Robot Arm System for Automatic Satellite Capture and Berthing

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ABSTRACT

Load control is one of the most important technology for capturing and berthing free flying satellite by a space robot arm, because free flying satellites have difference of motion rate mutually. The performance of active compliance control technique depends on the location of the force sensor and the arm's structural compliance. A compliance control technique with thinking over the robot arm's structural elasticity and a consideration for an end-effector appropriate for it are presented in this paper.

INTRODUCTION

The capture and berthing technique using space robot arm is proven of its effectiveness and its convenience by some space shuttle missions. This technique is also effective for the future unmanned space missions such as repairing, refueling, retrieving or resupplying missions for spacecrafts.

There are two themes for the future capture and berthing technique. One is the unmanned automatic technology. The other is the extension of the allowance for the difference of mutual flying motion rate.

Load applied on both satellites and arm is a key factor to extend the allowance.

This paper shows the consideration for both active and passive load control techniques , especially a joint compliance control and a joint compliance mechanism. Evaluation test result using space robot ground test facility is also mentioned.

SYSTEM ARCHITECTURE

On a capture and berthing mission, the chaser satellite with robot arm approaches to the target satellite and coincides the motion rate to the target satellite using chaser's thruster control. After the relative navigation flying, a TV camera on the robot arm end-effector acquires a view of the target marking near the grapple fixture on the target satellite and the robot arm tracks it by visual feedback control As the target marking, single dot pattern on black back plate is used. Range and direction to the Target satellite can be detected by image processing for the marking image through the arm wrist TV camera.

Detection of the target satellite attitude is no need for capturing. Because, mutual attitude error of the satellites is smaller than the allowable misalignment for the end-effector capturing performance.

On the capturing phase, the chaser's thruster control is shut off and both satellites drift each other in small rate. Impact loads caused on the target satellite capturing is dumped by the arm compliance control and the passive elasticity of the arm.

ARM CONTROL ARCHITECTURE

Load control is one of the most important technology for capturing and berthing free flying satellite by a space robot arm, because free flying satellites have difference of mutual motion rate. On capturing a satellite, the motion energy is transformed to potential energy of the arm distortion and electric energy generated by the joint motors.

The transient force/moment caused on the arm is depends on the elasticity of the arm and its active compliance control. A typical profile of the transient force on satellite capturing is shown in the figure 1. The tip elasticity of an multi-joint arm is changed as the arm portion and the direction.

The performance of active compliance control depends on the location of the force/torque sensor. However much of force controlled robot arm has a 6-DOF force/torque sensor on its wrist, arm structural flexible mode poles are in the force control loop. Single axis model using such wrist-located force/torque sensor is shown in figure 2. The pole cannot easily be cancelled, therefore the bandwidth of the loop is limited at low frequency near the pole.

Joint Compliance Mechanism

One of the solution for getting wider bandwidth of force control loop is to apply the joint torque control loop using a torque sensor on each joint. The control loop configuration is shown in figure 3.

On each joint, joint compliance control is applied. The arm structural flexible mode poles are out of the control loop. Therefore, the loop can be designed for wide bandwidth.

A JCM(Joint passive Compliance Mechanism) is installed on the actuator output shaft of each joint. The JCM elasticity reduces the impact load caused on capturing satellite. And the JCMs dumping characteristics suppress the resonance peek of the arm flexure. The JCM cross-section view is shown in figure 4.

END-EFFECTOR FOR CAPTURE AND BERTHING

For capturing satellite, large allowable misalignment is required of the arm end-effector. Considering the allowable misalignment performance, the end-effector size and mechanism feasibility, two fingers with conical guiding holder type mechanism were selected. Its fingers have suitable elasticity which reduces the impact load on initial contact to the target grapple fixture.

The target grapple fixture is a handle which has rectangular conical outer shape. Figure 5 shows the layout of the end-effector finger mechanism. The outer sleeve moves translationally forward/backward on capturing/ releasing the grapple fixture. The taking back motion on releasing achieves zero rate releasing.

Figure 6 shows the breadboard model of the end-effector. The performance of the end-effector was verified with individual testing and demonstration on the Capture and Berthing Test-bed.

EVALUATION TEST ON TEST-BED

The Capture and Berthing Test-bed is a H/W simulator for capture and berthing mission using robot arm. It consists of a 1.5m length 6-DOF robot arm, its control computer, operation console, television systems, image processor and a 6-DOF satellite motion simulator. These are shown in figure 7.

The satellite motion simulator has orthogonal laid-out 3 actuators, 3-DOF gimbal and a 6-axes force/torque sensor on its tip. The force/torque sensor detects the force/torque applied by the robot arm. The data from the sensor are integrated and used for calculation of the chaser/target sattelites motion difference. The motion differnce is simulated as the table motion.

The operation console has a console computer and a graphic work-station. It is used for predictive simulation display which compensates the signal transmission delay on manual augmented teleoperation.

Demonstration of satellite capturing using the test-bed was successfully completed. On the demonstration, evaluations for automatic satellite capture and berthing task capability, control algorithm andend-effector mechanism are performed. Quantitative variables examined included task performance time and implied load histories on the end-effector. The load histories are shown in figure 8.

Comparison with the manual tele-operated capturing is also studied. Indices of quality for mental work-load and physical discomfort to perform the task manually as a back-up mode were also employed.

CONCLUSION

For automatic satellite capture and berthing, special end-effector and control algorithm should be applied. An end-effector concept and an arm control algorithm were presented in this paper. Testing results using robot arm and motion simulator were also presented.

REFERENCE

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[2] H.Hashimoto,et.al:Simulation for developing JEM Remote Manipulator In Proc. of i-SAIRAS '92

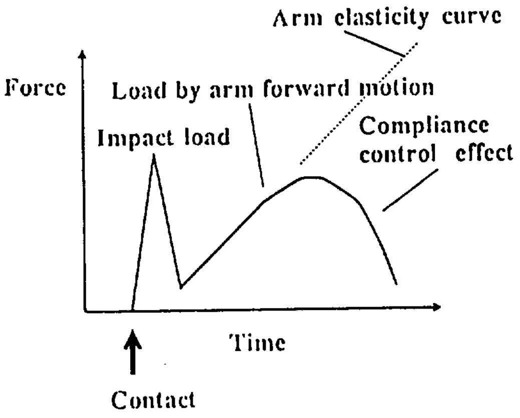

Figure 1. Typical transient force profile on capture and berthing of satellite

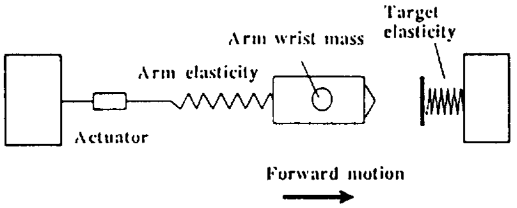

Figure 2. Force controlled arm single axis model

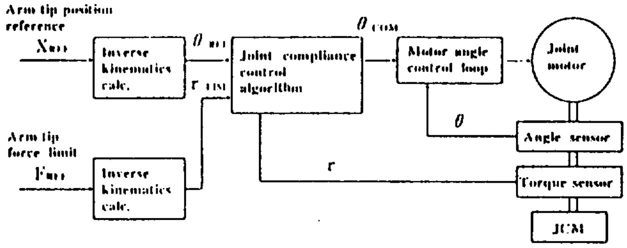

Figure 3. Joint compliance control system model

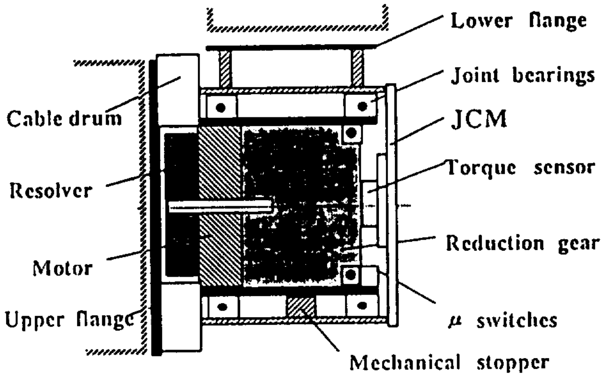

Figure 4. Joint Compliance Mechanism's cross-section

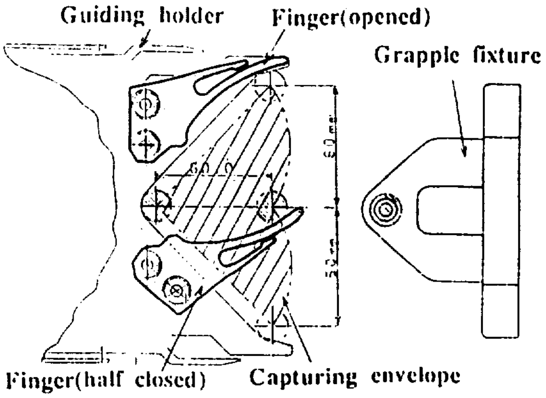

Figure 5. Capture and berthing end-effector mechanism

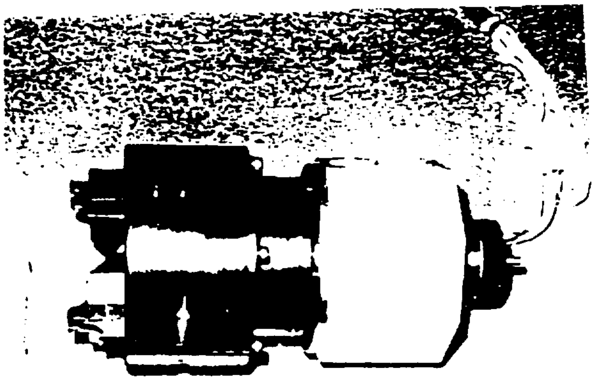

Figure 6. Breadboard model of C&B end-effector

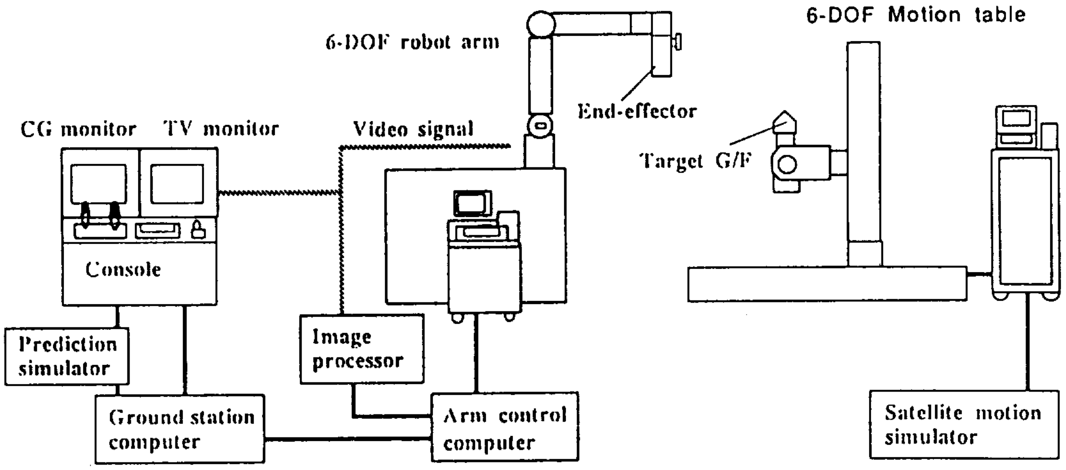

Figure 7. Configuration of C&B Test-bed

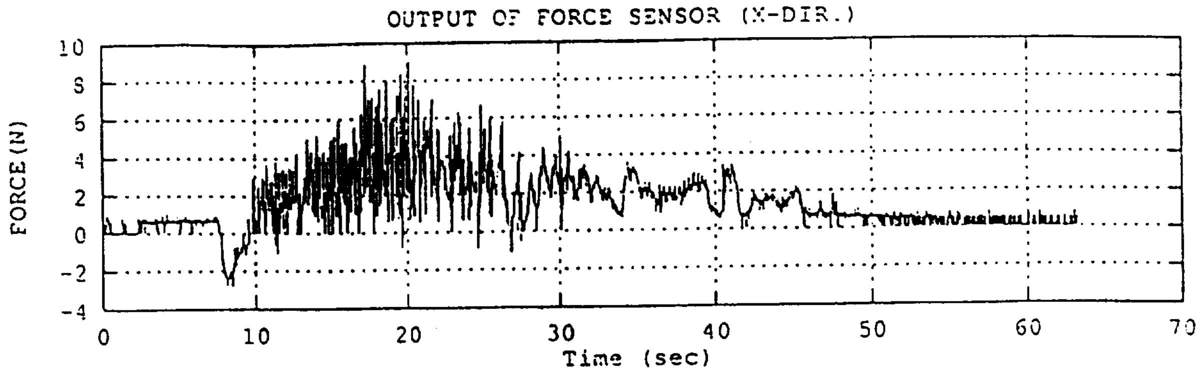

Figure 8. Load history at arm tip on C&B demonstration using C&B Test-bed