Automatic Satellite Capture and Berthing with Robot Arm (ASCABRA)

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ABSTRACT

The NASDA office of R&D is studying an automatic technique to capture and berth free-floating satellites using a robot arm on another satellite. A demonstration experiment plan with the Japanese engineering test satellite ETS-VII is being developed based on the basic research on the ground. The overview and key technologies of this experiment plan are presented in the paper, and future applications of the automatic capture technique are also reviewed.

INTRODUCTION

The technique to capture and berth a satellite with a robot arm for on-orbit servicing is widely used in the US shuttle missions (payload supporting missions) such as European Retrievable Carrier (EURECA) and Hubble Space Telescope (HST). However, all these were performed manually by on-board crew members.

One way to achieve effective and economical on-orbit activity is to use unmanned on-orbit servicing systems. The automatic capture technique is one of the most important techniques for realizing this unmanned system. This technique will be used to develop the On-orbit Service Vehicle (OSV) and Geostationary Service Vehicle (GSV).

Following the basic study to develop the automatic capture technique, the NASDA office of R&D developed a capture and berthing experiment plan using Engineering Test Satellite-VII (ETS-VII), which will be launched in 1997. The implementation plan for this additional experiment will be determined in the near future considering the ETS-VII development schedule and operational resources.

This paper presents an overview of the capture & berthing experiment plan and key technologies of the experiment (Figure 1). It also covers future applications of this technique.

EXPERIMENT AI PLAN USING ETS-VII

System Overview

ETS-VII is a NASDA's test satellite for verifying rendezvous docking (RVD) and space robot (RBT) technologies. The RVD system consists of a GPS receiver, rendezvous radar, proximity CCD sensor (PXS), docking mechanism (DM) and on-board guidance computer. RVD experiments will be performed by a 2.2-ton "chaser" satellite and a 0.4-ton "target satellite". A 2-meter, 6-DOF robot arm is attached to the chaser. The Japanese data relay satellite COMETS will be used for nominal RVD and RBT operations.

For the ETS-VII capture and berthing experiment, the chaser satellite will stay in front of the target satellite using PXS data and thrusters. The attitude control of the target will be terminated after the relative stability of the two satellites is obtained. An on-board visual feedback technique is used to guide the special arm effector towards the grapple fixture on the target, while the PXS monitors the relative movement of the two satellites. For the capturing phase, thrusters of the chaser will be inhibited to avoid potential coupling between the reaction control system and the arm control systems. After the capture, the arm moves the target satellite to DM attached to the chaser satellite and berths the target to the DM.

Sequence of Events

The sequence of events (SOE) during the ETS-VII capture berthing experiment is designed considering the following constraints:

- All operations from release to capture of the target satellite must be finished within 30 minutes, which is equal to one pass of COMETS coverage.
- Appropriate lighting conditions must be provided to execute relative navigation using the RVD proximity sensor and RBT visual feedback control of the arm.

Table 1 shows the draft SOE during the experiment. Data link and lighting condition of the SOE is shown in Figure 2.

Load Control in the Capture and Rigidization Phases

To avoid excessive load on the arm and the target satellite, the grapple fixture and the effector were designed with the proper stiffness, and an arm control method will be developed. The effector is designed to have a wide capturing area. The effector's two fingers close and capture the grapple handle of the target quickly, and a sleeve of the effector moves forward relatively slowly to rigidize the effecter to the fixture (Figure 3). A compliance control method using force and moment sensor data is also used to relieve the arm load during the phase.

Visual Feedback

A visual feedback technique is used to guide the effector to the grapple fixture on the target. The software in the robot mission on-board computer (RMOC) calculates the relative position (and orientation: option) between the hand camera and the target mark just beside the grapple fixture on the target satellite at the frequency of approximately 2 Hz. Hand camera image are changed to B/W images to measure center positions and sizes of circles on the target marks, from which relative position and orientation are determined. The threshold for on-board B/W images can be changed by ground command to accommodate lighting condition on orbit. The effector is then guided precisely to the fixture.

Ground tests were conducted using hardware equivalent to flight models. The test results show that the tracking performance of the visual feed back control is precise with relative to the effector's capturing area. Figure 4 shows an image of the target mark taken by the hand camera in ground test configuration.

Safety Control

Automatic failure detection and recovery functions are considered for this crucial experiment to avoid a collision of the two satellites. The RBT and RVD subsystems detect their own faults. In case of failure, a coordinated malfunction procedure will be implemented. The malfunction procedures differ depending on when the failure occurs during the experiment.

The general concept of each case is as follows:

- Approaching phase
  The RBT quenches its movement, and RVD starts the collision avoidance maneuver (CAM).

- Capture phase
  The RBT quenches its movement. The CAM will be inhibited to avoid collision.The ground controller will take over the operation.

- Berthing phase
  The RBT quenches its movement, and RVD stops the drive of the docking mechanism (DM).

FUTURE APPLICATIONS OF ASCABRA TECHNIQUE

The following applications are being considered using the technique of automatic satellite capture and berthing with a robot arm (ASCABRA) for the coming on-orbit servicing era.

- Capturing a supply satellite and vehicle on orbit

Rendezvous and docking is one way to execute the above task. ASCABRA is another way, and it has the merit that fewer active guidance, navigation and control systems are necessary on supply satellites or vehicles. In addition, a robot arm can be used for different kinds of tasks; for example, to transfer on-board replaceable units (ORUs) from satellite to satellite. Instead of preparing many dedicated subsystems, it has the advantage of using a manipulator for many purposes.

- Capturing of on-orbit satellites requiring service

A Geostationary Service Vehicle (GSV) or On-orbit Service Vehicle (OSV) have been proposed in several agencies and companies to repair, refuel, reorbit, and deorbit satellites. It is not practical to require special and complicated equipment on customer satellites for GSV or OSV to rendèzvous and dock. In addition, many customer satellites rotate or tumble on orbit.

Considering these facts, the ASCABRA technique is the most promising way to execute the task.

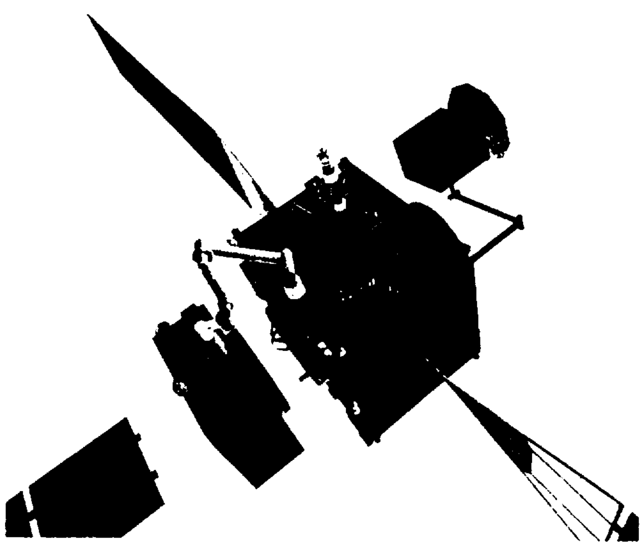

Figure 1: ETS-VII Capture and Berthing Artist's Image

CONCLUSION

Automatic satellite capture and berthing with manipulator is considered a key technology for future on-orbit servicing systems.

The results of the studies to develop the technique and an experiment plan using ETS-VII were presented in this paper.

ACKNOWLEDGMENT

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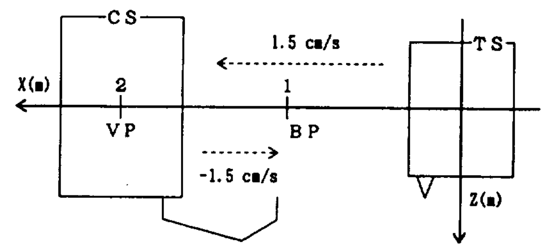
[2] Inaba N, 1994, "ETS-VII Capture and Berthing Experiment Plan", GAS-94005, NASDA Office of R&D.



NO	ACUMULATED TIME (MM:SS)	DISTANCE CS to TS (m)	EVENT
1	00:00	0.35	TARGET SATELLITE (TS) SEPARATION
2	03:00	2	VICINITY POINT (VP) ARRIVAL
3	05:00	2	VP DEPARTURE
4	07:00	1	BERTHING POINT (BP) ARRIVAL
5	09:00	1	ARM MORTION START (PROGRAM)
6	10:00	1	ON-BOARD VISUAL FEEDBACK START (TS ATT. CONT. OFF)
7	12:00	1	FUNCTION CHECH FROM GROUND, CS THRUSTERS INHIBIT.
8	14:00	1	FINAL APPROACH TO GRAPPLE FIXTURE
9	14:10	1	CAPUTURE BY TOOL HEAD FINGURES
10	14:14	1	RIGIDIZATION
11	14:30	1	STABILIZATION
12	15:30	1	MOVE TS TO DOCKING MODULE (DM) POSITION BY ARM
13	17:50	0.42	DM DRIVE TO BERTH, ARM COMLY
14	19:40	0.38	TOOL HEAD OPEN, ARM WITHDRAW
15	21:40	0.38	FINAL BERTHING BY DM
16	22:00	0.35	EXPERIMENT OPS. TERMINATION

Table 1: SOE during the ETS-VII Capture and Berthing

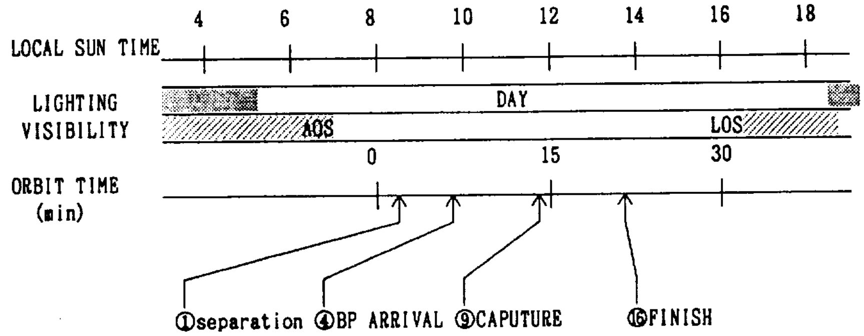


Figure 2: SOE (Data Link & Light Condition)

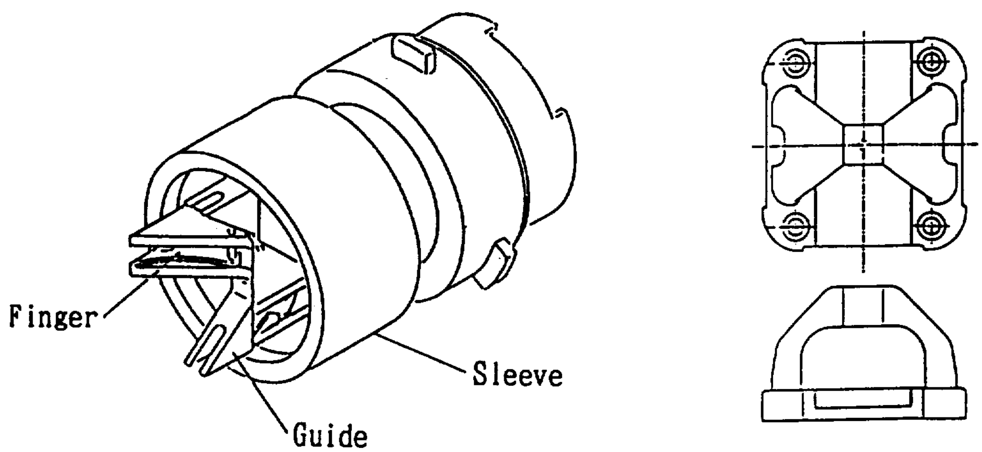
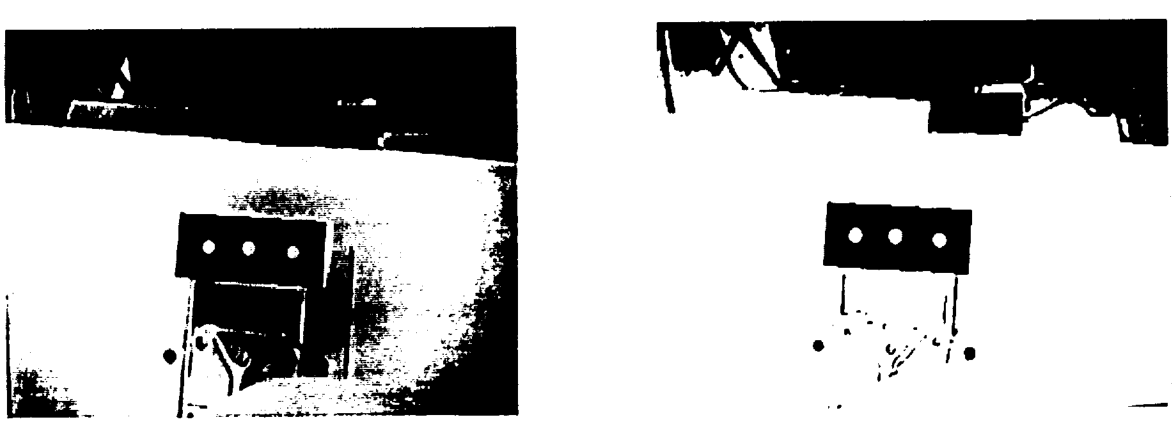


Figure 3: Caputuring Effector and Fixture



Original Image B/W Image

Figure 4: Target Mark Images (Hand Camera View)