Research and Development of Reconfigurable Brachiating Space Robots

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Abstract

This paper presents a summary of the system of "Reconfigurable Brachiating Space Robot". The robot consists of a center hub and three 6 degree-of-freedom arms with an end-effector and a pivot, which has a reconfigurable mechanism, for each arm. This space robot is capable of moving over the Japanese Experimental Module of the International Space Station in a brachiating manner and also of arm reconfiguration according to the various task requirements. This paper discusses the mechanisms of the arm module, the end-effector and the docking element in detail, and also focuses on the fundamental concept of controllers' system as well as the communication system of the RBR.

1. Introduction

It is very important to develop space robots supporting space activities, especially internal and external vehicular activities for future space utilization. We have started a joint project with NASDA and other Japanese institutes to develop the Reconfigurable Brachiating Space Robot (called RBR) to be tested on the Japanese Experimental Module (JEM) of the International Space Station (ISS). The RBR is designed to make locomotion by grasping handrails and to reconfigure its structural topology in order to have various kinds of functions. This paper gives outline on current research and development status of the RBR, in particular, on the hardware design, the communication and controller design and the experimental demonstration of the RBR mainly conducted by Tokyo Institute of Technology's group.

The objectives of this research study are design, manufacture, test, and demonstrate a space robot with the following:
i) Modular design of the joints
ii) Simplification of the harness and the wiring by employing advanced communication method and decentralized control of the joints
iii) Multi-functional reconfigurable end-effector

Furthermore, the following operational aspects are also considered:
i) Execution of predetermined tasks according to well-established teaching playback modes
ii) Improved interaction with human operators

2. System Architecture

As Shown in Figure 1, the RBR system consists of three 6 degree-of-freedom (DOF) arms with an end-effector and a pivot, and a center hub (box) to attach the arms. The hub has three ports (end-effector) to attach arms. Each arm has six revolute joints, one end-effector on its tip and one pivot on the other end. Each arm can be attached to and removed from the center hub as well as another arm and the pivot placed on any point over the space system by the combination of the end-

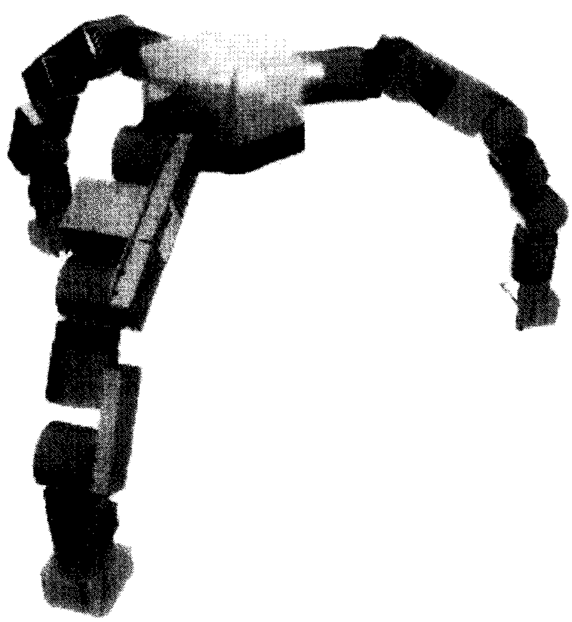

Figure 1 Conceptual model of Reconfigurable Brachiating Space Robot

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effector and the pivot. Thereby the RBR has a variety of compositions with the center hub and the three arms. The end-effector is designed for holding handrails with three fingers with helping of a small TV camera. It also has power and communication connectors mating to the pivot connector. All of the three arms are initially attached to the hub independently; however, its arm-combination can be changed to the another adapted for the given tasks.

3. Major Subsystems

In this section, three major subsystems will be described with specifications. Included are the joint and the arms, the end-effector and pivot and embedded drivers and controller.

3.1 Joint and Arm

A unit of the Joint Module is shown in Figure 2 with specification of Table 1. As shown in Figure 3, one arm is composed of the six Joint Modules in roll or pitch configuration. The basic design criterion is "modularized unit" with integrated electronic devices into a mechanical part. It should be noted that the arm can be operated in a stand-alone mode with a communication controller located at the arm, without a central communication controller located at the center hub. Each of the six Joint Modules has the same components summarized as follows:

i) Mechanical part includes DC servomotor, harmonic drive, rotary encoder and other sensors in a compact form. The major design challenge is to secure ample the space necessary for the harness and wiring of the DC power line and the

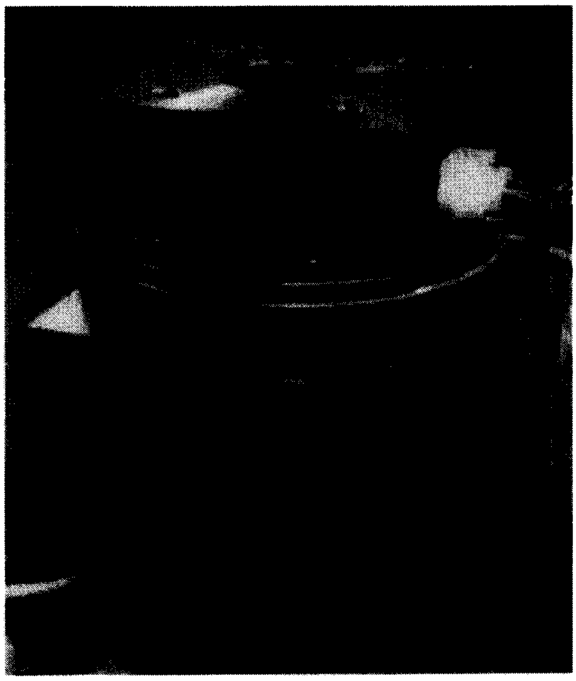


Figure 2 Unit of Joint Module

Table 1 Specification of Joint Module

Item	Specification
Drive unit	DC Motor (217W) + harmonic drive (1:120)
Angle detecter	3ch Rotary Encoder (1000 CPR)
Joint Torque [Nm]	20.06 (Max39)
Joint Speed [rpm]	21.94 (Max43.88)
Movable area [degree]	-170~+170 (Roll) -120~+120 (Pitchl)
Size [mm]	ϕ 92x76.5
Weight [kg]	1.0

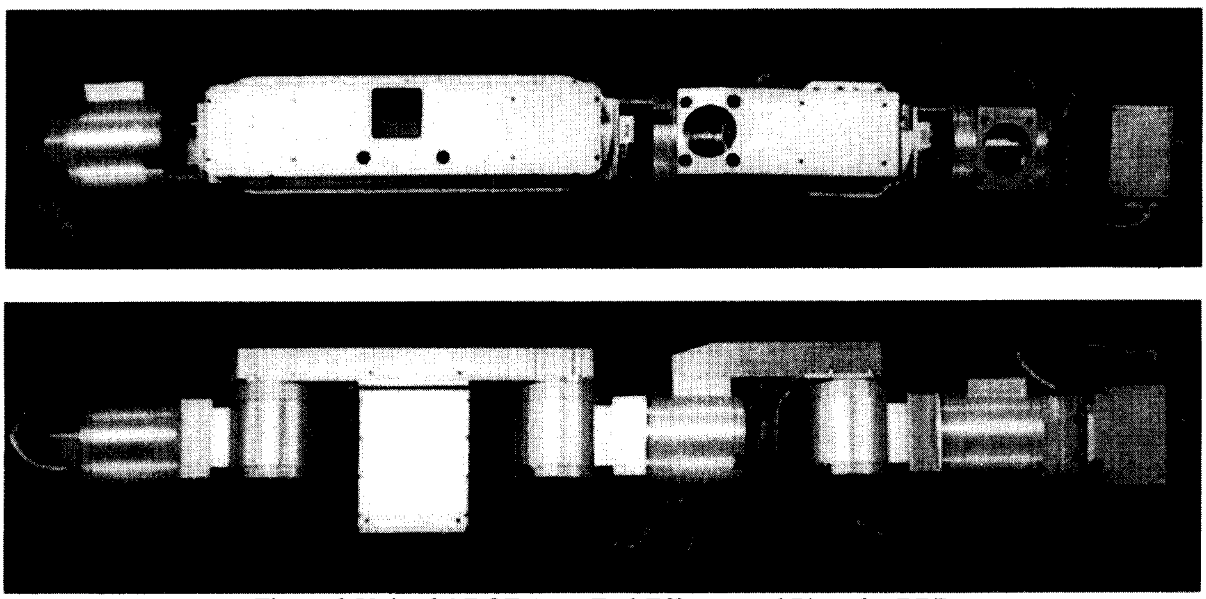


Figure 3 Unit of 6 DOF Arm, End-Effector and Pivot for RBR

communication line for control to the arm and the Joint Module. A hollow shaft of the motor has been utilized at rotating axis for the harness and wiring to pass through this point. This requirement conflicts the downsizing design requirement, both of which must be traded under the currently available state-of-the art technology.

ii) The major characteristics of the electronic part are the motor driver which is named "Device Controller", explained in section 3.3. The Device Controller controls the Joint Module by pulse width modulation (PWM). Mode under the local feedback loop with the rotary encoder and the command signals sent from the communication controller through TIA/EIA-485.

3.2 End-Effector and Pivot

The End-Effector and the Pivot are shown in Figure 4 with the specification of Table 2. Fig.4 (a) is detached configuration and (b) is attached configuration. The pivots are normally placed on the spacecraft or the ISS/JEM Space Experimental Payload (SEP) wall and provide electric power and communication signals to the end-effector through the connector. In addition, the pivot is placed the arm of the tip for connecting to the center hub and is provided electric power and communication signals from the end-effector located the center hub. Both the end-effector and the pivot have the following interface:

i) Mechanical interface between the end-effector and pivot is required for mating. The mating is realized by radial opening of three claws of the end-effector outward to the extent that it touches the stopper and then by translational drawing action of the claws to secured position of the both units, and both of the electronic connectors is connected.

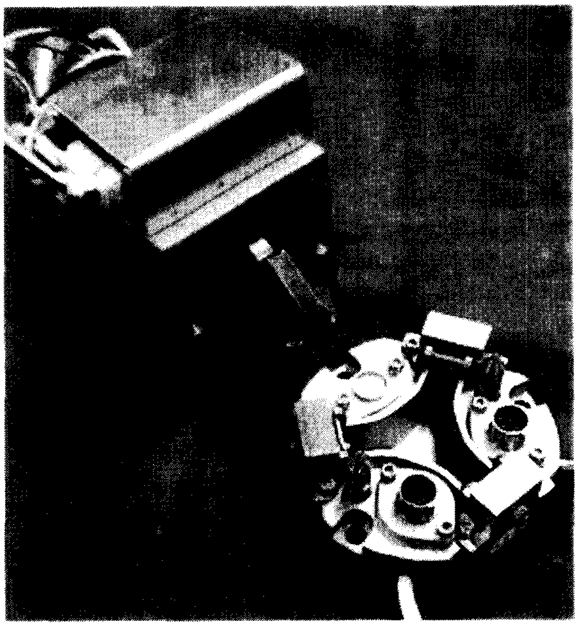
ii) In the brachiating mode, the claws of the end-effector are fully open first and then start closing inward and grasp the handrail with one claw at one side and the other two claws at another side. The force is controlled by current measurement on the Device Controller.

iii) Electronic interfaces are the same as the Joint Module, because the identical Device Controller of the Joint Unit drives the servomotor of the end-effector.

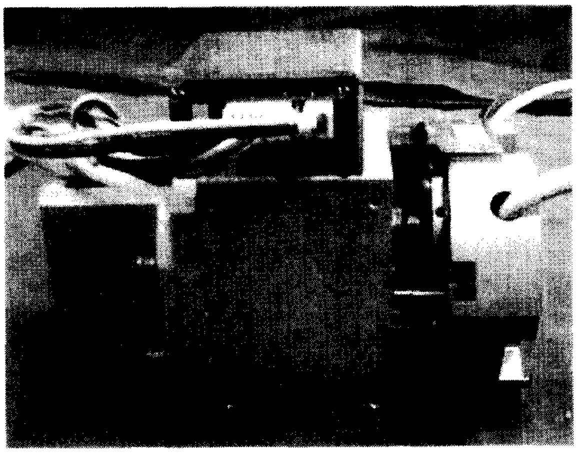
In addition, a miniature-sized CCD camera is installed inside the end-effector that can be used for the precise control of the arm.

3.3 Embedded Driver and Controller

One of the most important key technologies required for realizing reconfigurable robots is the system of distributed the controllers for the joint's



(a) Detached Configuration



(b) Attached Configuration

Figure 4 End-Effector and Pivot

Table 2 Specification of End-Effector and Pivot

Item (End-Effector)	Specification
Drive unit	DC Motor (67W) + harmonic drive (1:100)
Grip Torque [Nm]	5.0
Grip Speed [rpm]	7.0
Size [mm]	ϕ 100×120
Weight [kg]	1.0
Option	CCD Camera
Electrical Interface	Power Line Ethernet Line

Item (Pivot)	Specification
Size [mm]	ϕ 90×40
Weight [kg]	0.5
Electrical Interface	Power Line Ethernet Line

motor drivers and joint-to-joint or arm-to-arm communication. The RBR makes reconfiguration of arm compositions, so that it is required to have an autonomous control for each arm working at the moment of reconfiguration as well as any permissible configuration. It is necessary for this requirement to provide the continuous power supply and the information transmission, and be adapted to hot swapping between the distributed controllers of the each arm during attaching and removing operations.

Each arm has a hierarchical system consisting of two layers, shown in figure 5: the top layer is a main controller named Communication Controller, and the other seven sub-controllers named Device Controller for six Joint Module and an end-effector. The Communication Controllers utilize a high-end PC and communication interfaces, as shown in figure 6 with specification of Table 4. Most components used are embedded by PCMCIA, which makes extensions and/or repairing of functional parts by exchanging PCMCIA.

Figure 7 shows the Schematic of the Device Controller. The Device Controller is composed of 16 bit MPU (Hitachi H8) with a TIA/EIA-485 transceiver, PWM drivers for the joint motor and interfaces with sensors including the encoder and the area/limit sensors. Figure 8 shows the Device Controller with specification of Table 3. The size of the Device Controller is small enough to be installed in a mechanical adapter of the Joint Module. The Device Controller communicates with the Communication Controller through the TIA/EIA-485 line. Each arm has the identical

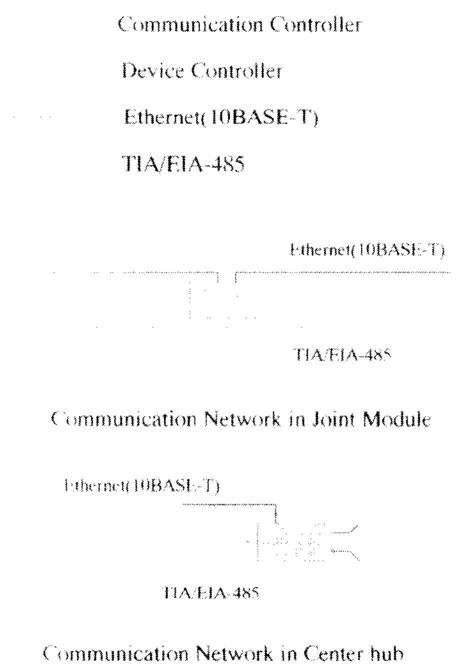


Figure 5 Schematic of Network System of RBR

system and communicates with each other using Internet Protocol (IP) through 10BASE-T line. The Communication Controller performs a high-level control while the Device Controllers execute a low-level control of the Joint Module. The high-level control is calculation to a trajectory of a brachiating and reconfigurating motion or any tasks by inverse kinematics and analysis that the arm interference with each other. The low-level control is a local control of the Joint Module, which is an angle and/or angular velocity of the joint, a current of the motor and judgement of the area/limit sensors. The angle, the angular velocity and the current of the motor is controlled via proportional and differential control (PD Control). The control command and the parameter are set through the TIA/EIA-485.

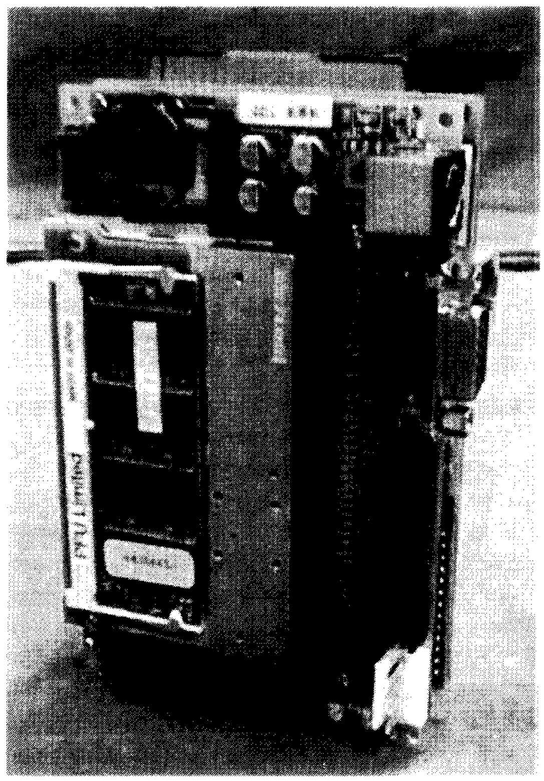


Figure 6 Communication Controller

Table 4 Specification of Communication Controller

Item	Specification
CPU	Intel Pentium MMX 200
Frequency [MHz]	200
RAM [MBytes]	64
HDD [MBytes]	Compact Flash 45
NIC	2Ethernet(10BASE-T) TIA/EIA-485
OS	Debian GNU/Linux + RT-Linux
Size[mm]	124×78×44
Weight[g]	310

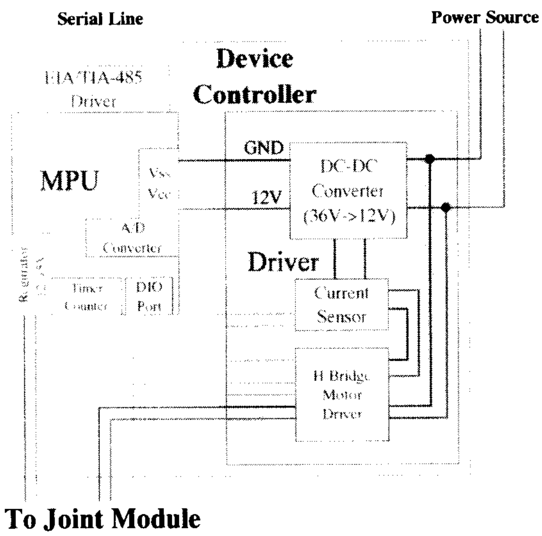


Figure 7 Schematic of Device Controller

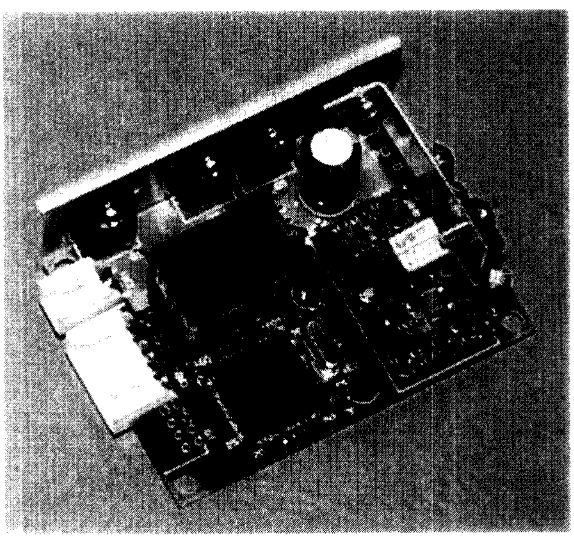


Figure 8 Device Controller

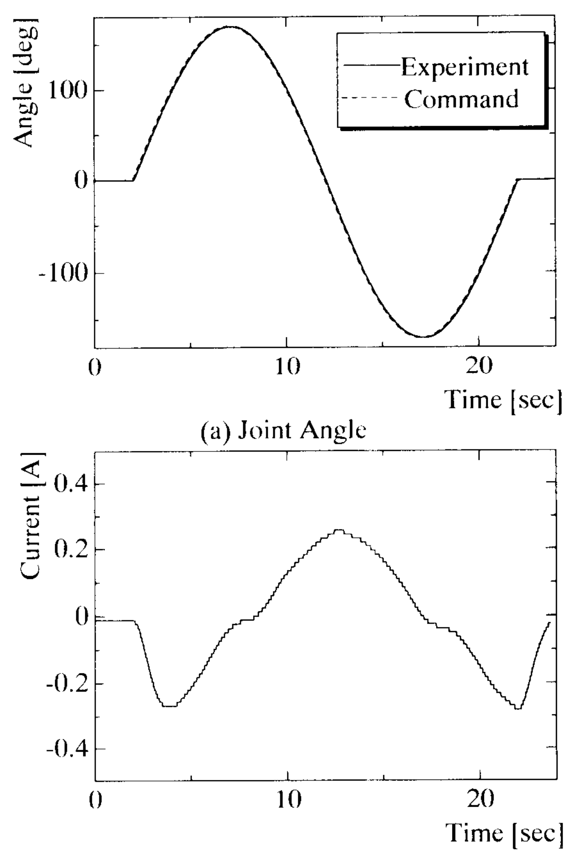
Table 3 Specification of Device Controller

Item	Specification
Motor Power [W]	Max. 288
Input Voltage [V]	18～48
Output Current [A]	2 (Peak 6)
Onboard MPU Frequency [MHz]	Hitachi H8/3048F 16
Control Period [msec]	1
PWM Frequency[kHz]	32～192
Control Mode	Position Velocity Current
Interface Baud Rate [bps]	TIA/EIA-485 (RS-485) 38400
Size [mm]	70x50x25
Weight [g]	50

The design philosophy of this control system is modularization and usage of standard off-the-shelf-products. The major advantage of this system is that the number of the cables inside the robot arm is only fourteen: two for the power line, four for the Device Controller line (TIA/EIA-485), four for the Communication Controller line (10BASE-T) and four for spare. The spare cables are used to change the cut wires or extend the communication line to 100BASE-TX. This reduction in the wire number is indeed the key to realization of this RBR system.

4. Preliminarily Experiment

We conduct preliminarily experiment to verify the performance of the Device Controller. In this experiment, the PD Controller of the joint angle is tentatively installed in the Communication Controller for debugging, so the control period is 10[msec], because of the communication cycle. If PD Controller is moved to the Device Controller, then the control period will be reduced to 1[msec]. The current of the motor driver is measured and filtered by the Device Controller. A cut-off frequency is about 5[Hz]. The experiment is to let the joint angle to follow a sinusoidal command



(a) Joint Angle

(b) Current of Motor Driver

Figure 9 Experimental Data

input with period 20[sec]. Figure 9 shows the experimental data of the joint angle (a) and the current of the motor driver (b). Fig.9 (a) shows that the Device Controller can control the joint angle by PWM. Fig.9 (b) shows that the filter can remove the high frequency noise of the current sensor. In this experiment, we have confirmed the capability of the Device Controller. In immediate future, we will demonstrate the overall capability of the distributed control systems including the seven Device Controllers and one Communication Controller with emphasis or the communication performance.

5. Conclusion and Future Plan

The basic design features and the major characteristics of the Reconfigurable Brachiating space Robot (RBR) have been presented.

This R & D research project started in FY 1997 as part of the Ground Research for Space Utilization and will terminate at the end of FY 1999. During the remaining period of this fiscal year, it is planned to carry out the following experiments and demonstrations:

i) Brachiating capability in a standard configuration using handrails installed in the 3 Dimension Testbed already installed at TIT.
ii) Reconfiguration capability with power supply and information transmission for various configurations.
iii) Joint performance and characteristics in quasi-microgravity condition using parabolic flight in an airplane.

Based upon the results from the experiments described above, onboard experiments will be proposed on the ISS/JEM exposed facility.

6. Acknowledgements

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