Proceeding of the 7th International Symposium on Artificial Intelligence, Robotics and Automation in Space:
i-SAIRAS 2003, NARA, Japan, May 19-23, 2003

Design and Ground Experiment of Reconfigurable Arm System

Nobumasa Yamaguchi, Ryuichi Hodosima, Ikutarou Morita, Saburo Matunaga
Tokyo Institute of Technology
2-12-1 Ookayama, Meguro-ku, Tokyo, 152-8552, Japan
lupin@lss.mes.titech.ac.jp

Keywords : reconfigurable system, communication line

Abstract

Future in-orbit missions will include inspecting, repairing damaged satellites, constructing large structures, refueling satellites, supporting EVA (extra vehicular activities) of astronauts and so on. In order to conduct these missions, we have proposed a concept of Reconfigurable Robot satellite Cluster for various future in-orbit servicing missions. The system consists of multiple satellites with reconfigurable arms. The reconfigurable arms realize the reconfigurability of the system. Utilizing the reconfigurability, the system can perform various in-orbit servicing missions by changing their configurations. In order to investigate the feasibility of proposed system, we constructed a reconfigurable arm model. The reconfigurable arm model consists of two parts. One part is an arm part of 5 degrees of freedom with two reconfigurable end-effectors and a pivot. Another part is a docking part of two degrees of freedom. And we conducted the ground experiments to verify the reconfigurability by using two dimensional micrograbity experiment system which has been constructed by our laboratory.

In this paper, we introduce the ground experiment system, show the design of reconfigurable arm system and describe the experiment of verifying the re-configurability.

1. Introduction

It is important to develop in-orbit servicing satellites which perform inspections, observations, capture, recovery, repair and de-orbit of uncontrolled satellites and so on. ETS-VII (Engineering Test Satellite VII) , which was launched by NASDA in 1997, tested the fundamental techniques of the rendezvous-docking and the robotic arm operations. There are, however, many technical problems remained. On the other hand, researches on many small satellites cooperation to perform variable advanced missions attract much attention now.

We have proposed a concept of robot satellite cluster systems – Robot Satellite Clusters [1]. The systems consist of multiple robotic satellites with reconfigurable manipulators. The purpose of the system is to conduct various missions of capturing uncontrolled satellites, supplying electric power and fuel, as well as conducting variable orbit servicing missions. The system also reduces the risk of failure.

The features of Robot Satellite Clusters are the followings.

(1) Reconfigurability

The robot satellites are connected between arm docking ports and end-effectors, or between satellite docking ports. The system can adapt to the mission by changing the configuration. In addition, the satellites can transfer electrical power and information with the interface of arm docking ports and end-effectors.

(2) Small Size, Light Weight and Low Cost

Small and cheep satellites can perform variable advanced missions by cooperating each other. Therefore mass-producing small and cheep satellites makes the cost lower. And the weight of each satellite becomes lighter.

(3) Redundancy and Distribution

Enough number of satellites realizes the system redundancy, and can reduce the risk of failure. Part of functions can be distributed so that each robot satellite performs the each different mission. We developed a ground experiment system by using of the concept.

At first, this paper introduces the experiment system our laboratory has developed. Second, we explain a design of reconfigurable arm for ground experiments, and show the modified arm in detail. Finally, we describe fundamental function tests.

2. Ground Experiment System

We have developed a ground experiment system in order to conduct a ground experiment for verification of the satellite system mentioned above. The system consists of three satellite simulators, a ground station, and a position determination system.

The simulator called DISC (Dynamics and Intelligent Simulator for Clusters) has nitrogen thrusters and wireless LAN communications system. Two- dimensional micro gravity is realized by use of air lubrication. Fig.1 shows overview of the satellite simulator system and Table 1 shows its specifications.

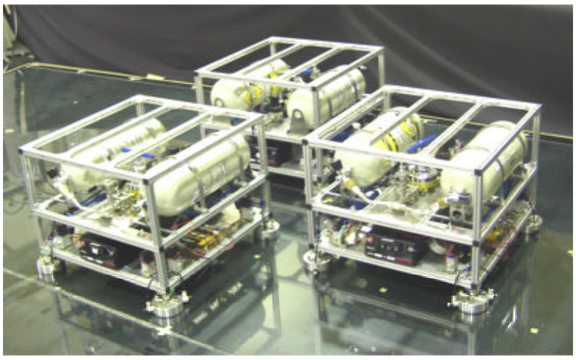


Fig.1 Overview of Simulators

Table 1 Specifications of the Simulators

Weight	**42 [kg]**
Moment of Inertia	**2.4 [kgm2]**
Pressure in Air Tank	**100 [kgf/cm2]**
Volume of Air Tank	**8.6 [l]**
Control Cycle	**50 [ms]**
Communication Rate	**5.0 [Mbps]**
Thrust	**2.0 [N]**
Time of Experiment	**5.0 [min]**

One CCD camera and fiber optic gyros are used in order to determine the position and attitude of the satellites. The CCD camera, which is installed on the ceiling over the flat floor, determines the positions of the satellites by using pattern matching. Then the position data are transmitted to each satellite. Fig.2 shows a schematic of ground experiment system including the position determination system. Using the system, we have conducted the following experiments: communications experiment between the satellites as well as between the satellites and the ground station, Dynamics and control of cluster satellites coupled with manipulators or tethers [5], capturing and berthing experiment of an uncontrolled satellite by cluster satellites [6].

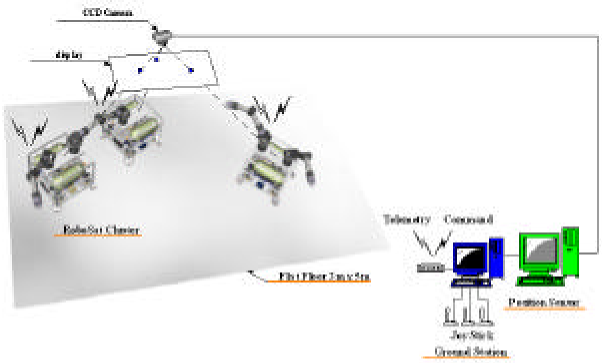


Fig. 2 Schematic of Experiment System

3. Reconfigurable Arm System

3.1 Manipulator System

We research the concept and feasibility study and the analytical study with the ground hardware simulating. One of the most important requirements for the ground hardware is ability to conduct tasks mentioned in introduction. The ability is realized by the followings.

(1) The force and torque of the arm are much enough to conduct reconfiguration and variable tasks under the gravity.

(2) The system has reconfigurability.

We designed the arm with considering (1), (2). The arm consists of two basic parts. One is an arm with 5 degrees of freedom to make reconfiguration, and the other is a docking part with 2 degrees of freedom. The satellite simulator with the reconfigurable arm has 8 degrees of freedom in total. The satellite simulator and the arm should cooperate each other while conducting reconfiguration.

Fig.4 shows DOF configuration of the reconfigurable arm for the satellite. The configuration of DOF is roll, pitch, roll, pitch, roll, beginning the bottom. The arm has 5 DOF and can connect/disconnect itself between the second and the third joints(from the bottom of the arm). When we consider the configuration of degree of freedom, we must solve two problems. One problem is that large moment applied in the root of the arm by the dead weight of the arm under the gravity environment. Another problem is that the function for the reconfigurability requires the symmetry of the arm. In order to solve these problems, we divided the arm into an upper part and a lower part, and designed that the upper part of the arm is light in weight, and the lower part of the arm can generate powerful torque.

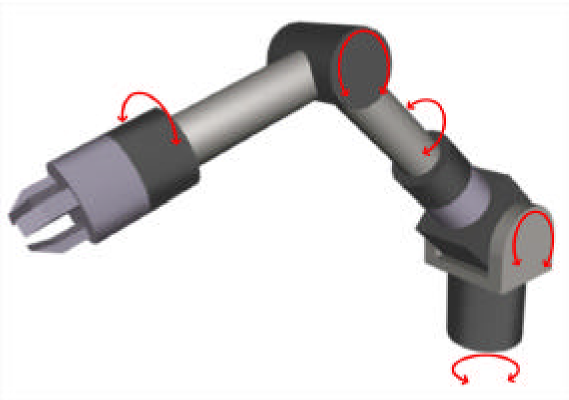


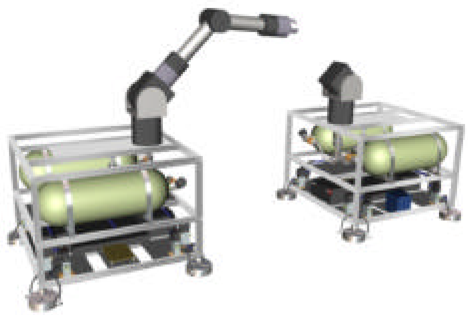
Fig. 4 Sketch of New Reconfigurable Arm

The upper part has a mobility and the lower part can produce high power and work as a docking port. The upper part is put on the end-effectors on each side of the arm and the end-effectors can connect/disconnect with the pivot in the lower part of the arm mechanically and electrically. Each motor is controlled with the DC. We can conduct various experiments with the mechanisms as shown in Fig.5. We can also conduct 3-dimensinal cooperation experiments.

We use distributed motor drivers that are named “Device Controller”. The Device Controller is composed of 16-bit MPU with a TIA/EIA-485 transceiver, PWM drivers, interfaces with sensors. The Device Controller realizes distribution of the controller and simplification of the harness. And each joint has mechanical parts. The mechanical part of the joint module includes a DC servomotor, a harmonic drive, a rotary encoder and photo micro sensors.

(a) DISC 1 approaches to DISC 2

(b) A Reconfigurable arm connects to DISC 2



(c) A Reconfigurable arm disconnects from DISC 1

Fig. 5 Sketch of Reconfiguration Experiment

We used the high power actuator (150W) for the lower part so that the lower part is able to generate high torque with the design concept. As a result, the weight tends to increase but there is not so problem in case of reconfiguration. The upper part is the main part for reconfiguration, so we reduced its weight and kept the shape symmetry as much as possible. We selected the actuator to generate the torque required for the minimum power (90W). The weight of the this arm is about 30 kg and its length is about 1500 mm.

Fig.6 shows an overview of the arm. The weight of this arm is about 30 kg and its length is about 1500 mm.

Fig.6 Overview of the Arm for Satellite Simulator

3.2 Communication System of Reconfigurable Arm System

Fig.7 shows an system block diagram.

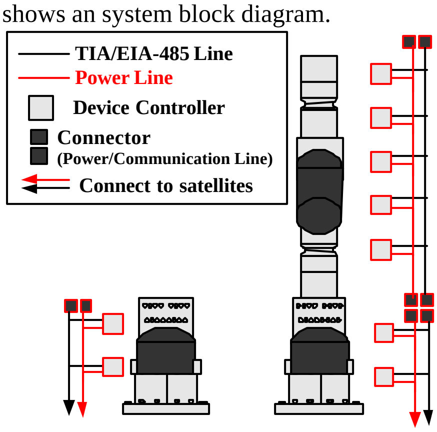


Fig.7 System Block Diagram

This system consists of TIA/EIA-485 Line, Power Line and Device Controllers. Each Device Controller controls the joint connected with itself. We adopt TIA/EIA-485 Standards as communication standards. The standards provides a lighter harness system than other system. To achieve a function of reconfiguration, we have to connect/disconnect the communication line. But the arm system has only one communication line because of minimizing harness. Connection/ disconnection of communication line changes the configuration of it. That will disturb communication between satellite and each device controller. In order to avoid the disturbance, three methods can be considered. The first method is to develop a new communication protocol whose error correction enhanced. The second method is to make a transponder. It is located between satellites and each Device Controller. And it controls the communication between a satellite and Device Controllers. The last method is to intercept physically the side of communication line connected to other part. The first method is considered to inferior to the other methods in reliability, we do not adopt it. And comparing with the second and last methods, the second method requires more resources than the last one. Therefore we adopt the last method to avoid disturbance of communication. We add switches to each end-side of the upper arm as Fig.8. We can connect/disconnect communication line without disturbing communication by using the switches.

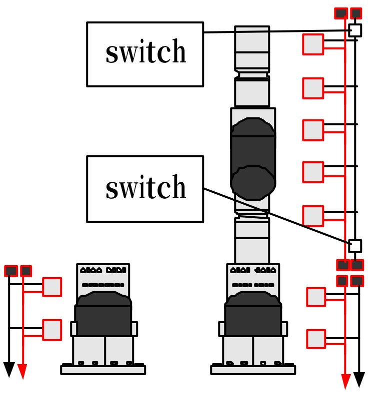


Fig.8 Location of Communication Switch

3.3 Arm System Configuration

We integrated the reconfigurable arm system with the ground experiment system. And we verified the function of reconfiguration. Fig.9 shows overview of the experiments.

(a) Before Docking

(b) After Docking

Fig. 9 Docking Experiment

4 Experiments of the Basic Motion

We conducted two experiments. A DISC with the arm pushes and rotates another in order to find out whether the arm has enough power to conduct various experiments. Because pushing and rotating are the basic motions of various missions. Fig.10 shows the experiments.

Fig.10 Overview of pushing and rotating experiments

In pushing experiment, the carrier was not controlled about the position, but just thrust only. The DISC with the arm pushes another DISC for about 1500mm.

Fig.11 shows the position of them at that time, and the current of the center joint of the upper part.

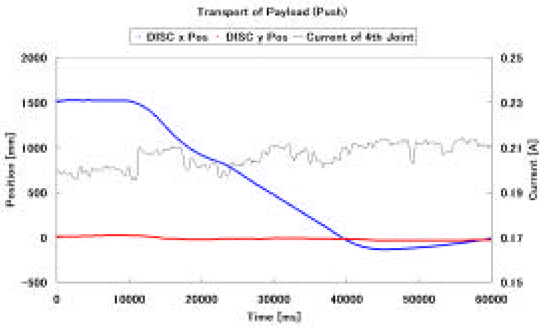


Fig.11 Current of Center Joint while Pushing

In rotating experiment, the relative distance and angle were only controlled. The DISC with this arm circled another DISC so that the radius of its circle is 1250mm. And Fig.12 shows the position of them while rotating, and the current of the lowest joint.

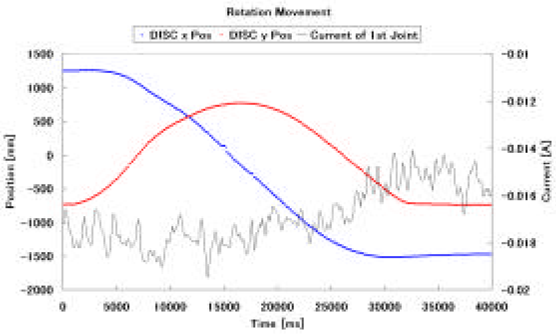


Fig.12 The Current of Joint when Rotating

From these results, we got the data of each joint of the arm. And the data said that the current of the each joint was within their limits. We conducted only basic motion this time, but it is expected that this arm has enough power to perform various experiments from this result.

5. Conclusion

We designed the reconfigurable arm for the on-ground satellite simulator in order to conduct the ground experiments of the required missions. The design concept consists of three points as the follows. The first is the function of the arm should compensate for its own weight against gravity. The second is to avoid the disturbance of communication while the reconfiguration. And the last is that the arm should be distributed to each satellite. From the first point, we have designed that the arm consists of two parts, the lower part that is powerful in torque and the upper part that is light in weight. From the second point, we add switches to the upper arm. From the last point, we adopt Device Controllers as motor driver. Furthermore, we conducted verification experiments for the basic functions of the designed arm, and the feasibility of the developed system is successfully confirmed.

Reference

[1] Saburo Matunaga, Osamu Mori, Shingo Tsurumi, and Hideto Okada, "Robot cluster system and its ground experiment system", 51st, Congress of the International Astronautical Federation, IAF-00-A. 3. 06, 2000.

[2] Yoshiaki Ohkami, Ryoichi Hayashi, Hiroshi, Yamamoto, and Saburo Matunaga, "Research and Development of Reconfigurable Brachiating Space Robots," *5th International Symposium on Artificial Intelligence, Robotics and Autonation in Space*, 1999, pp.547-552.

[3] Ryoichi Hayashi, Saburo Matunaga and Yoshiaki Ohkami, "Design Concept and System Architecture of Reconfigurable Brachiating Space Robot," J. of Robotics and Mechatronics, Vol.12, No.4, pp.425-431, 2000.

[4] Ryoichi Hayashi, Saburo Matunaga and Yoshiaki Ohkami, " Experimental Evaluation of Reconfigurable Brachiating Space Robot," J. of Robotics and Mechatronics, Vol.13, No.5, 2001, pp.548-553.

[5] Osamu Mori and Saburo Matunaga, "Tension Control of Tetherd Satellite Clusters," *22nd International Symposium of Space Technology and Science*, Morioka, Japan, 2000, ISTS-2000-k-21.

[6] Shingo Tsurumi, Saburo Matunaga, Shigemune Taniwaki, and Yoshiaki Ohkami, "Coordinated Control Experiment with a test bed imitated with a Satellite-Mounted Manipulator," *Proc. 9th Workshop on Astrodynamics and Flight Mechanics*, ISAS, 1999, pp.265-270.

[7] Ryuichi Hodoshima, Nobumasa Yamaguchi and Saburo Matunaga, "Design and Ground Experiment of Reconfigurable Arm Sy stem for Robot Satellite Cluster" *23th International Symposium on Space Technology and Science, Japan, 2002,* 2002-d-04, pp.675-680