Reconfigurable Space Manipulator for In-orbit Servicing

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Abstract

Recently the construction of the International Space Station (ISS) has begun and the Space Shuttle Remote Manipulator System (SRMS) and the Space Station Remote Manipulator System (SSRMS) are used for the construction. These manipulators are operated by onboard crews and accomplish the tasks that cannot be done by human hands, such as the transportation of the large and heavy objects. Although these manipulators are useful for these kinds of tasks, there are plenty of needs to use more advanced manipulator systems for in-orbit servicing applications such as unmanned orbital service robots and Extra Vehicular Activity (EVA) support robots. There are also a lot of challenging technologies to realize such applications effectively. Thus we have been doing research on technologies for the next generation in-orbit servicing robot systems. The Reconfigurable Space Manipulator (RSM) is the one of the results from our research. The manipulator is designed to apply for various space applications. This paper presents the task analysis results for the next generation in-orbit servicing robots, the system concept of the Reconfigurable Space Manipulator and some system design results for the manipulator.

Introduction

Crew-operated manipulators such as the SRMS on the Space Shuttle and the SSRMS on the ISS have played very important roles for current space activities. The importance of the robots will become larger and larger in the 21st century when more of a variety of space activities will be realized. In Japan, the first step to acquire the technologies for space robots was to develop the robot experiment system on the Engineering Test Satellite VII (ETS-VII) (Oda, 1999) and to obtain the basic technologies about space manipulators in orbit through the experiment on ETS-VII. ETS-VII was launched on November 1997. And the robot experiments have successfully been performed since then and will last until the end of 1999. At present, we have moved on to the research of the next generation space robots which have the abilities to realize more effective space utilization in the 21st century. Though there are many challenging problems to develop such space activities, we can apply the new technologies for space robotics such as new electronics, advanced control theory, innovative information processing software and the latest

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communication technologies. These technologies have been progressing through a variety of researches and commercial developments. The basic concept of our approach to develop next generation space robots is to use these new technologies to improve ordinary space manipulator systems.

Requirements and Characteristics for Next Generation In-orbit Servicing Robots

Before the system design of a next generation in-orbit servicing robot, we tried to analyze the requirements for robots in the future space missions. Our study begins with the investigation of in-orbit servicing applications which can be realized around 2010. From the study, we chose the following five candidates as the design references of the in-orbit servicing robot missions:

(1) EVA support robot on ISS

Although the r-ORU (robot essential Orbital Replacement Unit) can be replaced by remote manipulators such as SSRMS or Japanese Experimental Module Remote Manipulator System (JEMRMS), there are some e-ORU (EVA essential ORU) replacement tasks which cannot be done by SSRMS or JEMRMS and require the EVA of a crew. In the future, to reduce the risk of crew EVA as well as the long dead time for EVA preparation, EVA support robot (EVR) will conduct some basic tasks to treat e-ORU. Figure 1 shows the image of the construction by robots.

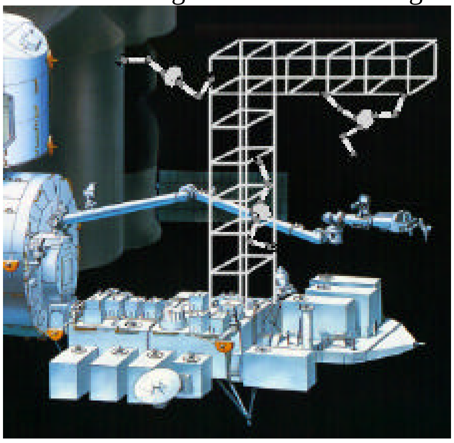

Figure 1. The Construction by EVA support robots on ISS

(2) IVA support robot on ISS

When the ISS is fully operational, many experiments will be maintained by ISS crews. Since the total crew time is limited on ISS, it is important to save the crew time by using automation and/or robots. It would be satisfactory to use automation for each experimental instrument. However if an IVA (Intra Vehicular Activity) support robot (IVR) becomes available in the future, it can be used more general experimental activities. In addition, IVR can be used for the transportation of ORUs, and it can be used as the movable remote camera inside the ISS.

(3) Inspection robot for ISS and an unmanned platform

Since the ISS and an unmanned platform are large structures, it is difficult to put monitoring cameras such that crews or ground operators can monitor the entire space vehicle. Thus there is a need to inspect ISS or an unmanned platform from their own proximity zone using a free flying inspection robot. The robot can fly around the target and take the pictures or inspect the object using special sensors.

(4) Orbital servicing robot for an unmanned platform

There will be some need to do experiments outside of the ISS in the future. The high level zero-gravity experiments and hazardous material/biological experiments are such examples. For this purpose an unmanned co-orbital platform can be developed in the 21st century. A co-orbital platform has an advantage in transportation of experimental instruments, because the transfer vehicles for ISS can also be used for a co-orbital platform. In addition to such experiments, since the platform is unmanned and restrictions are not as severe as in the ISS, the platform can be used as a testbed for advanced technologies. Figure 2 shows the concept of the unmanned co-orbital platform. Since the platform is unmanned, this system requires the servicing robots that conduct the transportation and replacement of ORUs, operate the experimental instruments and perform the advanced technologies experiments.

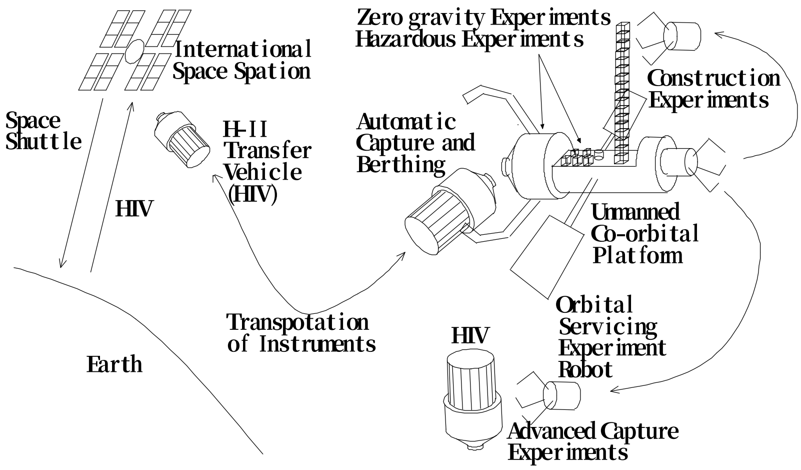

Figure 2. Orbital servicing robot for an unmanned platform

(5) Rescue space robot for re-orbiting

As the first step for the rescue service, a rescue space robot for re-orbiting may be available around 2010. The rescue robot is launched from the earth when a satellite is inserted into wrong orbit due to malfunction of a transfer vehicle. The rescue robot can transport the satellite from a wrong orbit to the right orbit. Since the satellite is under control of the ground operators, the capture of the satellite by the rescue space robot is not very challenging. If the rescue space robot system is officially regarded as the backup when a transfer vehicle fails to insert a satellite into the right orbit, a marker and handrail can be attached to the satellite and the capture will become less difficult.

For an in-orbit servicing robot to conduct the above missions, the main requirements and characteristics that the robot should have are as follows:

(a) Applicability to various tasks
(b) Reduction of system penalty for users (compactness, light weight, and simple system)
(c) Enhancement of work performance
(d) Mobility and transportability
(e) Inspection capability
(f) High reliability and high safety
(g) Autonomous capability

System Concept of Reconfigurable Space Manipulator

We have been studying the Reconfigurable Space Manipulator (RSM) (Wakabayashi, 1997) which has the capabilities and characteristics discussed in the previous section. Technologies such as new electronics, advanced control theory, innovative information processing software and the latest communication technologies can be used for satisfying the required abilities and characteristics. At present, the technologies shown in Table 1 are applied to the RSM. They will be updated as new technologies become available.

Table 1 Technologies to realize the required abilities and characteristics

Required abilities	Technologies to realize the abilities
(a) Applicability to various tasks	- Reconfigurable manipulator system - Multiple mode operation (stand alone mode, plural manipulation mode, combined mode, multi-agent mode, etc.) - Configurable computer system - High speed communication network with hot swap - Scalable function system for required tasks
(b) Reduction of system penalty for users (compactness, light weight and simple system)	- Decentralized small controller - Modular design of joint - Networking robot system - Small force manipulator with inner force operations
(c) Enhancement of work performance	- High performance MPU - Parallel processing system - Dexterous manipulator/hand - Cooperative control of plural manipulators - Robust image processing - Sensor fusion - Artificial intelligence - Interactive operation with ground operators - Specialized tools for particular tasks
(d) Mobility and transportability	- Symmetry manipulator - Wide range hand eye camera - Walking system - Passive/semi-active carrying port
(e) Inspection capability	- Inspection sensors (camera, IR sensor, etc) - Proximity flying system - Attitude control with thrusters ,gravity gradient stability and manipulator control
(f) High reliability and high safety	- Onboard supervision - Fault tolerant system - Graceful degradation system - Redundant manipulator
(g) Autonomous capability	- High performance MPU - Self- monitoring system - Artificial intelligence - Adaptive Control

Study for System Design of Reconfigurable Space Manipulator

Although there are some problems to be solved and some unclear items that need further studies, we did the system design of the Reconfigurable Space Manipulator (RSM) for trial. Some of the results are shown below:

(1)Operation modes of the Recofigurable Space Manipulator

There are ten principal operation modes, and the RSM changes its configuration for executing each different task. Though a human operator commands the reconfiguration, the RSM changes its configuration by itself. Figure 3 shows the configurations in each mode.

(a) Stand-alone mode	(f) ORU transport mode
(b) Walking mode	(g) Satellite mounted mode
(c) Serial link mode	(h) Inspection mode
(d) Plural manipulation mode	(i) Macro-mini combination mode
(e) Small object transport mode	(j) Multi-agent mode

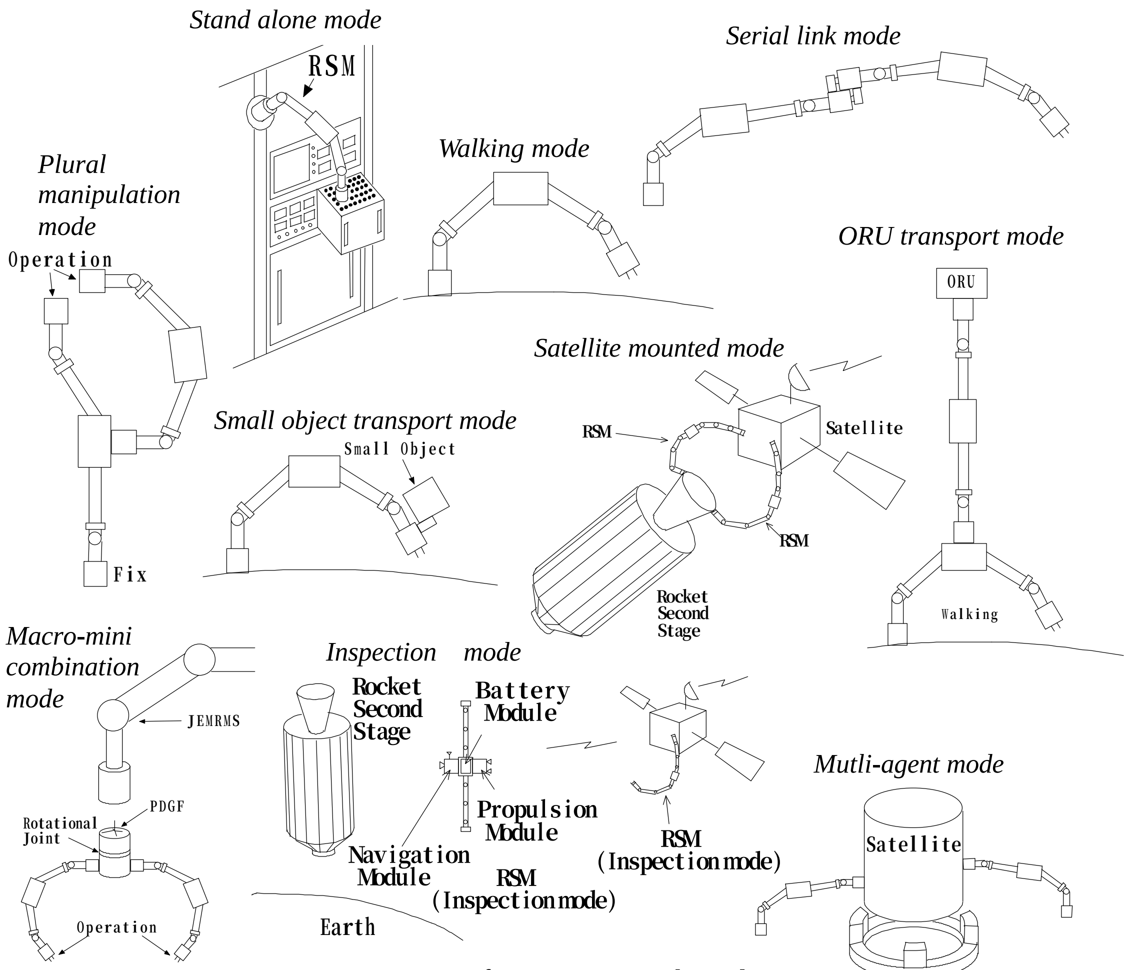

Figure 3. Configurations in each mode

(2) Reconfigurable Manipulator

Figure 4 shows the shape of the reconfigurable manipulator. The manipulator is symmetric and has 7 degrees of freedom. The end-effectors are attached at both ends of the arm. Four pivots are attached to the manipulator as shown in Figure 4. A passive mechanism is used for a pivot, and the end-effector grasps the passive pivot for mating. The battery module is attached when the manipulator is walking by itself. The navigation module and propulsion module are attached when the manipulator is in the inspection mode.

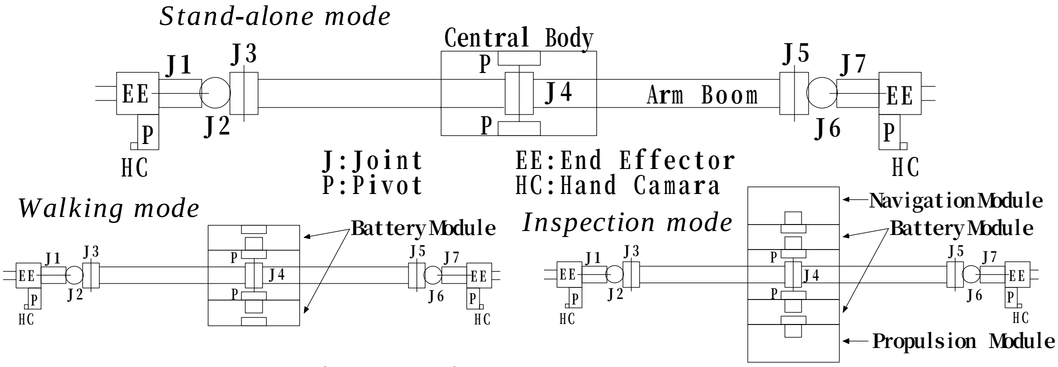

Figure 4. Shape of the Reconfigurable Space Manipulator in various modes

(3)Network Decentralized Controller System

To realize its reconfigurable capability, the RSM uses a decentralized control system connected by a high-speed serial data bus. Since the data bus is connected or detached when the manipulators are connected or detached, the data bus must have hot-swap capability. The computer system of the manipulator is also configurable to optimize its processing power. Since the computer system can be used as a parallel processing system and/or a task-level fault tolerant system, the system can be used for more complicated tasks or the two fail-safe requirements such as the inspection missions around the ISS. Figure 5 shows the one of the proposed decentralized systems.

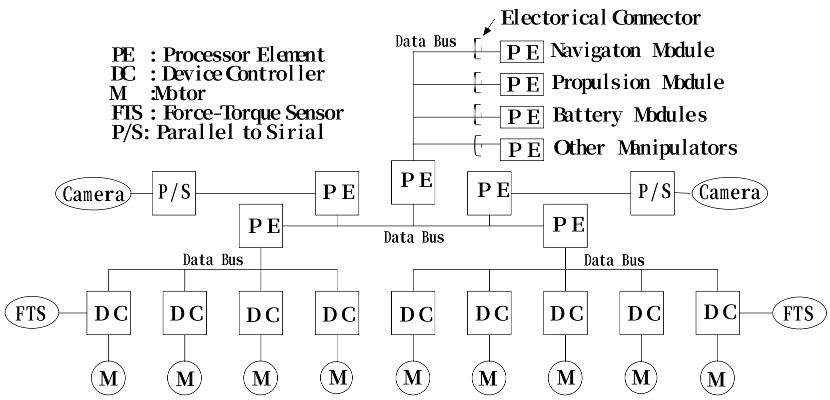

Figure 5. One of the proposed decentralized systems

(4) Summary of the other characteristics

Table 2 shows a brief summary of the other characteristics of the system design results based on the technologies shown in Table 1. For reference, the design results are compared with the manipulator on ETS-VII in Table 2.

Table 2 Specifications of ETS-VII and RSM

Specification Items	Manipulator on ETS-VII	RSM
Size. Weight	2m, 100kg	~2m, 30kg
Executable tasks	ORU replacement Capture (only for low rate)	ORU replacement, Capture, Inspection, Construction
Mobility	No	Walking, Free Flying
System vision	Camera + Driver electronics	Smart small camera with deep focus length
Man-Machine I/F	CG prediction	Virtual Reality
Accuracy of hand Pointing	Absolute : ~10 mm Relative : ~3mm	Absolute : ~3 mm Relative : ~0.5mm
Cooperative Control	Arm-Attitude cooperative	Arm-Attitude cooperative Plural Arm cooperative Multi-Agent cooperative
Weight of End Effector	13kg	~1kg
Joint weight	10kg	~600g
Joint torque	~40Nm(continuous)	~5Nm (continuous)

(5) Manufacture for trial

The three-dimensional trial model named Recomfigurable Brachiating Space Robot (RBR) (Ohkami et al., 1999) has been developed at the Tokyo Institute of Technology. Figures 6 and 7 show the arm and the decentralized controller (DC) of RBR. The design concepts of RBR are as follows and they are succeeded by RSM:

- Reconfiguable mechanism for various tasks
- Decentralized control system with high performance data bus which simplify the wiring
- Modular design of joint for simple assembly

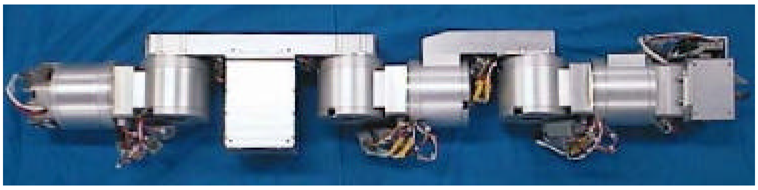

Figure 6. Arm of the RBR

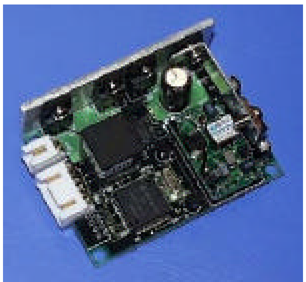

Figure 7. DC of the RBR

Conclusions

At present we have continued to study the RSM to improve its design, and we have also proposed the Reconfigurable Space Manipulator to apply to in-orbit servicing missions such as an EVA mission with robots or an unmanned orbital servicing mission by robots.

Reference

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