STARS-II MISSION DESIGN FOR SPACE EXPERIMENT OF TETHERED ROBOTIC SYSTEM
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ABSTRACT

STARS-II is a pico-satellite which will launch by H-IIA rocket of the Japan Aerospace Exploration Agency on 2013. The primary object of STARS-II is technical verification of tethered robotic system. STARS-II consists of Mother Satellite and Daughter Satellite connected by Electro Dynamic Tether. STARS-II has actuators in order to perform tether deployment and robotic mission. Main missions on STARS-II are follows. 1) Electro Dynamic Tether deployment by gravity gradient. 2) Electrical current gathered by Electro Dynamic Tether. 3) Attitude is controlled by arm link motion based on tether tension due to gravity gradient. 4) Tether deployment and retrieval by tether tension control. In this paper, detail of mission design is described.

1. INTRODUCTION

The tethered space robot is a new type of space robot system proposed in previous work [1]. It differs significantly from the Tethered Satellite System (TSS) studied so far [2], [3] in three aspects. First, we assume that the tether is to be extended at a relatively short distance. Second, we do not envision either gravity force or centrifugal force to be an influence on the tether extension. Instead, we employ a tether extension strategy assisted by the initial translation momentum of the subsystem. Third, we envision the tethered subsatellite to be a multi-body system. The major advantage 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 applying methods developed in free-flying space robot studies [4], [5].

Many times of microgravity experiment for a tethered space robot have been performed by parabolic flight by an airplane, by a drop capsule [6] and by sounding rocket.

In recent years, space debris is growing into a serious problem. And it is necessary to remove space debris. Electric Dynamic Tether is effective technique for removing space debris.

Therefore, the primary object of STARS-II is defined technical verification of Electric Dynamic Tether system and tethered robotic system. This paper describes detail of mission design and mission system.

2. MISSION on STARS-II

Main missions on STARS-II are follows.

I: Electro Dynamic Tether deployment by gravity gradient.

It is necessary to deploy Daughter Satellite toward the Earth for the experiment of Electro Dynamic Tether. Therefore, Mother Satellite and Daughter Satellite attitude are controlled under the docking condition. Attitude is controlled by magnetic torque and torque by tension control system. While Daughter Satellite is faced the Earth, Electro Dynamic Tether is deployed by initial velocity applied by the deployment springs. And then, whole system can be stabilized by gravity gradient.

II: Electrical current gathered by Electro Dynamic Tether.

Electrons in space plasma are gathered by Electro Dynamic Tether which is a bare tether, and they are emitted from Daughter Satellite. As a result, electrical current is passed through Electro Dynamic Tether.

III: Attitude is controlled by arm link motion based on tether tension due to gravity gradient.

Daughter Satellite controls its attitude by arm link motion using tether tension (on Electro Dynamic Tether), which is applied by gravity gradient.

IV: Tether deployment and retrieval by tether tension control.

Electro Dynamic Tether is connected to Kevlar tether at its end. By tension control of Kevlar tether by the reel, relative positions of Mother Satellite and Daughter Satellite can be controlled.

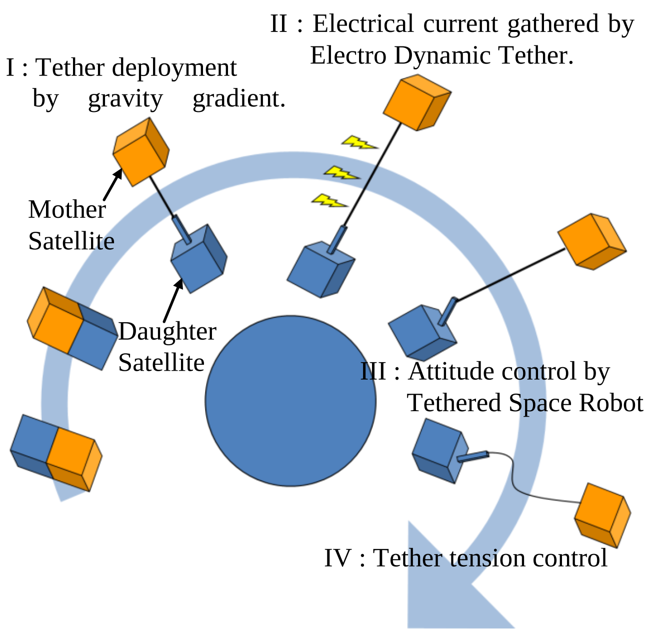

Figure 1 Mission overview

3. Success Level on STARS-II

Success levels on STARS-II are follows.

Table 1 Success Level on STARS-II

Level	Requirement
Minimum	Orbit injection
	Status monitor by HK data
Mission	Attitude is controlled under the docking condition.
	Tether deployment
	Stabilization by gravity gradient
Full	Electrical current gathered by Electro Dynamic Tether
	Attitude is controlled by arm link motion based on tether tension due to gravity gradient
	Tether deployment and retrieval by tether tension control
Spin Off	Technology exchange between radio ham and students
	Passing of skill in student project
	Organize event at community
	Create space community
	Development of satellite in cooperation between the public, private and academic sectors at community

1) Minimum success

Minimum success is defined as technical learning for development and operation. In this level, requirements are demonstrated on KUKAI.

・Orbital injection

・Status monitor by HK data

After satellite enter orbit, Satellite start transmit the HK data.

2) Mission success

Mission success is defined as technical verification of tether deployment and stabilization by gravity gradient.

・Attitude is controlled under the docking condition.

Attitude is controlled by Torque on Tether reel motor and magnetic torque. Attitude is estimated by gyro sensor, magnetic sensor and current sensor of solar cell.

・Tether deployment.

While Daughter Satellite is faced the Earth, Electro Dynamic Tether is deployed by initial velocity applied by the deployment springs. Distance of Mother Satellite and Daughter Satellite is measured by GPS.

・Stabilization by gravity gradient.

Tether consists of Electric Dynamic Tether and Kevlar tether. While Electric Dynamic Tether deployment, tension is micro. Therefore Daughter Satellite almost never rebound. After deployed Electric Dynamic Tether, Kevlar tether is deployed. All Kevlar tether is deployed, over tension is generated. Thus, diminish the velocity of deployment by tension control.

3) Full success

Full success is defined as technical verification of Electric Dynamic tether system and tethered space robot on pico-satellite.

・Electrical current gathered by Electro Dynamic Tether.

While stabilization by gravity gradient, generate induced electromotive force by earth magnetic field. And electric current is gathered by emission of electron.

・Attitude is controlled by arm link motion based on tether tension due to gravity gradient.

While stabilization by gravity gradient, Attitude is controlled by arm link motion based on tether tension due to gravity gradient. Quick motion of arm generates over tension, and disturb satellite attitude in stabilization by gravity gradient.

・Tether deployment and retrieval by tether tension control.

Electro Dynamic Tether is connected to Kevlar tether at its end. By tension control of Kevlar tether by the reel, relative positions of Mother Satellite and Daughter Satellite can be controlled.

4) Spin off success

Spin off success is defined as development of satellite at community.

・Technology exchange between radio ham and students .

Satellite telemetry data and Pictures are transmitted to ground stations through amateur radio frequency.

・Passing of skill in student project

・Organize event at community

・Create space community

・Development of satellite in cooperation between the public, private and academic sectors at community

Passing of skill in student project

4. STARS-II

3.1. Outline of STARS-II

STARS-II consists of Mother Satellite and Daughter Satellite. Mother Satellite has tether deployment system and tension control system. Daughter Satellite has tethered robot system.

Figure 2 shows the flight model of STARS-II. The left and the right show the daughter and the mother satellites, respectively, and they are connected by tether. Each satellite has two paddles for mounting solar battery cells, antenna and GPS system. The scale and the mass are:

Mother satellite
Mass: 5.0 kg
Length: 160 x 160 x 253 mm
(without solar paddles and cone).

Daughter satellite
Mass: 4.0 kg
Length: 160 x 160 x 158 mm
(without solar paddles and arm link).

Figure 2 STARS-II

3.2. Tether Deployment System

Figure 3 shows tether deployment system equipped on the mother satellite. The ring is supported by 4 springs which are compressed. Therefore springs are extended and the ring is pushed up, then the daughter satellite is deployed. Electric Dynamic Tether is turned around spool. Spool is arm of tethered space robot. After deployment Electric Dynamic Tether, Kevlar tether is deployed. Kevlar tether is turned around tether reel.

Electric Dynamic Tether is deployed about 300m, and its end attached Kevlar tether. Tether deployment system by spool has been repeatedly tested on SPRINT-A.

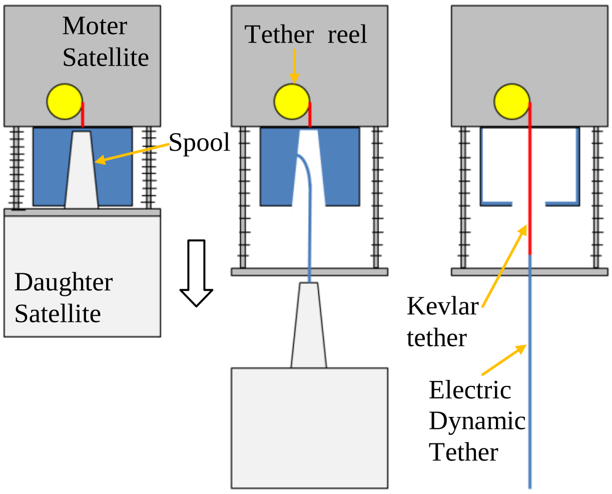

Figure 3 Tether deployment system

3.3. Tension Control System

Electric Dynamic Tether is turned around spool. Spool is arm of tethered space robot. After deployment Electric Dynamic Tether, Kevlar tether is deployed. Kevlar tether is turned around tether reel. Electro Dynamic Tether is connected to Kevlar tether at its end. While Electric Dynamic Tether deployment, tension is micro. Therefore Daughter Satellite almost never rebound. After deployed Electric Dynamic Tether, Kevlar tether is deployed. All Kevlar tether is deployed, over tension is generated. Thus, diminish the velocity of deployment by tether tension control.

Tether tension is controlled to be constant by tether reel system. As shown in figure 5, the tether reel system consists of a tether reel and a reel motor [2224-006SR (3.71:1): Minimotor SA] connected through torque transmission device [Permanent wave torque EC: Koshin Seikosho Co. Ltd.], which transmits constant torque from the reel motor to the tether reel, then tether is controlled tension.

Electric Dynamic Tether is turned around spool. Spool is arm of tethered space robot. After deployment Electric Dynamic Tether, Kevlar tether is deployed. Kevlar tether is turned around tether reel.

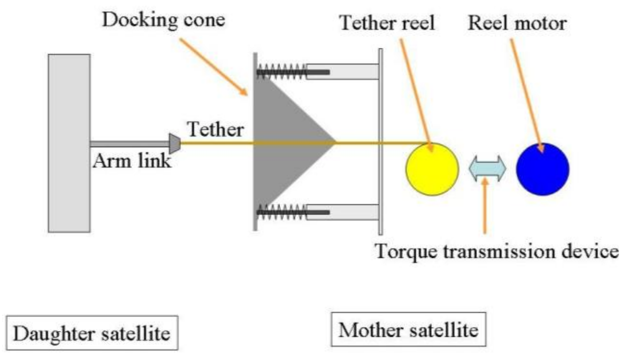

Figure 4 Tether reel System

3.4. Robotic system

First, let us consider a simple planer model for a tethered space robot consisting of one base and one arm link, as shown in Figure 5. The base attitude is in equilibrium when the mass center of the robot is located on the tether extension line. Tether tension torque acts on the robot when the mass center deviates from the tether extension line. Because the tether is attached to the end of the arm link, the tether tension torque can be controlled by arm link operation. It should be noted that attitude control is possible around the vertical axes with respect to the tether extension line, and the arm link needs two degrees of freedom. Here, let's consider the following simple PD control for attitude of the base:

$$\phi = k_{p\theta}(\theta - \theta_c) + k_{d\theta}(d\theta / dt) \tag{1}$$

where θ and ϕ denote base attitude angle and arm link angle with respect to the base, respectively. θ_c denotes the desired attitude, and $k_{p\theta}$ and $k_{d\theta}$ denote control gains, respectively. By employing equation (3), attitude of the base around tether extension line can be controlled. The first term $k_{p\theta}(\theta - \theta_c)$ cannot damp rotational vibration of the base around equilibrium, though it can cause large tether tension torque toward the equilibrium. In order to suppress rotational vibration, the second term $k_{d\theta}\, d\theta / dt$ is necessary.

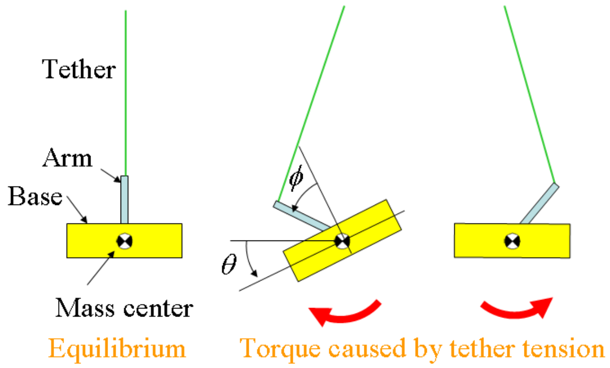

Figure 5

For the purpose of attitude control of the vertical axes of the tether extension line, the differential gear mechanism is employed as shown in Figure 6. It consists of three pinion gears. Two red gears fixed to the input shafts, and one yellow gear fixed to the arm link. By rotation input as shown in the left figure, the yellow gear rotates, and then the arm link rotates. By rotation input as shown in the right figure, the yellow gear does not rotate, and then the arm link rotates with the green frame. By employing the differential gear mechanism, the two arm motors can be fixed on the robot body. Gear ratio of the red one and the yellow one is 1:2. Therefore relation of arm angle and motor rotation is defined by the following equations:

$$\phi_y = (\psi_0 + \psi_1)/4, \tag{2}$$
$$\phi_z = (\psi_0 - \psi_1)/2, \tag{3}$$

where ϕ_y and ϕ_z denote arm angles in the y axis and the z axis, respectively. ψ_0 and ψ_1 denote rotation of motor 0 and motor 1, respectively.

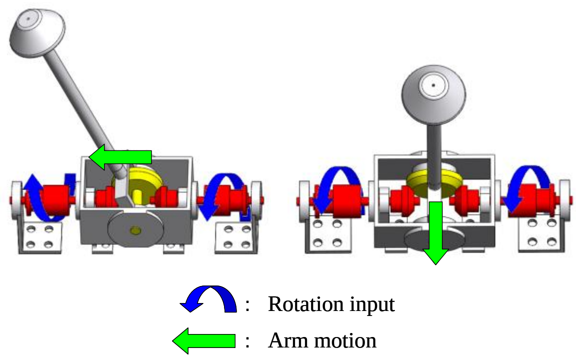

Figure 6

5. CONCLISION

This paper describes detail of mission, the tether deployment system, tension control system and robotic system of STARS-II.

6. REFERENCE

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