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Capture Experiment of Rotational Satellite Using In-Orbit Maintenance Vehicle

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Abstract

Satellites sometimes encounter unexpected problems. A space maintenance platform with robot arms is expected to investigate anomaly and to repair failure modules of satellites in space. We are studying a maintenance platform system that has functions for assembly, inspection and diagnosis of small satellites in orbit. We have developed a ground test-bed of In-Orbit Maintenance Vehicle with robot arms. This paper describes experimental results of capturing a target small satellite by using the ground test-bed with robot arms.

1. Introduction

We have proposed In-orbit Maintenance Vehicle which has functions, such as assembly / disassembly, inspection, diagnosis, capture, and abandonment of satellites. [1] The Maintenance Vehicle's mission is to maintain a satellite constellation system by assembly / disassembly, inspection diagnosis of small satellite by using robot arms. We developed the ground test-bed of In-orbit Vehicle with robot arms [2] due to verify those missions, and have verified assembly /disassembly task of small satellite by using robot arms [3]. This paper describes experimental results of capturing a rotational small satellite by using robot arms of the ground test-bed with.

2.Ground Test-bed of In- orbit Maintenance Vehicle

Figure 1 shows an overview of ground test-bed of In-orbit Maintenance Vehicle with robot arms. One robot (Assembly arm) is used for the assembly / disassembly task, and the other (Inspection arm) is used for capturing and inspection of satellites.

When this vehicle captures the target it uses a newly developed capture hand. The capture hand is based on the wire driven single actuator. It has two fingers of three joints, which has an adaptive mechanism to the object envelope [4]. This capture hand is able to open/close by gripped by Inspection arm. This vehicle has several computers, controllers, three air bearings, eight thrusters, batteries, and radio communication

system. It is able to move on flat floor by wireless.

In these experiments, we used a rotating target satellite that has a handrail and a target marker attached just above the satellite. The target satellite is supported by a one-axis motor and a spherical bearing, so this target is able to rotate on one-axis and hold several attitudes. And this target is able to move on flat floor by air bearings.

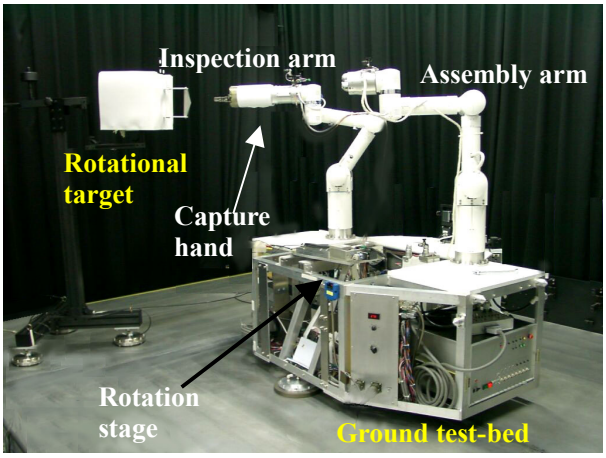

Figure 1 The ground test-bed of the platform system

3. Capture mission

Table.1 shows a capture mission of satellite. This mission consists of an approach by Maintenance Vehicle and an approach/capture by the robot arm.

This experiment was carried out under following conditions

- Relative Velocity between the vehicle and the target is fully small and a single eye camera of Maintenance Vehicle has already caught a target image
- The target is carrying out 1-axis rotation and this rotational rate is measured beforehand and is estimated.

Table.1 Task sequence of Capture Satellite

Missions	Number	Task
Capture satellite	TASK1－1	Approach by Maintenance Vehicle
	TASK1－2	Approach by Robot Arm
	TASK1－3	Capture by Capture Hand

3.1 Functional composition

Figure 2 shows function block diagram of capture mission

The Maintenance Vehicle measures relative positions and attitudes by image processing of the marker attached just above a rotating target satellite using the single eye camera on the end effector of the robot arm. From the time series data of the measured relative positions and attitudes, a motion of the target is presumed by between alignment assistant, and each computer controls Maintenance Vehicle and the robot arm.

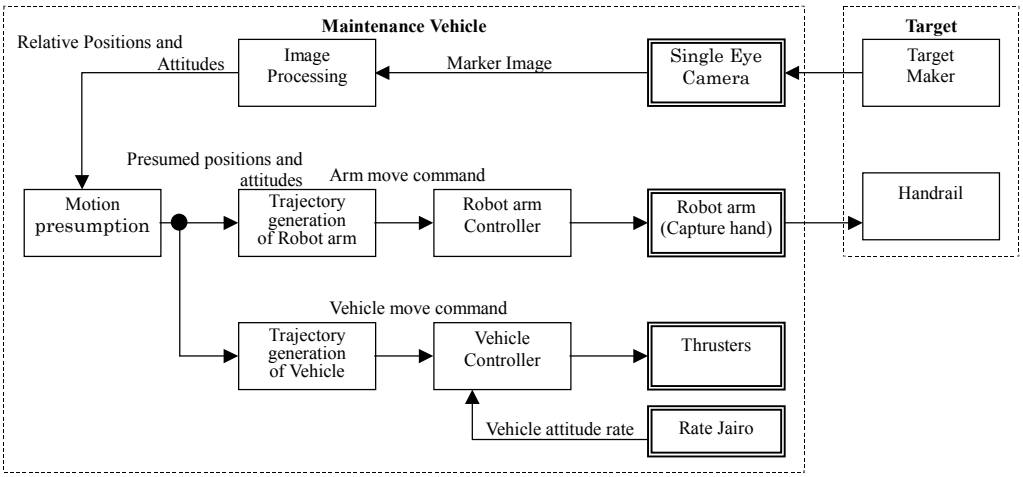

Figure 2 Function Block diagram of Capture mission

3.2 Target Measuring

Figure 3 shows the target marker attached on the satellite. This marker is a black square and four white circles are located equally in the black square.

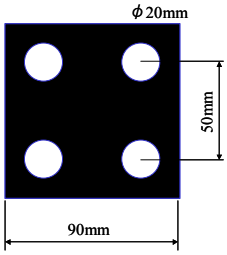

Figure 3 Target Marker

The vehicle measures positions and attitudes of the target by using image processing of white circles.

3.3 Approach by Maintenance Vehicle

Figure 4 shows about approach strategy by Maintenance Vehicle.

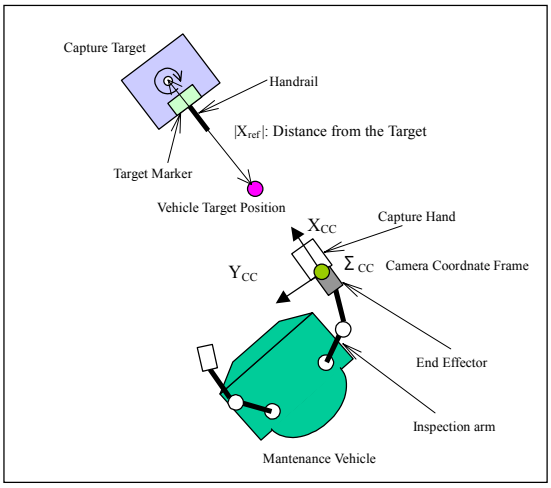

Figure 4 Overview of approach by Maintenance Vehicle

First the vehicle determines its target position by measured positions and attitudes of the rotating target satellite. Second it generates its trajectory (velocity profile) from current position to target position in consideration of the rotational rate of target satellite.

After that the vehicle approaches the rotating target satellite by velocity feedback control while it can measure the marker. When it cannot measure the target marker, the Maintenance Vehicle approaches the target by coasting. Under approaching the target, its attitude is controlled by using a rate gyro so that the marker may come in the center of a camera view.

When the vehicle arrives around target position it changes velocity feedback control into position feedback control. And when the robot arm begins to approach and capture the rotating target satellite the vehicle changes position feedback control into drift condition

3.4 Approach by Robot Arm and Capture by Hand

When the vehicle sets into drifting state, the robot arm with the capture hand begins to approach the target. Figure 5 shows the top view of the positional relationship between the hand and the target. The arm captures the target with the following tactics. First, the arm predicts a capture point using the position and the velocity of the handrail capture point every time it measures the marker. It approaches that lastly a predicted capture point, and it captures the target when it can position to that point.

The robot arm determines that a reference point is a pre-gripping point. The robot arm moves to the predicted capture point that is calculated by a result of motion presumption (Shown in Figure 6). After a distance between the reference point and a predicted capture point is sufficiently small, the robot arm changes the reference point to a gripping point. The robot arm begins approaching to capture the handrail by the capture hand. The reference point is changed from the pre-gripping point to the gripping point, so that the capture point is driven into an area that the capture hand can grip handrail. Figure 7 shows the flow of capturing the target by the robot arm. In these experiments the robot arm approaches the target by

position feedback control.

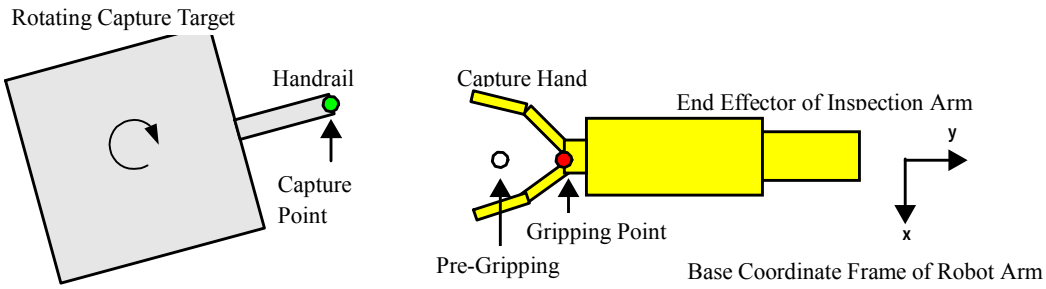

Figure 5 Overview of approach by Robot Arm (Initial Positional Relationship)

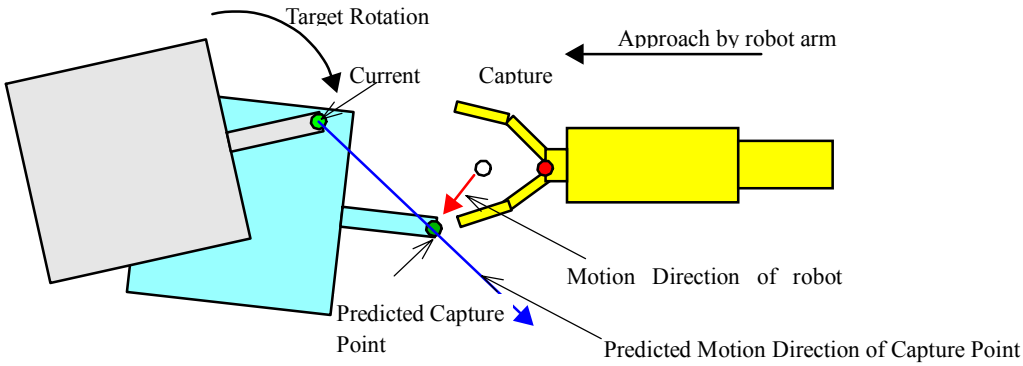

Figure 6 Approaching by Robot Arm

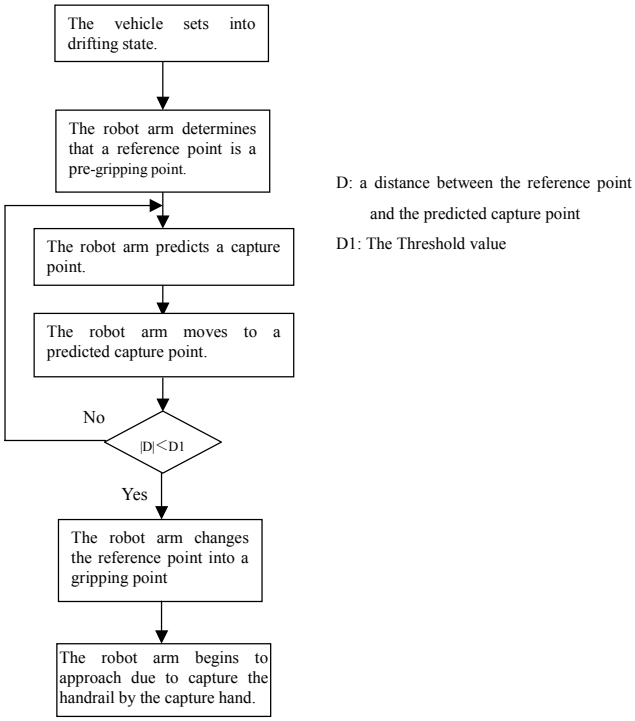

Figure 7 Flow of capture a rotating satellite

4. Experimental Results of Capturing a Target

4.1 Capture by Robot Arm

The experiments of capturing by the robot arm only were carried out under the following conditions.

- Maintenance Vehicle does not move.
- The target is located in area that the robot arm can capture.
- The target rotates at 1 rpm around Z-axis (Base Coordinate Frame of Robot Arm)
- The target is able to move on surface plate by air bearings.

These experimental results are shown in Figure 8 and 9. Figure 8 shows X-position of the tip of the robot arm in the base coordinate frame of the robot arm. Figure 9 shows Y-position of the tip of the robot arm in the base coordinate frame of the robot arm.

These results suggest that the robot arm track the rotation of target satellite (Figure 8) and approach the target satellite (Figure 9). And we verified an effect of the adaptive mechanism of the capture hand.

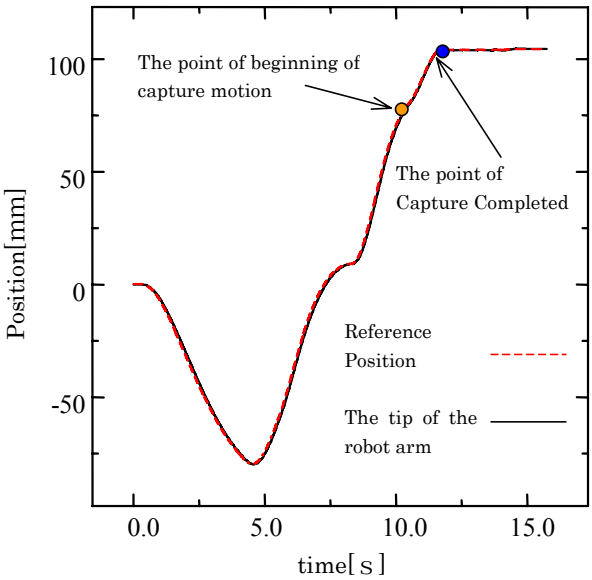

Figure 8 X-position of the tip of the robot arm

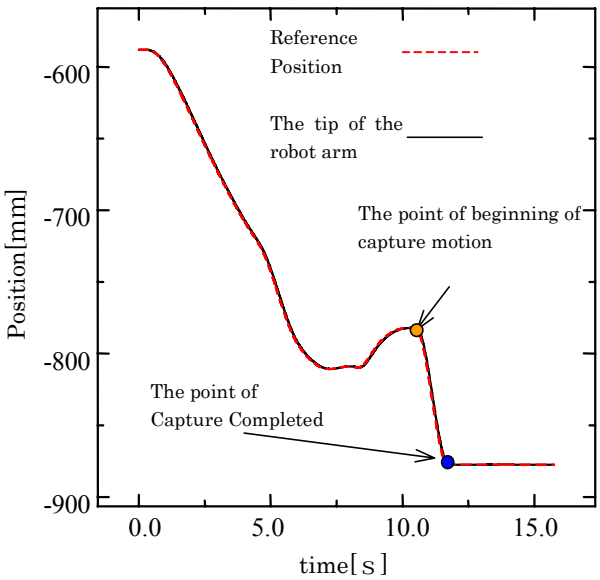

Figure 9 Y-position of the tip of the robot arm

4.2 Capture by Maintenance Vehicle

The experiments of capturing by Maintenance Vehicle were carried out under the following conditions.

- The target rotates at 1 rpm around Z-axis (Base Coordinate Frame of Robot Arm)
- The target is able to move on surface plate by air bearings.

The experiment result is shown in Figure 10. Figure 10 shows relative distance between the single eye camera and the target satellite. This result suggests that at the beginning of approach the Vehicle accelerates enough to approach during a coasting and that after approach of the vehicle the robot arm approaches the target by a speedy motion.

Under the condition that a nonlinear friction and slope of surface plate is small, motion specification of the vehicle is satisfactorily and capture mission has proved successful.

Although we had several improvements, we confirmed feasibility that in space this method is applied approximately

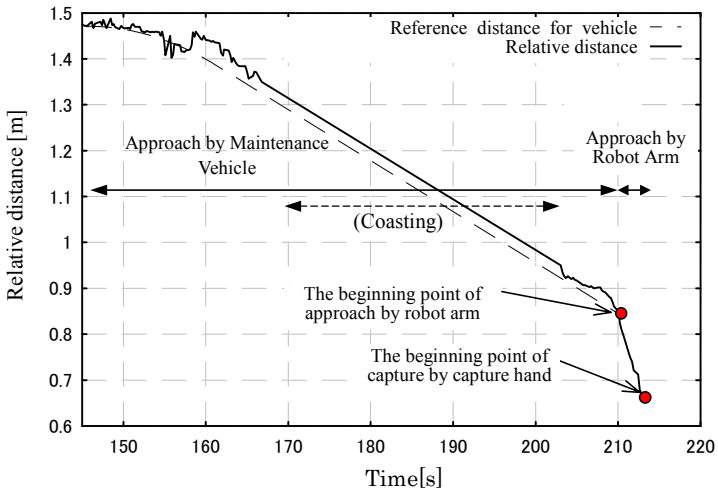

Figure 10 The Result of Approach by Maintenance Vehicle

5.Conclusion

It is confirmed that Maintenance Vehicle that has the robot arms has successfully captured the rotational satellite. Future issues about capturing a satellite are

- The methods of measurement of satellite and navigation, guidance and control of the vehicle when camera can't measure a target maker.
- The methods of capturing more complicated rotational satellite.

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