DEVELOPMENT CONCEPT FOR SPACE TETHERED AUTONOMOUS ROBOTIC SATELLITE I

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ABSTRACT

Space Tethered Autonomous Robotic Satellite I (STARS-I) project has carried since January 2005 under the leadership of Kagawa University. The main objective of STARS-I project is technical verification for Tethered Space Robot (TSR). TSR is a new type of space robot system proposed in the previous work. STARS-I consists of two small cubic satellites, one satellite has a function of tether deployment and retrieval (mother satellite), and the other is a robot having one arm, and the arm end is attached to tether. Mission sequence is follows: firstly two satellites separate by an initial velocity; secondly tether is deployed and retrieved, also daughter satellite controls its attitude by arm motion under tether tension; finally two satellites dock. This paper describes Bread Board Model concept for STARS-I.

1. INTRODUCTION

Tethered Space Robot (TSR), which is connected to a piece of tether, is a new type of space robot system proposed in the previous work [1]. TSR differs significantly from the Tethered Satellite System (TSS) studied so far, mainly in three aspects. First, we assume that the tether is to be extended for a relatively short distance, 10-100m. Second, we do not envision gravity force and/or centrifugal force influencing tether extension. Rather, we will employ tether extension strategy assisted by an initial translation momentum of the subsystem. Third, we envision the tethered subsatellite to be a multi-body system. Major consequence of the multi-body nature of the subsatellite is that its attitude can be controlled under tether tension by its own link motion. This can be done by employing methods borrowed from free-flying space robots studies.

For the purpose of technical verification for TSR, small satellite project, named as Space Tethered Autonomous Robotic Satellite I (STARS-I), started in January 2005 under the leadership of Kagawa University. STARS-I consists of two small cube satellites, one satellite has a function of tether deployment and retrieval (mother satellite), and the other is a robot consisting of one base and one arm (daughter satellite). Main mission to verify TSR technology will be performed as follows: firstly mother satellite ejects daughter satellite by an initial velocity, secondly deploys and retrieves it by tether control, at the same time daughter satellite controls its attitude by arm link motion, and finally mother and daughter satellites dock.

STARS-I project is organized under management section by subsystems as electrical power subsystem, data handling subsystem, telecommunication subsystem, camera subsystem, structure subsystem, deployment subsystem, attitude control subsystem, environment subsystem, and ground station. Electrical power subsystem, data handling subsystem, telecommunication subsystem, camera subsystem, and ground station are bus system, then those subsystems will be developed referring to another cube sat XI-IV by University of Tokyo [2], Cute-I by Tokyo Institute of Technology [3], launched in 2003, or SEEDS by Nihon University to be launched in August 2005. Though another cube sat technology can be also applied to structure subsystem and environmental subsystem, especially in design development withstand heat, vibration, vacuum, and space radiation. On the

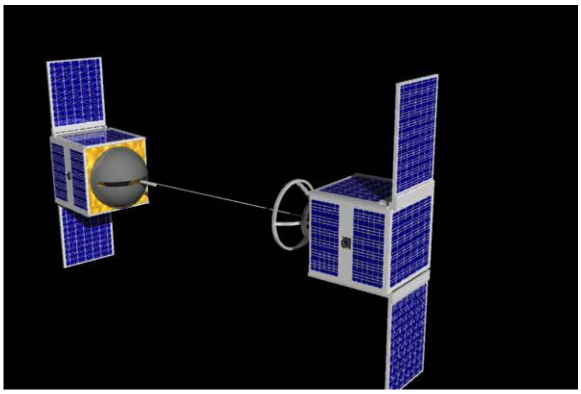

Fig. 1. Image CG for STARS-I

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other hand, structure subsystem has to develop docking mechanism of mother and daughter satellite for deployment and retrieval mission. Besides, environmental subsystem has specific objective to succeed in deployment and retrieval under environment on orbit influenced by gravity gradient torque, magnetic torque, radiation torque, and aerodynamic torque. Deployment subsystem and attitude control subsystem are specific in STARS-I project. Main objective of deployment subsystem is to eject daughter satellite, deploy and retrieve it, and equipments are mounted on mother satellite. On the other hand, main objective of attitude control subsystem is to control attitude of daughter satellite by arm link motion. This paper describes Bread Board Model concept for STARS-I.

2. OUTLINE OF STARS-I

Main mission of STARS-I is to verify technology for TSR. STARS-I consists of two subsatellites called “mother satellite” and “daughter satellite,” respectively. Those satellites are connected through a peace of tether, and tether is deployed for 1m to 10m. The minimum success level is set as:

i) deployment and retrieval of daughter satellite from mother satellite,
ii) attitude control of daughter satellite by arm motion.

Mother satellite has a function to deploy and retrieve of tether, and daughter satellite has TSR function, that is attitude control by its own link motion under tether tension. Experimental mission is performed as:

I) mother satellite gives an initial velocity to daughter satellite;
II) daughter satellite is deployed and retrieved under tether control by mother satellite;
III) daughter satellite docks with mother satellite.

Mother satellite and daughter satellite have following subsystems respectively.

Electrical power subsystem
Data handling subsystem
Telecommunication subsystem
Camera subsystem
Structure subsystem,

Mother and daughter satellites have specific subsystems “deployment subsystem“ and “attitude control subsystem”, respectively.

3. BUS SYSTEM

3.1 Electrical power subsystem

Functions of electrical power subsystem are: generating electrical power by solar panel; charging control of battery; delivering electrical power to other subsystems through data handling subsystem; and monitoring electrical current consumption and temperature of electrical circuit board. Charging control IC controls charging Li-Ion battery. Regulators generate voltages 4.2V, 5.0V, 6.0V to deliver to subsystems. Ammeters and voltmeter monitor at respective points, and thermo sensor monitors temperature of electrical circuit board. Figure 2 shows electrical power subsystem.

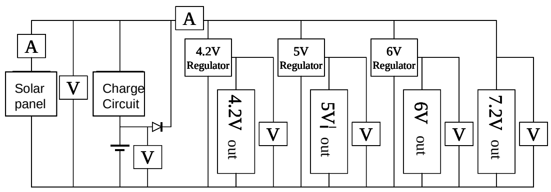

Fig. 2. Electrical power subsystem

3.2 Data handling subsystem

Data handling subsystem operates data among other subsystems, and delivers electrical power from electrical power subsystem to other subsystems. Also, it controls sequences and monitors condition of the satellite. Data of each subsystem is kept in the data handling subsystem, and sent to the ground station through telecommunication subsystem. Also, commands (experimental command, taking picture command, reset command for electrical power subsystem, etc.), from the ground station through telecommunication subsystem are delivered to each subsystem by data handling subsystem.

Data handling systems of mother satellite and daughter satellite are different in deployment subsystem and in attitude control subsystem. Figure 3 shows data handling system of mother satellite, here includes electrical circuit of deployment and retrieval. Then, command and telemetry data, and electrical power for deployment is been handling. Figure 4 shows data handling system of daughter satellite, here includes electrical circuit for attitude control. In both electrical circuits, micro switch informs condition of docking

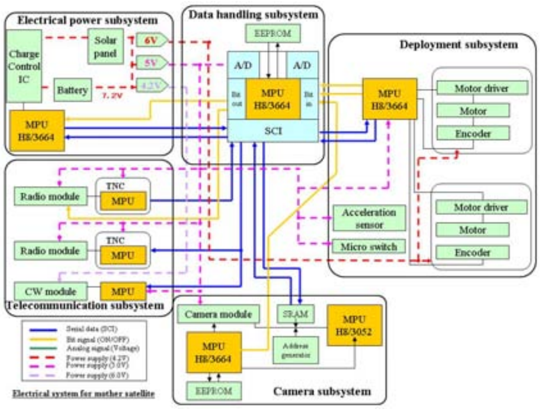

Fig. 3. Data handling of the mother satellite

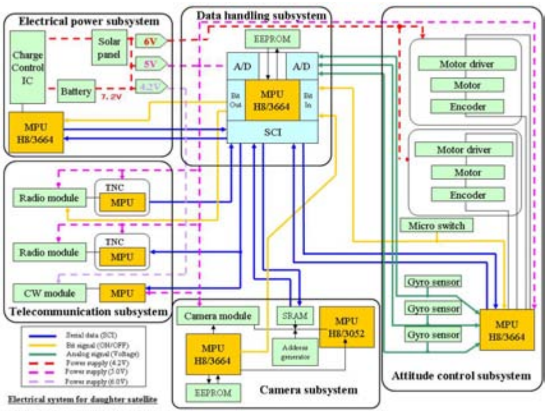

Fig. 4. Data handling of the daughter satellite

and separation, and other sensor data informs motion during experiment.

3.3 Telecommunication subsystem

Figure 3 shows telecommunication subsystem. Three telecommunication components are equipped.

(i) CW transmitter sending house keeping data to ground station:

Data: electric power generation, electric current and voltage of battery, temperature of electrical circuit board, battery, and structure, conditions of experiment, and camera data.

Electrical power: 4.2V delivered from data handling subsystem.

(ii) FM transmitter sending experimental data:

Data: gyro sensor, acceleration sensor, micro switch, encoder, camera data.

(iii) FM receiver to receive command (experimental command) from ground station.

Data: command to take a picture, to start experiment, to send data,
Electrical power: 5.0V

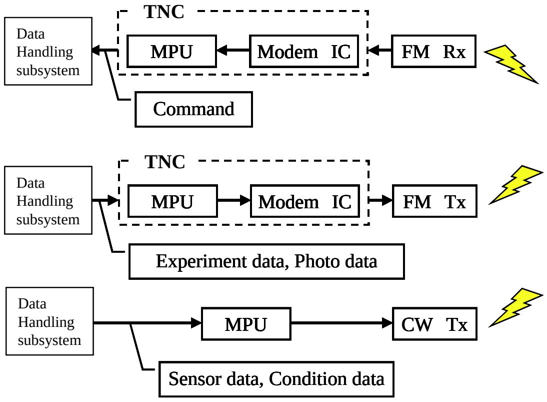

Fig. 5. Telecommunication subsystem

3.4 Camera subsystem

Camera subsystem controls to take a picture of mother satellite and daughter satellite each other during deploy and retrieve experiment, and of the earth. Figure 6 shows camera subsystem. H8 computer receives command to take a picture, then H8 operates CMOS module. Picture data is saved in EEPROM once, and those are sent to ground station through data handling subsystem and telecommunication subsystem when H8 receives command.

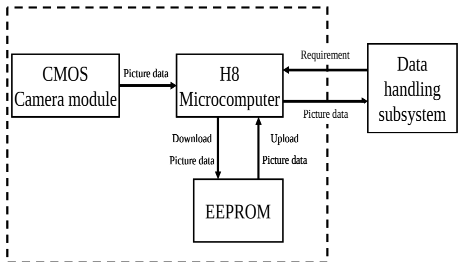

Fig. 6. Camera subsystem

4. MISSION SYSTEM

4.1 Structure subsystem

The main objectives of structure subsystem are to make equipments mounted on the satellite to perform their full functions on the ground, during launch, and on orbit, respectively. Also, it keeps and protects the equipments.

On the other hand, specific configuration of STARS-I has to be considered in structure subsystem. In order to ensure docking of mother and daughter satellites, docking part of daughter satellite is hemisphere, and that of mother satellite is a ball as shown in figure 7. Without high accurate navigation system and sensors, mother and daughter satellites can perform docking by these shapes.

4.2 Deployment subsystem

Deployment subsystem is one of important subsystems for STARS-I mission to verify TSR technology on orbit, and it is mounted on mother satellite. Its main objectives are to give an initial velocity of daughter satellite for deployment, and to deploy and to retrieve daughter satellite by tether control.

Eject unit makes an initial velocity of daughter satellite, here mother satellite has a velocity due to reaction force. Figure 8 shows eject mechanism. Hook attached to motor presses the spring, and hook unlatch the spring, then spring is extended by its potential energy. Thus, bowl supported by the spring gives an initial velocity of daughter satellite.

Deployment unit controls tether deployment and retrieval. It consists of tether reel, motor, and the torque transmission device (permanent wave torque), which keeps constant torque. Tether reel and motor are connected through permanent wave torque. By this mechanism, tether can avoid excessive tension and its sudden change. Basically, tether deployment and retrieval is controlled by motor velocity control. When excessive tension is applied on tether, differential rotation of tether reel and motor are occurred due to the permanent wave torque.

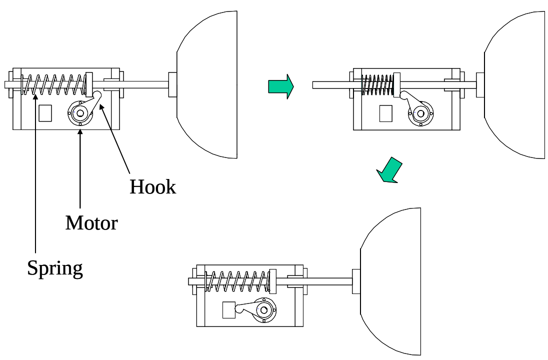

Fig. 8. Eject mechanism

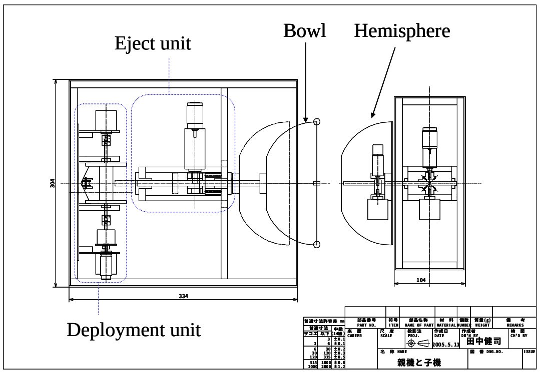

Fig. 7. Structure of STARS-I

4.3 Attitude control subsystem

Attitude control subsystem is very important to employ attitude control function of TSR. Attitude of TSR is controlled by tether tension and positions of the arm end and mass centre of the robot. Since relation of tether extension line and positions of tether attachment point and mass centre of the robot is operated by arm motion, torque due to tether tension acting on the robot can be controlled as shown in figure 9 (planner model). Therefore, two degrees of freedom for arm motion around the axis of tether extension line, and TSR attitude can be controlled around two vertical axes of tether extension line.

In attitude control subsystem of STARS-I, two motors are equipped on daughter satellite as shown in figures 10 and 11. Motor 1 is mounted on the main body of daughter satellite, and actuates the bowl. Its motion is shown in figure 10. Motor 2 is mounted on the bowl, and actuates the arm. Its motion is shown in figure 11.

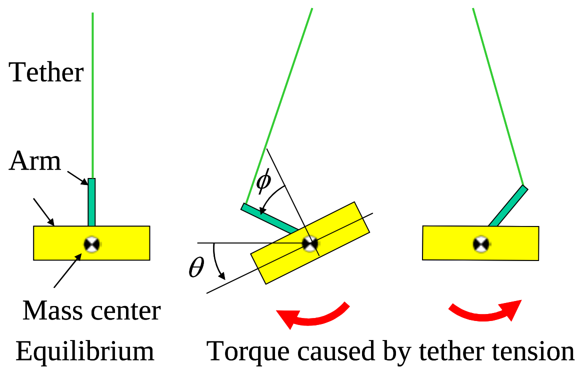

Fig. 9. Attitude control algorithm of TSR

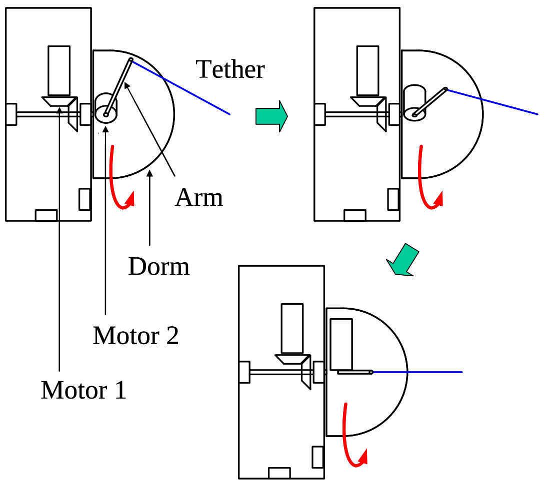

Fig. 10. Actuation of bowl

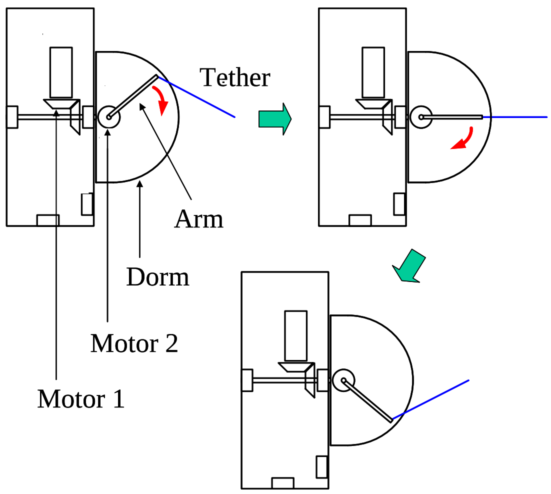

Fig. 11. Actuation of Arm

As a result, the arm end attached to tether can be placed in spatial space, and then attitude control around tether extension line is possible.

5. ENVIRONMENT SUBSYSTEM

Specific objective of environmental subsystem is success in deployment and retrieval under environment on orbit influenced by gravity gradient torque, magnetic torque, radiation torque, and aerodynamic torque. Since tether motion is very sensitive due to its flexibility, it is important to confirm motion and rotation of mother and daughter satellites during deployment and retrieval, influenced by natural external forces under consideration of initial condition of the satellite. Basic analysis on the ground for deployment and retrieval of tether will be performed by numerical simulations. Based on numerical simulation results, mission sequence will be planned.

6. GROUND STATION

Main objectives of ground station is tracking a satellite, securing communication line, and monitoring house keeping data, receiving experimental data and sending experimental command. Downlink data is house keeping data and mission data. House keeping data is mainly CW telemetry: electric power generation, electric current and voltage of battery, temperature of electrical circuit board, battery, and structure, and signals for condition of experiment. Mission data is packet as:

i) gyro data (attitude) from daughter satellite;
ii) acceleration data (position and motion) from mother satellite;
iii) micro switches (docking or separate) of mother and daughter satellites;
iv) encoder data (arm angle) from daughter satellite;
v) encoder data (tether extension length and eject condition) from mother satellite;
vi) pictures data in deployment and retrieval mission, and other pictures.

Uplink data is command to take a picture by camera, to start deployment, to send experimental data, etc.

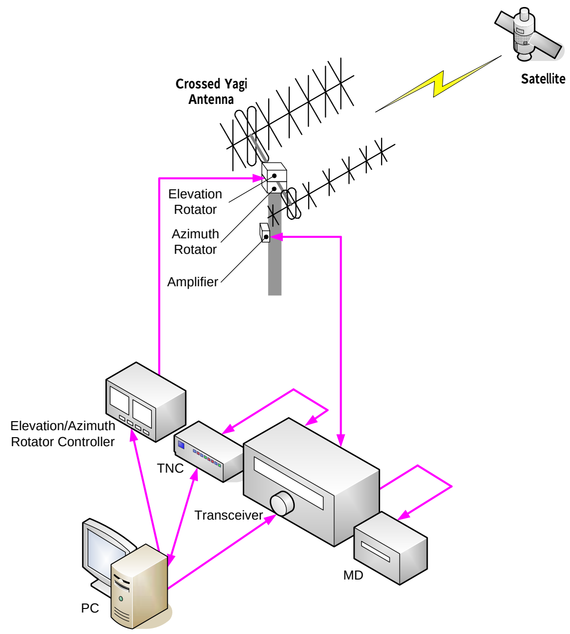

Fig. 12. Ground station

Currently, ground station in Kagawa is located at Takamatsu National College of Technology

7. SUMMARY

This paper has described Bread Board Model concept for STARS-I. STARS-I project is organized under management section by subsystems as electrical power subsystem, data handling subsystem, telecommunication subsystem, camera subsystem, structure subsystem, deployment subsystem, attitude control subsystem, environment subsystem, and ground station. Electrical power subsystem, data handling subsystem, telecommunication subsystem, camera subsystem, and ground station are bus system. Structure subsystem and environmental subsystem have to be developed for withstand heat, vibration, vacuum, and space radiation. On the other hand, structure subsystem has to develop docking mechanism of mother and daughter satellite for deployment and retrieval mission. Besides, environmental subsystem has specific objective to succeed in deployment and retrieval under environment on orbit influenced by gravity gradient torque, magnetic torque, radiation torque, and aerodynamic torque. Deployment subsystem and attitude control subsystem are specific in STARS-I project. Main objective of deployment subsystem is to eject daughter satellite, deploy and retrieve it, and that of attitude control subsystem is to control attitude of daughter satellite by arm link motion.

8. REFERENCES

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