Technical Verification Satellite "STARS" for Tethered Space Robot

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Abstract

The Space Tethered Autonomous Robotic Satellite (STARS) is being developed in Kagawa University and it will be launched by the H-IIA rocket by Japan Aerospace Exploration Agency (JAXA) in summer 2007. The main purpose of the STARS is technical verification for a tethered space robot proposed in 1995. The STARS consists of mother and daughter satellites connected by tether. The mother satellite deploys tether having the daughter satellite, which is a tethered space robot. Attitude of the daughter satellite is controlled by its own arm link motion, and the camera mounted on the daughter satellite takes a picture of the mother satellite during deployment. The STARS requires following techniques: (I) short tether deployment by initial velocity given by the mother satellite; (II) attitude control of the daughter satellite by its own link motion; (III) taking a picture of the mother satellite by the daughter satellite during tether deployment; (IV) inter satellite communication for cooperation control of tether deployment by the mother satellite and arm motion by the daughter satellite.

1. Introduction

The Space Tethered Autonomous Robotic Satellite (STARS) has been developed since January 2005 under the leadership of the Kagawa Satellite Development Project in the Kagawa University. The main objective of the STARS is technical verification for a tethered space robot. A tethered space robot is a new type of space robot system proposed in the previous work [1], [2]. It differs significantly from the Tethered Satellite System (TSS) studied so far [3], [4], mainly in three aspects. First, we assume that the tether is to be extended for a relatively short distance. 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 [5], [6].

The STARS consists of a mother satellite and a daughter satellite connected by tether as shown in figure 1. Tha mother satellite is a tether deployment system, and deploys the daughter satellite and retrieve it. The daughter satellite is a tethered space robot, and has one arm link attached to the tether at its end. Attitude control by arm link motion using tether tension is possible, then the camera mounted on the daughter satellite can be controlled for its orientation. Hence, the daughter satellite takes a picture of the mother satellite during tether deployment. Arm link motion of the daughter satellite should be controlled, after the daughter satellite released from the mother satellite, and before they docks each other. Also the camera of the daughter satellite should take a picture

Fig. 1: STARS

when tether length is long. Therefore, inter satellite communication is needed for performing the mission.

The main mission deploying a tethered space robot is described in section 2. Mechanical and electrical systems of the STARS are described in section 3 and 4, respectively. Section 4 explains separation mechanism from the rocket.

2. Deployment mission

The STARS will be normaly operated under docking condition, and the mother and the daughter satellites separated away only when the main mission performed during raoughly 30 seconds. Seaquence of the main mission is shown in figure 2. The mission begins based on the command from the ground station (Phase A). At first, electrical power is supplied to mission devices. Since tether deployment and robot motion are controlled by motor actuation and they need high electrical power, the electrical power is supplied only during the mission. Next, the mother satellite releases the daughter satellite, and the daughter satellite begins to control its attitude by arm link motion (Phase B). The daughter satellite, whose attitude is controlled during deployment, takes a picture of the mother satellite when tether length becomes to be long enough (Phase C). Finally, the daughter satellite docks with the mother satellite (Phase D). After the mission is terminated, mission data and picture data are transmitted to the ground station.

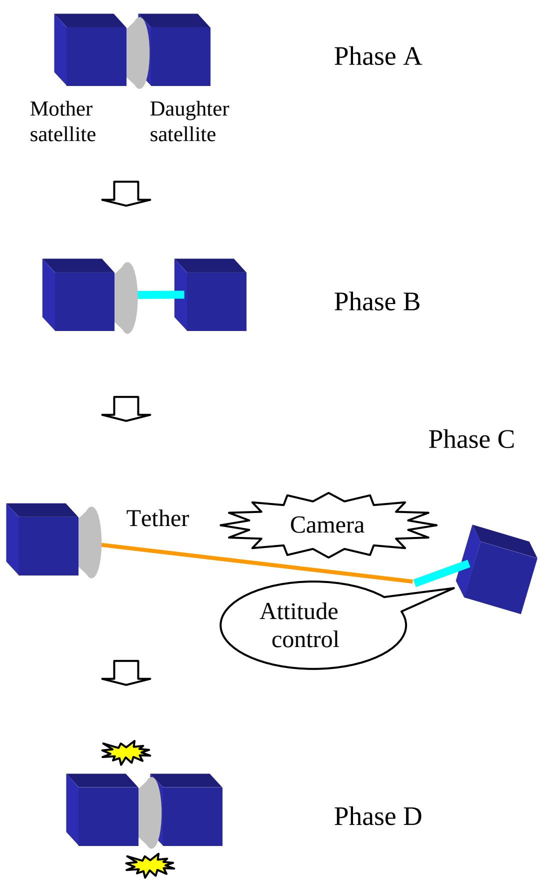


Fig. 2 Mission sequence

Here explains attitude control of the daughter satellite by arm link motion. Let's consider a simple planer model for a tethered space robot consisting of one base and one link arm as shown in figure 3. Base attitude is in equilibrium when the mass center of the robot is located on tether extension line. Tether tension torque acts on the robot when the mass center deviates from tether extension line. Because tether is attached to the end of the arm link, the tether tension torque can be controlled by arm link operation. It is noted that attitude control is possible around vertical axes with respect to tether extension line, and also the arm link should have two degrees of freedom.

3. Mechanical system

As shown in figure 1, the STARS consists of the mother satellite which is the tether deployment system in the right hand, and the daughter sattelite which is a tethered space robot in the left hand. Spacifications of the STARS are:

Mother satellite

Mass:	4.0kg
Length:	160 x 160 x 300 mm

(without antenna, solar paddle)

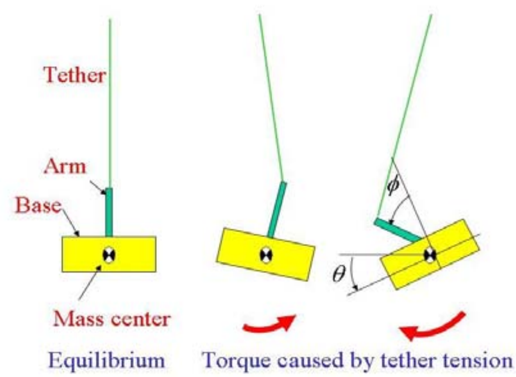


Fig. 3: Attitude control by arm link motion

Daughter satellite

Mass: 3.0kg

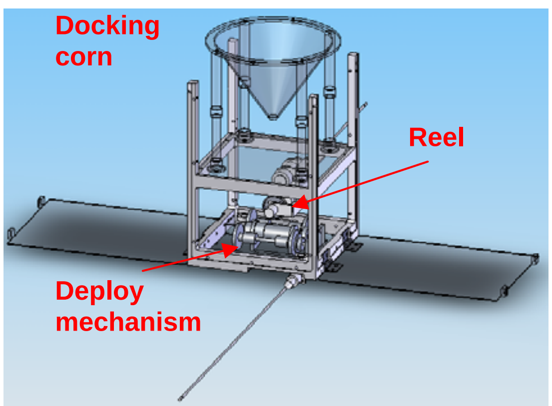
Length: 160 x 160 x 120mm

(without antenna, solar paddle, arm link)

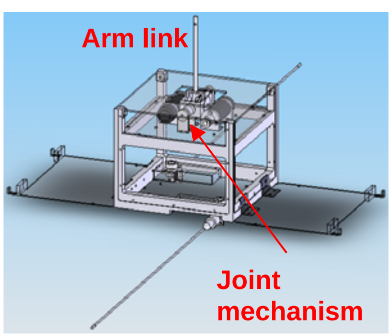
Figure 4 shows main mechanisms of the STARS. The mother satellite concicts of deploy mechanism, reel mechanism, and docking corn. The daughter satellite has one link arm, which is actuated by a joint mechanism.

A. *Deploy mechanism*

The release mechanism mounted on the mother satellite gives an initial translation velocity to the daughter satellite. As shown in figure 5, the release subsystem consists of springs, wires, their pulleys, and one motor whose gear has gearless parts. First, the wires are wound up by pulleys rottated by the motor. When the wires are wound enough, the gearless part of the motor comes to pulley gears, then the pulleys rotate freely. Then springs are extended. As a result, initial translation velocity is given to the daughter satellite. This seaquence is repeatable, therefore the deployment mission can be performed maniy times on orbit.



Mother satellite



Daughter satellite

Fig. 4: Mechanical system

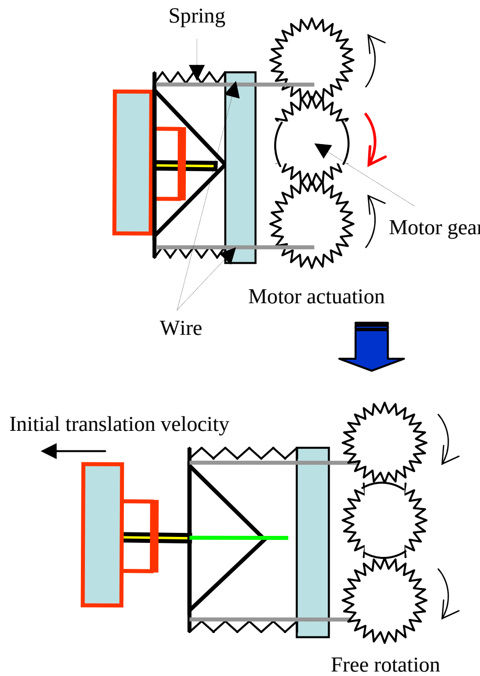


Fig. 5: Deploy mechanism

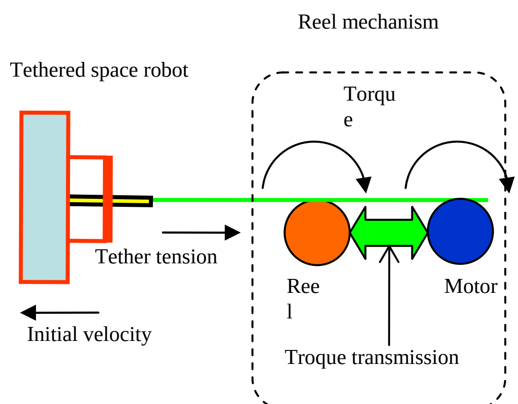


Fig. 6: Reel mechanism

B. *Reel mechanism*

The reel mechanism controls tether tension during deployment and retrieval of the daughter satellite. Tether is deployed and retrieved by the reel rotated at constant torque, which is controlled by the torque transmission device actuated by the motor. As a result, the daughter sattelite is deployed and retrieved

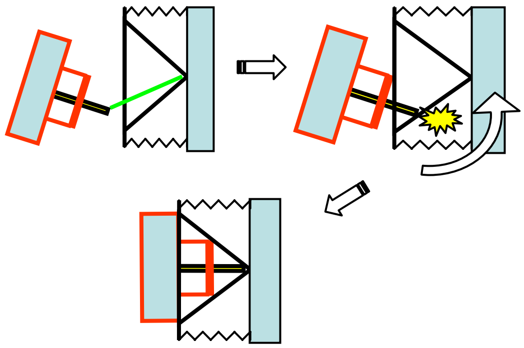


Fig. 7: Docking mechanism

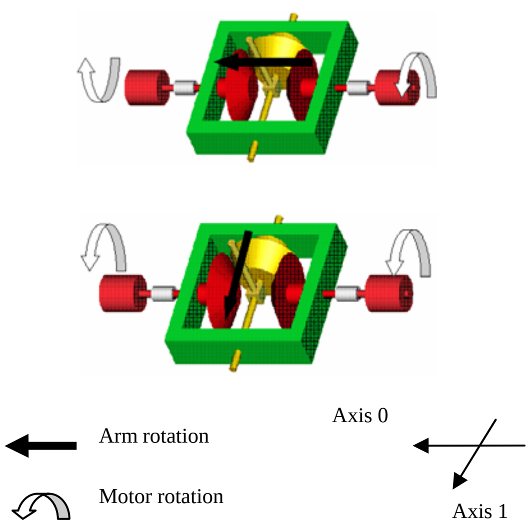


Fig. 8: Joint mechanism

at constant tether tension, that is, excessive tether tension change can be avoided.

C.   Docking corn

The daughter and the mother satellites docks at the end of the deployment mission. Docking corn equipped on the mother satelllite makes it possible to dock with the daughter satellite smoothly and keep relative attiude of both satellites under condition that the daughter satellite keeps the arm link at normal position. Docking motion is illustrated in figure 7.

D. Joint mechanism

For the purpose of attitude control of vertical axes of tether extension line, the STARS employs a deferential gear mechanism as shown in figure 8. Rotation axes of two motors are same, and it is denoted by axis 0, and axis 1 is vertical to it. The two motors fixed on the satellite body. Both motors rotate as in the upper figure, the arm link rotates around the 1 axis, and when the two motors rotate as in the below figure, the arm link rotates around the 0 axis, respectively.

4. Electrical systgem

Figure 8 shows electrical system of the STARS. It consists of electrical power subsystem (EPS), communication subsystem (COMM), control & data handling subsystem (C&DH), and camera subsystem (CAMERA). The whole electrical system is mounted on each satellite. Therefore, the mother and the daughter satellites are independent radio stations. Communication link of the STARS is shown in figure 9. One ground station set up at the Kagawa University operates the two satellite stations, and downlink is possible at amateur radio stations over the world through amateur radio frequencies. The two satellites communicate inter-satellite communication through the Bluetooth. The STARS uses the inter satellite communication for the deployment mission, and also for attitude control by magnetic torquer. In the deployment mission, the mother satellite controls two motors for the deployment and the reel mechanisms, on the other hand, the daughter satellite controls two motors for the joint mechanism. Then, the same electrical hardware can be applied to both satellites, and control software should be implemented for each control.

The electrical power subsystem performs generating electricity by solar cells, charging and discharging batteries, and managing voltage for delivering electricity to other subsystems. Characteristics of the EPS are follows: batteries power is necessary to actuate motors; and the minimum function, which is communication with the ground station, is operated only by solar power.

The communication subsystem communicates with the ground station through amateur radio frequencies. Basic function of the COMM is transmitting FM telemetry data from the C&DH, and receiving command from the ground station and sending it to the C&DH. Also, the COMM can reset the C&DH. When electrical power is very small, the STARS performs only CW downlink. At that time, only the EPS and the COMM are working.

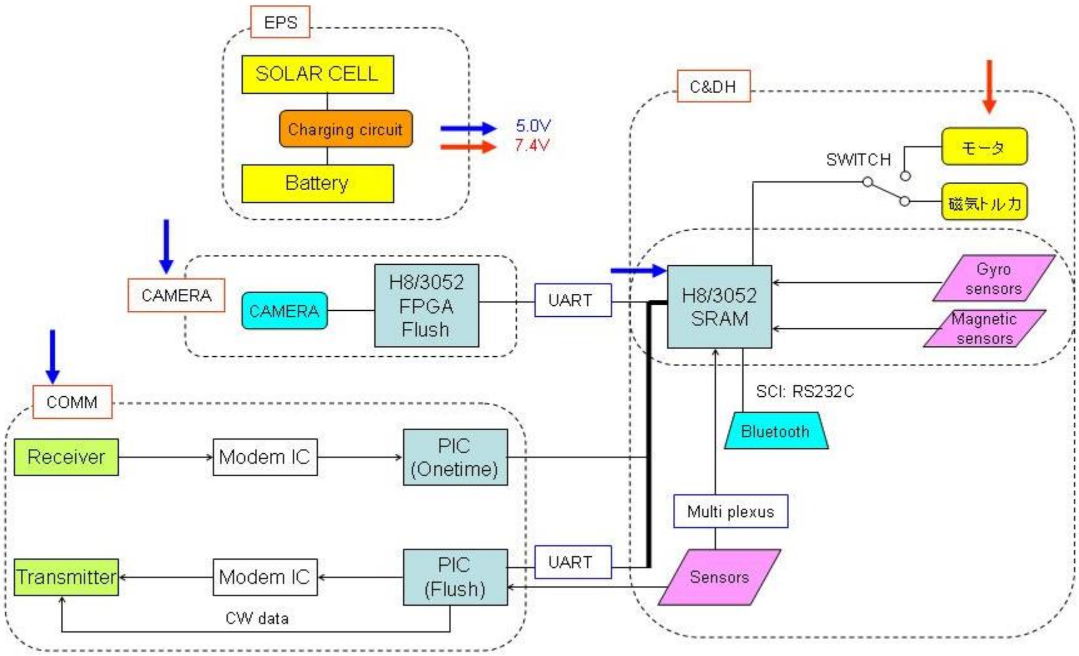


Fig. 9: Electrical system

The control & data handling performs data handling of the STARS, control of the deployment mission, and control of camera. Sensor data is temporally memorized on the C&DH, and transmitted to the ground station by the ground command. The deployment mission is started by the ground command, and performed based on cooperation control by inter satellite communication through the Bluetooth. Also, the C&DH manages electrical power to deliver to the CAMERA and the motors which consume much power.

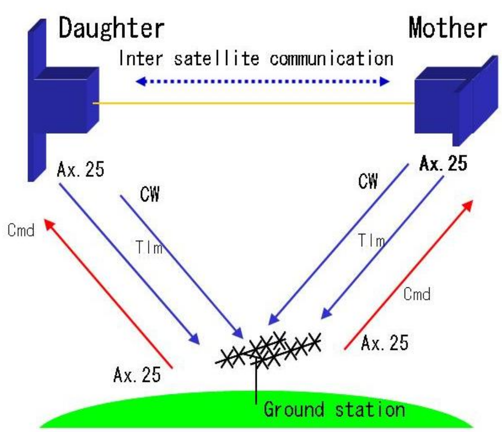


Fig. 8: Communication link

5. Separation mechanism on the rocket

Figure 9 shows configuration of the STARS mounting on the rocket. The STARS stowed in the separation box completely under docking condition of the mother and the daughter satellites. The top cover is closed by nylon line, and the side cover is closed by mechanical stopper. The separation box deployed as

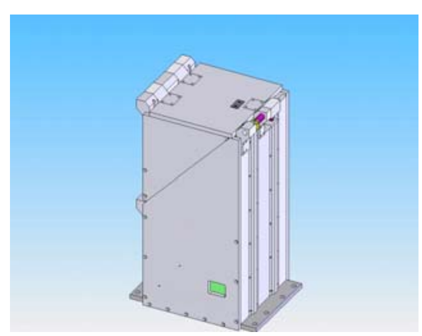


Fig. 9: Separation box

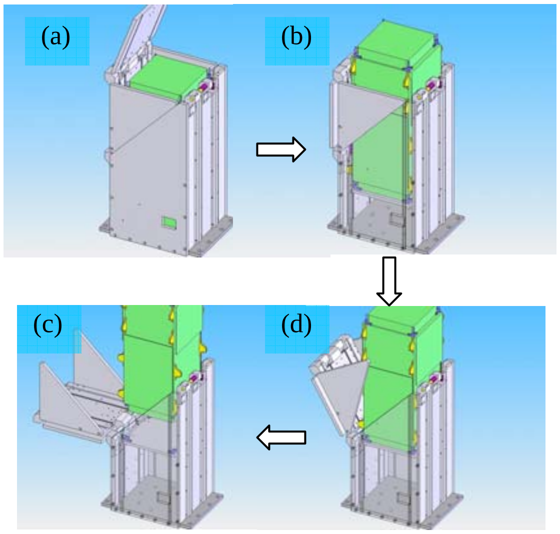


Fig. 10: Separation sequence

shown in figure 10. First, the top cover is opened by cutting the nylon line by heater cutter. In the same time, the bottom plate, where the STARS is mounted on, moves upward due to spring force. The bottom plate is stopped at the middle height of the box, and then the side cover is opened by releasing the mechanical stopper by the bottom plate. Then, the STARS is separated from the rocket.

Configuration of the STARS just after separation from the rocket is shown in figure 11-(a). The antennas are stowed by nylon line, and the solar paddles are stowed by electrical release attachment. Also, the mother and the daughter satellites are fixed by electrical release attachment. First, the antennas are deployed autonomously by cutting nylon line by heater cutter as shown in figure 11-(b). The solar paddles are deployed by ground commanding. Finally, the mother and the daughter satellites are separated.

6. Conclusion

This paper describes the Space Tethered Autonomous Robotic Satellite (STARS). The STARS is being developed for technical verification of a tethered space robot, which is a new space system. The STARS mission and its mechanical and electrical system have been explained. Microgravity experiment of the STARS was performed for verification and evaluation of the orbital mission.

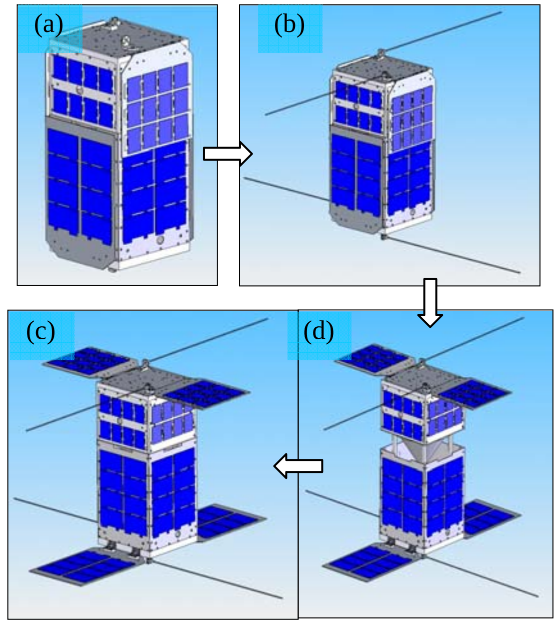


Fig. 11: Initial sequence

7. Acknowledgment

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8. References

[1] M. Nohmi, D. N. Nenchev and M. Uchiyama, "Tethered Robot Casting Using a Spacecraft mounted Manipulator," AIAA Journal of Guidance, Control, and Dynamics, 24-4, 2001, 827-833.

[2] M. Nohmi and S. Yoshida, "Experimental Analysis for Attitude Control of a Tethered Space Robot under Microgravity," Space Technology, Vol. 24, No. 2-3, pp. 119-128, 2004.

[3] P. M. Bainum and V. K. Kumar, "Optimal Control of the Shuttle-Tethered-Subsatellite System," Acta Astronautica, 7-6, 1980, 1333-1348.

[4] V. J. Modi, P. K. Lakshmanan and A. K. Misra, "On the Control of Tethered Satellite Systems," Acta Astronautica, 26-6, 1992, 411-423.

[5] Z. Vafa and S. Dubowsky, "On the Dynamics of Space Manipulators Using the Virtual Manipulator, with Applications to Path Planning," The Journal of the Astronautical Sciences, **38**-4, 1990, 441-472.

[6] Y. Umetani and K. Yoshida, "Resolved Motion Rate Control of Space Manipulators with Generalized Jacobian Matrix," IEEE Transaction on Robotics and Automation, **5**-3, 1989, 303-314.