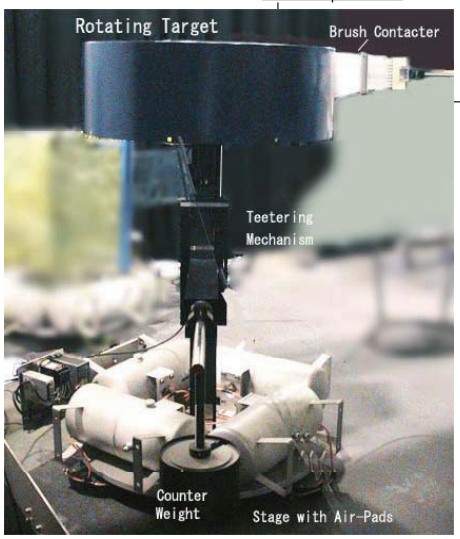
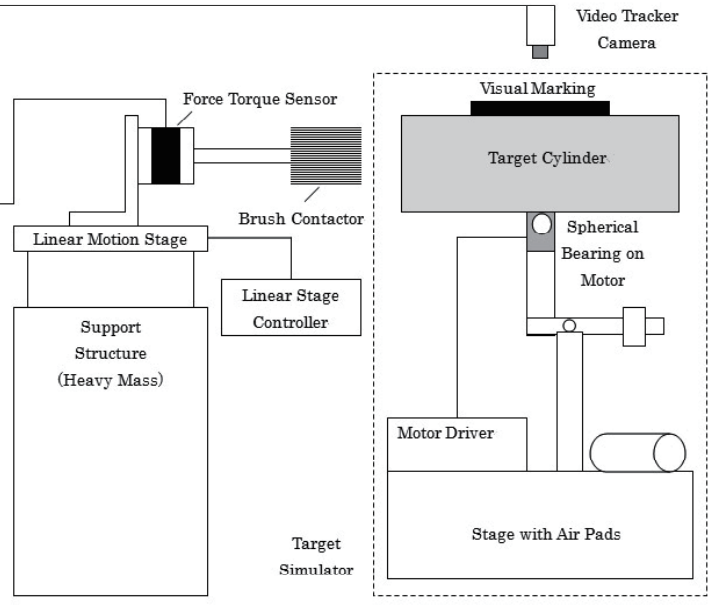
Experiments on Test-Bed

Composition of the test-bed with 6DOF-floated rotating target





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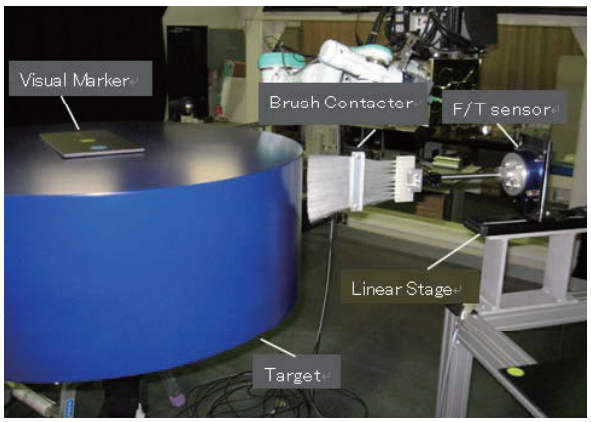
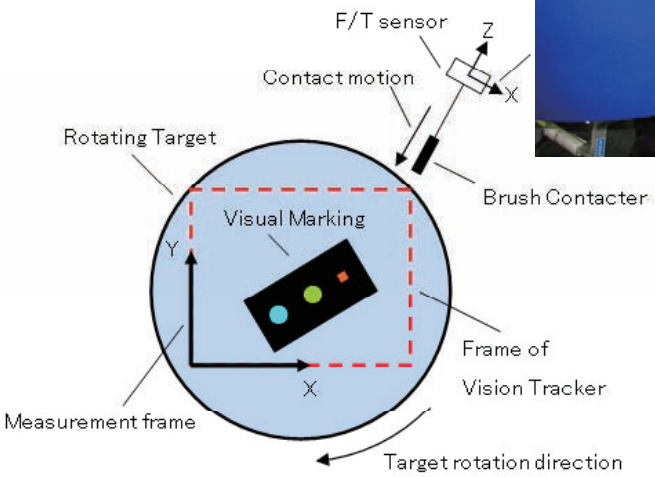
Experiments on Test-Bed

Configuration

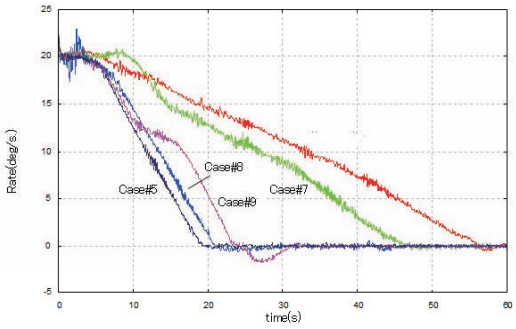




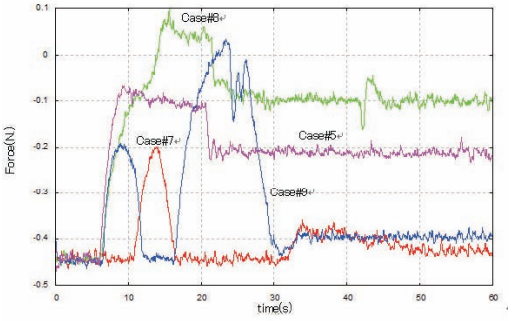
Experiments on Test-Bed

Testing Results

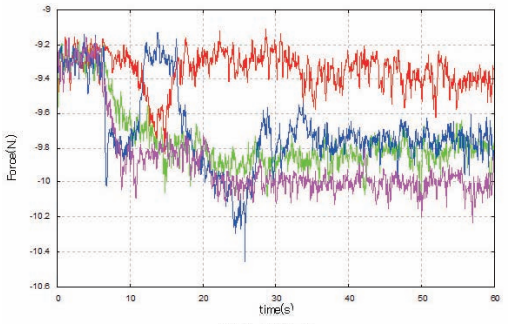
Rotating floated target was slowed down by brush tapping without excitation of nutation



Rotation rate of target



(a)摩擦反力



(b)押し付け反力

Conclusion

■Method for capturing and braking a tumbling non-cooperative space debris was studied.

■We propose a new brush type contactor as end-effecter of a robot arm for reducing the rotation rate and tumbling motion of target debris.

■As a means for relieving the loads generated during target tapping, we propose a new control method which controls the arm tip force according to a contact force profile.

■Feasibility of the method's were confirmed with the results of simulations and hardware experiments.

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Thank you for your attention

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