

Japan & OOS: Selected Prospects

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Abstract

In Japan, development of space robot technology and rendezvous / docking technology have been continuously advanced. However there is no concrete flight for utilization of on-orbit servicing(OOS) in the country. Each laboratory of space organization in Japan cooperates and is advancing study of OOS, and efforts are continued towards utilization of OOS missions. The strategy and development trend of OOS related organization of Japan is reported in this paper. In NAL, the scenario and system configuration of debris removal mission are studied. The motion measurement, the rotation dumping and the impact relief method in debris capture are studied also. On the other hand, it is inquiring also about the assembly of a large aperture space telescope and space radio telescope by the robot on an orbit. This paper reports these OOS application study and its topics.

1. Introduction

In Japan, development of space robot technology and rendezvous / docking technology have been continuously advanced with the JEMRMS for the ISS, Manipulator Flight Demonstration(MFD) in 1997, and Engineering Test Satellite VII(ETS-VII). However, most of space development budgets are supplied to development of a large-sized rocket or close satellite development. For this reason, there is no plan of a concrete flight about the OOS missions which are considered as low priority missions. However, in Japan,



Fig.1 Space robot test bed in NAL

each laboratory of space organization cooperates and he is advancing study of OOS, and efforts are continued towards utilization of OOS missions. The strategy and development trend of OOS related organization of Japan is reported. Moreover, in NAL, study and development are furthered with emphasis on space debris removal mission and the on-orbit assembly of a large aperture reflector. Outline of these studies and development is described.

2. Market of OOS of Japan

2.1 Consolidation of Organizations in Japan

NAL, ISAS and NASDA, which are space research and development organizations in Japan, will be consolidated in October 2003. CRL and TAO will be consolidated also in 2003.

2.2 Space Development Trend of Japan

Japan's (NASDA's) space development is again looked over in order to call it efficient practical use of the limited fund, and development with emphasis on observation, positioning, and a communicative field is furthered.

Research and development of the science mission field have mainly been furthered by ISAS using comparatively small rockets (M-V) and satellites. However, it is expected that rocket development of ISAS is unified by an organization's merger with the rocket development by NASDA. For this reason, utilizing a large-sized satellite for the science field is also considered.

3. OOS R&D Strategy and Trend of Japan

3.1 R&D Strategy

The basic strategies which NAL considered for OOS realization are shown in the following.

- (a) The possibility of an onboard servicing is appealed by demonstration with a ground test bed.
- (b) The missions scenario creation and the feasibility study used as backing of validity are advanced.
- (c) Development of key components are furthered.
- (d) Even if partial, the opportunity of all flight demonstration is utilized.

Encouraged by the success of ETS-7 Space Robotics and Rendezvous-Docking Mission in 1998-1999, feasibility study and related technology development for advanced OOS are being promoted at NAL, CRL, AIST and NASDA. Framework for joint research activity has been established in 2001 among NAL, CRL/TAO and AIST.

3.2 NASDA

NASDA is pursuing the HTV-based servicing vehicle for stranded satellite rescue, as its main mission.

Assuming other functional healthiness and no hook and scar, following technologies are being developed, Automatic rendezvous, static laser radar, scanning laser radar, laser range finder and vision sensor, Satellite capturing and berthing by space robotics.

3.3 CRL

CRL is working actively in flight technical demonstration, component development of the OOS using small satellites. For example, the following activities are carried out.

- Concept design on Orbital Maintenance System(OMS) for remote inspection technologies
- Micro OLIVE mission (2002): technologies demo. for remote inspection using piggy-back satellite (Fig.2)
- Development of Space Servicing Equipments to Accept Space Servicing (Rescue Package)

Fly around experiment using twin satellites is also planned in 2006.

3.4 AIST

AIST has developed a ground-based-demonstrator for on-orbit micro satellite assembly by a space robot. This system is considered as a key component of their "Space Environment Preservation System" aiming at satellite servicing from the cradle to the grave. Assembly,

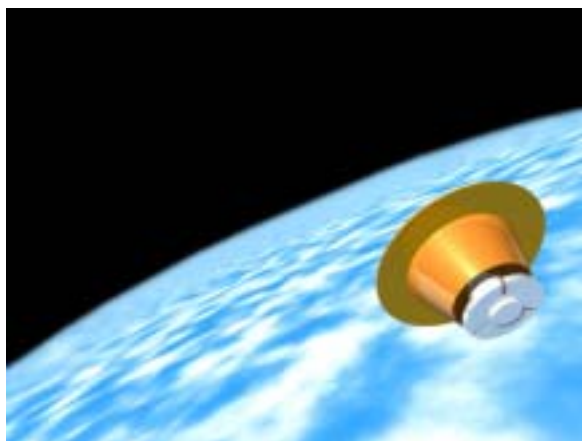


Fig.2 Released target of OLIVE mission :CG

capturing for diagnosis, maintenance and supply, recovering and disposal are studied.

3.5 NAL

In NAL, study of Disposal System for Post Mission Space Systems is advanced. Moreover, study of on orbit assembly, such as a large aperture reflector, is also done. For details, the following chapter describes.

4. Application Example

In NAL, study of an onboard servicing is advanced by making retrieval and de-orbit of the space debris, and the reflector assembly on orbit applicable to application. These missions need various OOS techniques.

Therefore, study of almost all OOS technology can be advanced by studying application to these missions.

4.1 Space Debris Removal Mission

When a malfunction satellite with which the broken artificial satellite or the life was exhausted is left on an orbit, there is a high possibility that itself not only becomes a big space debris, but that tanks, such as jet propulsion equipment, will explode / decompose, and they will become the origin of many small space debris. When failure is slight, it is also possible to repair a target satellite and to recover the function. For example, when neither solar array nor an antenna unfolds well by the fault of a deployment mechanism, with a robot arm, only by tapping a little, it unfolds safely and functional recovery can be carried out.

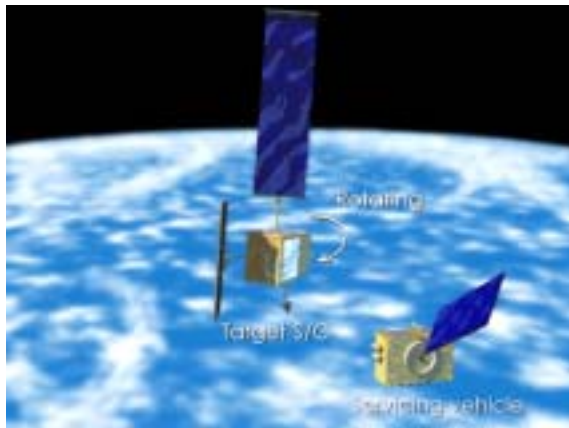
(1) Flow of debris removal work

As for the malfunction satellite for retrieval, the communication system is not working in most of cases. For this reason, measurement and prediction of the position on that flight orbit, rotational motion are dependent on the measurement by the radar and the optical observation from the ground. The opportunity of the satellite observation from the ground is limited and a measurement error is expanded as orbital propagation by lapse of time. For this reason, high accuracy cannot be expected from the presumed accuracy of the on-orbit position of a target, but a servicing vehicle needs to search for the wide range in the rendezvous for retrieval.

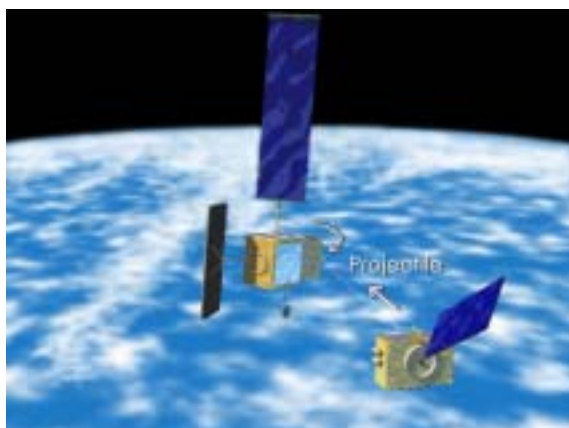
The work flow as conceptual figure of such a target retrieval and de-orbit are shown in Fig.3. Each work step is explained in the following.

Step1 (Motion measurement):

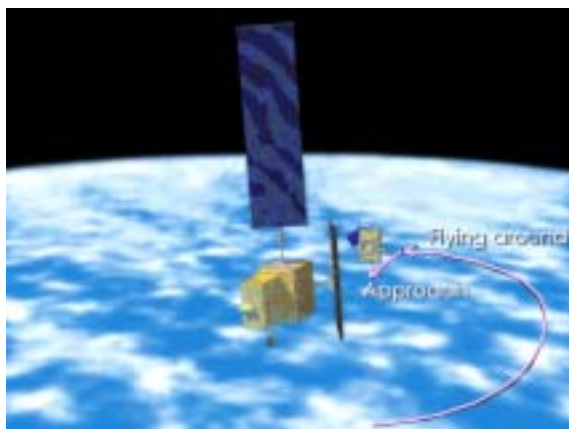
Moreover, about the rotational motion of a target, since the measurement from the ground is not easy, it is necessary for servicing vehicle to measure the target



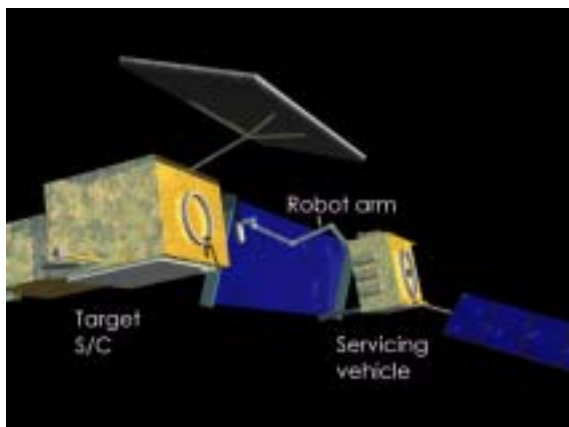
Step1: Motion measurement



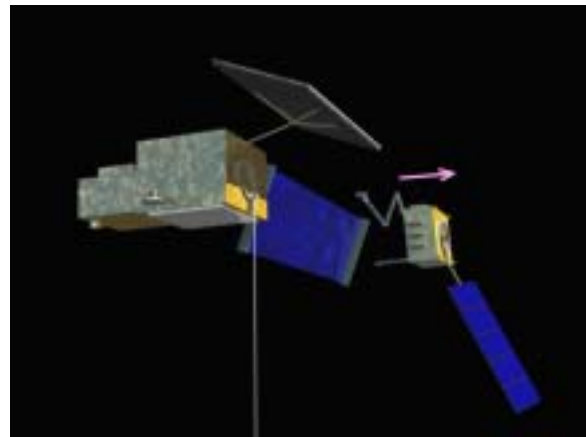
Step2: Momentum reduction



Step3: Flying around and final approach



Step4: Capture



Step5: Release

Fig.3 Flow of debris removal work

after the rendezvous near it.

Step2 (Momentum reduction):

It is necessary to choose the method of retrieval corresponding to the rotational movement for retrieval, and since it is difficult to capture a target when its rotation rate is high, it will be necessary to reduce the rotation rate.

Step3 (Flying around):

Depending on the target attitude, the flying around the target is carried out, and it will be necessary to turn in the direction suitable for capturing the target.

Step4 (Capture):

In capture of a cooperative target, although the automatic tracking to a capture part is possible, in capture of a non-cooperative target, the features, such as a certain form, are caught by measurement of the part for capture, and it is necessary to perform the tracking and positioning to it with image processing of a visual marking.

Step5 (Release):

After extension of a electric dynamic tether, the servicing vehicle releases the target.

It is natural to assume that there is a certain amount of remains rotational rate in retrieval of the space debris. By the performance of processing equipment for satellite was restricted, since a short execution cycle is not expectable, it is thought that the feed-forward control using the result of motion measurement is effective in tracking control by the visual feedback.

Moreover, in capture of a non-cooperative target, there is no visual marking on a target, and since it is assumed that some rate errors are caused in the automatic tracking control by the visual feedback. Some improvement in a performance of the buffer function by using force/torque control in a robot arm or a capture

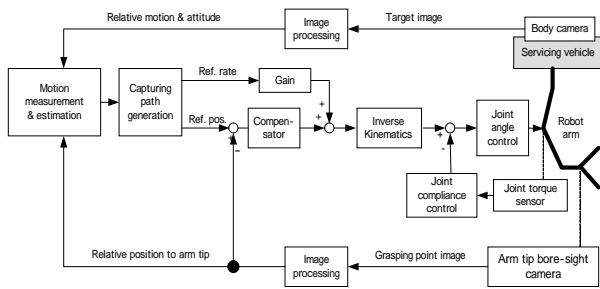


Fig.4 Block diagram of arm control system on capture task

mechanism are needed. The composition of the robot control system assumed is shown in Fig. 4.

4.2 Onboard Assembly Mission of Large Reflector

(1) Large space reflector

On Earth orbit, astronomical observation is under very good condition which is free from any absorption or disturbances by the Earth's atmosphere. So that space-based optical observatory can provide 10 times better performance than ground-based optical observatory. That is the reason why space-based observatories are built and planned to be developed. Similarly, there is also no absorption of radio wave on orbit. For this reason, it is suitable for observation by the radio telescope. Moreover, since the baseline length equivalent to an orbital diameter is obtained, especially Space-VLBI is promising. A highly precise large aperture reflector is required also for radio wave observation.

(2) Composition of large space reflector

The reflector which cannot be contained in the cargo space of a launch vehicle needs to be constituted on orbit. The following methods are listed as the construction method of the reflector of the large aperture on-orbit.

- (a) Deployable solid panel type
- (b) Mesh expansion type
- (c) Inflatable type
- (d) Onboard assembly type

However, at deployable solid panel type, the diameter is restricted by about 2 times of diameter of the cargo space. On the other hand, high accuracy is acquired neither by the mesh expansion nor the inflatable formula. In order to build the reflector of the accurate diameter of a large quantity, it cannot but depend on an assembly type. With assembly type structure, since high stiffness is acquired comparatively easily, it is suitable also for installation of the active adjustment mechanism of the surface form of a reflector.

(3) Advantages of using space robot

Space robot is useful for onboard assembling of such large space reflector. Because, segments of reflector are too large to be handled by an EVA crew. Advantages of unmanned assembly using space robot are as follows:

- Easy handling of large elements by positioning stability and long reach of robot
- Easy assembling of large space structure by mobility and cooperated control function of robots
- Precise positioning and fastening by visual feed back control function
- Automatic fine alignment of reflector segments using coordinated control with a sensor such as a laser ranging sensor
- High safety of crews by reducing EVA
- Low cost operation (reducing crew time, crew training ...)

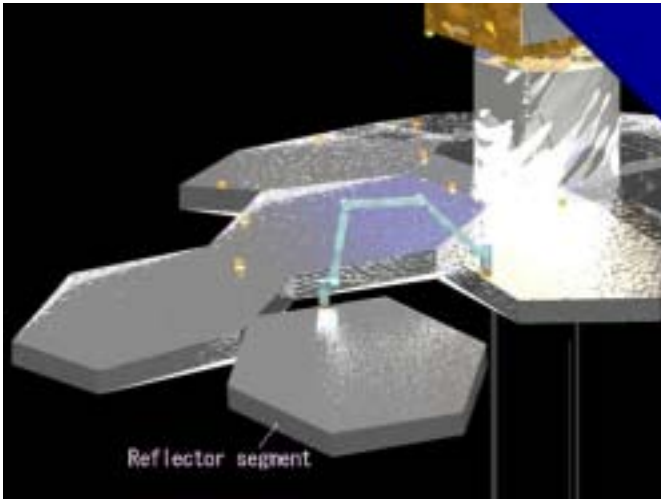
(4) Concept of reflector assembling

Fig. 5 shows a concept of telescope assembling. A robot arm takes out a reflector segment from a container and does positioning the joint part of it at the object parts of already assembled portion. The robot arm move to next task location along to the reflector structure by inch-worm motion. Throughout scenario for the Space assembling is as follows:

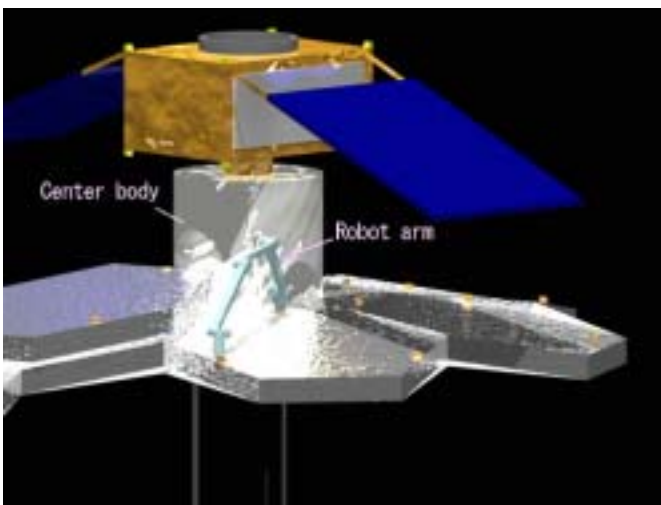
- Step 1: A robot arm launched together with the segments of a reflector is started and unfolded.
- Step 2: The assembly is performed by the arm moves on the structure. A robot arm's electric power and signal are supplied from the grapple fixtures prepared on the structure.
- Step 3: The arm checks the structure after an assembly.
- Step 4: A robot arm resides on the telescope permanently and is applied also for capture of a cargo, or the exchange work of components with maintenance missions.

5. Conclusion

The strategy and development trend of OOS related organization of Japan is reported in this paper. As the examples of OOS application study in NAL, debris removal mission and on-orbit reflector assembly are also introduced in this paper. International cooperation is indispensable to realization of such onboard-servicing missions.



-Attaching the reflector segment



- 8DOF arm movement on the structure by inch-worm motion

Fig.5 Artist concept of on-orbit reflector assembly

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