Initial Orbital Performance Result of Nano-Satellite STARS-II

M. Nohmi*

* Shizuoka University/ Kagawa University, Japan
e-mail: nohmi@eng.kagawa-u.ac.jp

Abstract

STARS-II was launched on 28 February 2014, as one of piggy bag satellites by the H-IIA rocket. It had been developed in Kagawa University.STARS-II consists of Mother Satellite (MS) and Daughter Satellite (DS) connected by Electro Dynamic Tether (EDT). MS deploys EDT having DS at its end. DS is a tethered space robot, and it has one arm whose end is attached to the EDT. Main missions are follows: (1) Electro Dynamic Tether (EDT) deployment by gravity gradient, (2) gathering electrical current by EDT, (3) Attitude control by arm link motion under tether tension by gravity gradient, (4) Tether deployment and retrieval by tether tension control. Unfortunately, STARS-II mission could not achieved perfectly under current status on the mid of April 2014. However, the STARS-II condition can be inferred by telemetries through CW beacons and change of orbit. This paper reports these results.

1 Introduction

Tethered space robot is a new type of space systems connected to tether, proposed in 1995 [1]. It has several advantageous characteristics comparing to existing space robots and tethered systems [2]-[5]. In the past, two kinds of space verification experiments were performed for a tethered space robot. The first satellite of Kagawa University "STARS," which is shown in figure 1, was launched by the H-IIA rocket on 23 January 2009 [6]. It is a mother-daughter satellite, a tethered satellite, and also a robotic satellite. These three main characteristics have been evaluated and verified on orbit, though attitude control for a tethered space robot could not be performed due to shorter tether extension than expected. On 31, August, 2010, TSR-S (Tethered Space Robot -S), which is shown in figure 2, was launched by the sounding rocket S-520-25 from Uchinoura Space Centre by JAXA [7]. One of S-520-25 experiments is for a tethered space robot. The proposed attitude control approach for disturbances suppression and change of the desired attitude for a tethered space robot have been evaluated and verified.

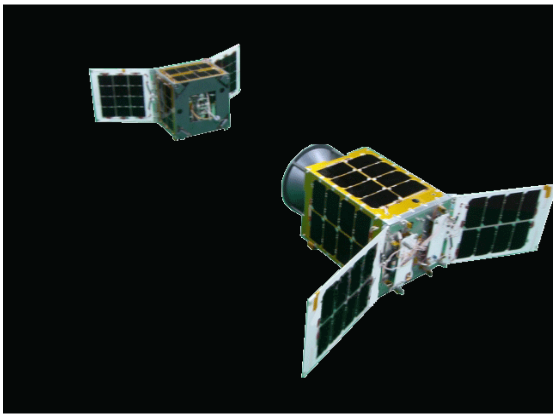

Figure 1. STARS.

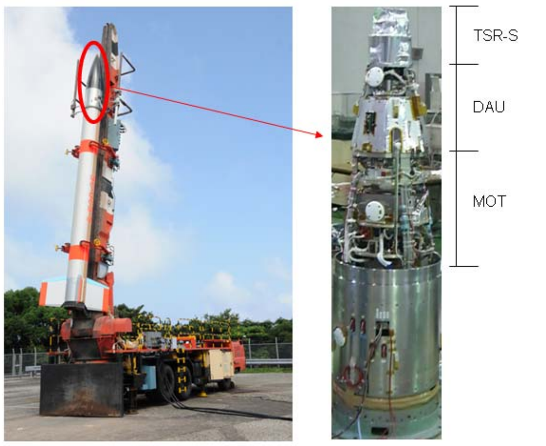

Figure 2. TSR-S on the sounding rocket S-520-25.

Here proposes active debris removal by a tethered space robot. Figure 3 shows a novel mission sequence. First, the spacecraft extend an Electro Dynamic Tether (EDT) by gravity gradient. Second, the tethered space robot at the end of EDT approaches space debris and catches it. Third, translating the tethered space robot having the debris toward the earth, the whole system of the spacecraft is transferred to lower earth orbit by EDT Laurent force. Finally, the debris enters the atmosphere after releasing by the tethered space robot.

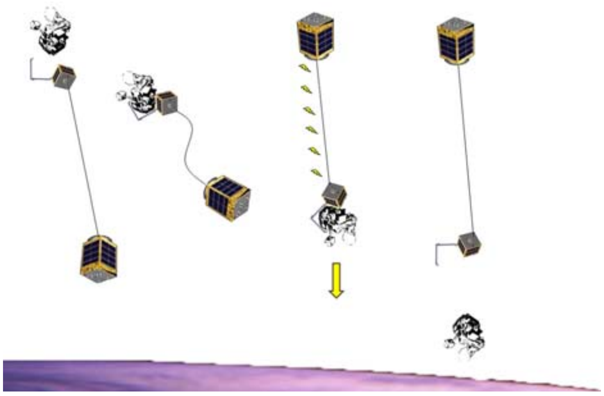

Figure 3. Debris removal by a tethered space robot.

The second satellite of Kagawa University is "STARS-II," which was launched by the H-IIA rocket on 28 February 2014. The main objective is to evaluate and verify the basic technologies for active debris removal: the first is tether deployment by gravity gradient; and the second is to gather electrical current on EDT. Also, tether tension control and tethered space robot control are expected to be demonstrated.

Unfortunately, STARS-II mission could not achieved perfectly under current status on the mid of April 2014. However, the STARS-II condition can be inferred by telemetries through CW beacons and change of orbit. This paper reports these results.

2 Outline of STARS-II

Figure 4 shows image of STARS-II. The planned orbit is planned as 407km altitude and 65 degrees inclination. It consists of Mother Satellite (MS) and Daughter Satellite (DS) connected by Electro Dynamic Tether (EDT). MS deploys EDT having DS at its end. DS is a tethered space robot, and it has one arm whose end is attached to the EDT. Each satellite has two paddles for mounting solar battery cells and antennas. The scale and the mass are:

Mother satellite (without solar paddles, deployment mechanism, and projections)

Mass: 4.2 kg

Length: 160 x 160 x 253 mm

Daughter satellite (without solar paddles, arm link, and projections)

Mass: 3.8 kg

Length: 160 x 160 x 158 mm

Main missions and their sequences are illustrated in figure 5.

Figure 4. STARS-II image.

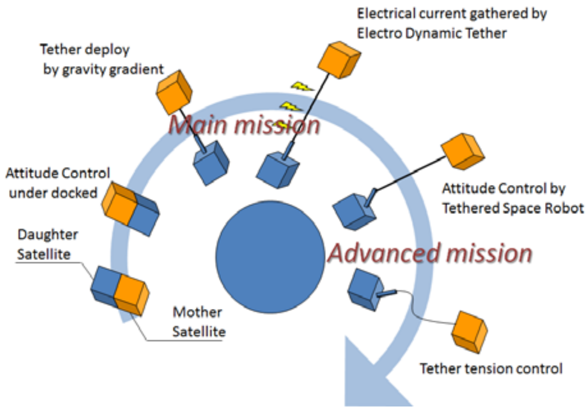

Figure 5. Mission sequence of STARS-II.

3 Mission Devices

3.1 Tether mounted on Mother

Figure 6 shows separation sequence of mother and daughter satellites. The left figure shows docking configuration mounted on the rocket. After separation from the rocket, mother and daughter satellites automatically deploy solar paddles and antennas. After initial checking out, tether deployment mission will be performed. Tether deployment is performed by the command from the ground station.

Figure 7 shows tether deployment device. Electrodynamic Tether (EDT) is 300m bare tether of aluminum code strand, and it stowed on the spool, which is arm link of the daughter satellite, and in the box mounted on the mother satellite. One end of EDT is attached to the top of the arm link, and the other end is connected to Kevlar tether (50m). Kevlar tether is stowed on the reel system, which can control tether tension by torque transmission device.

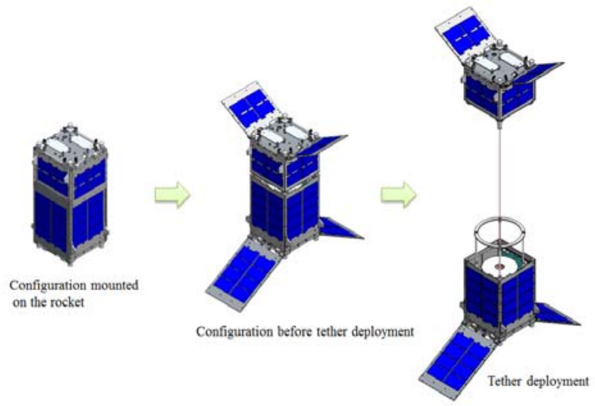

Figure 6. Docking and separation configuration.

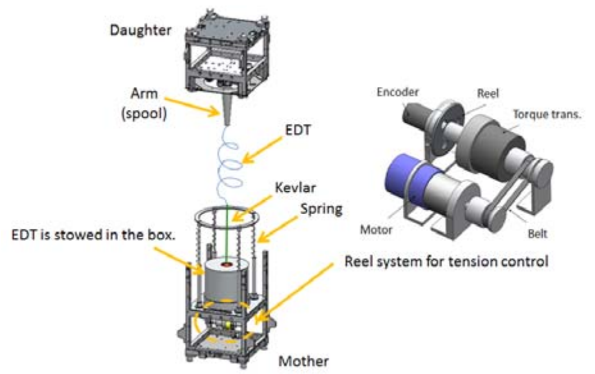

Figure 7. Tether deployment devices.

3.2 Electron emitter and arm link on Daughter

Here explains experiment for current gathering by EDT. When EDT deploying satellite is orbiting around the earth, electromotive force (EMF) is generated on EDT. Then, EDT current can be obtained by electron emitting. STARS-II employs filament as an electron emitter. It is suitable for nano-satellite because filament can work by small electrical power. Filament is mounted on the daughter satellite, and the daughter satellite is located in the direction of the earth under deploying EDT. Under such a condition, voltage of the daughter satellite is much lower than that of space ambient plasma. Then, electron can be emitted by heating up filament (over 1000K).

Figure 9 shows the arm joint mechanism mounted on the daughter satellite, which was developed for mounting on a micro space system. For the purpose of attitude control for two vertical axes of tether extension line, the differential gear mechanism is employed.

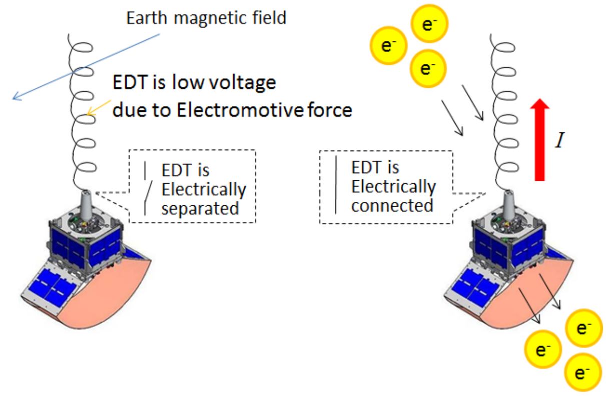

Figure 8. Mission sequence of STARS-II.

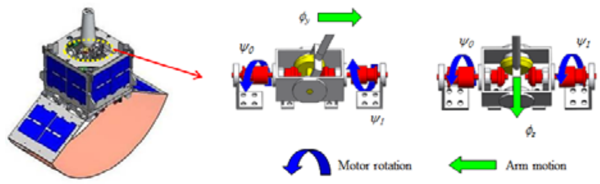

Figure 9. Mission sequence of STARS-II.

3.3 Type-style and fonts

STARS-II communicates with the ground station by amateur radio frequencies. For the purpose of simple deployment system on orbit and antenna directivity suitable, the mother satellite employs the Solar Paddle Antenna (mounted at the edge of a solar paddle), which was verified by the first satellite STASR-I in Kagawa University. The daughter satellite employs a new antenna using flexible film as shown in figure 10, which is reformed of the Solar Paddle Antenna.

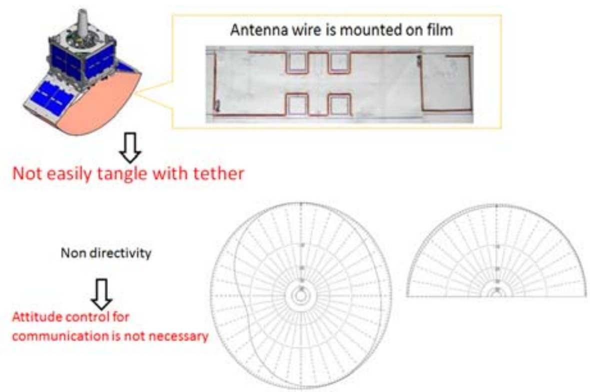

Figure 10. Film antenna for amateur radio frequency.

4 Operation Results

STARS-II was successfully launched at 3:37am (JST) on February 28, 2014. The planned orbital altitude is 390 km, and inclination is 65 deg. Also, it was planned to be separated from the rocket at 04:05am (JST) on the same day.

4.1 CW beacon reviving results in the 1st week

Table 1 shows CW beacon data format for STARS-II. It consists of 6 lines. There is the 14sec interval between lines. The first line shows call sign for amateur radio communication: JR5YDX for the Mother and JR5YDY for the Daughter. Headings of 2 - 6 lines are M2, M3, M4, and M5, M6 for the Mother, and R2, D3, R4, D5, and R6 for the Daughter, respectively. M2, M4, M6 and R2, R4, R6 lines are not transmitted when C&DH is OFF.

Table 1 CW format

JR5YDX/ JR5YDY				
M2/R2	Satellite internal time (6)			
M3/D3	RSSI (2)	Solar battery voltage (2)	Supply voltage (2)	Supply current (2)
M4/R4	Reset times of Com. (3)	Command receiving times (3)		
M5/D5	Com. voltage (2)	C&DH voltage (2)	Camera voltage (2)	Li-ion battery voltage (2)
M6/R6	Status 1 (3)	Status 2 (3)	Status 3 (3)	

( ): Number of digits

At the 1st pass of 5:13am - 5:23am (JST) on the launch day, CW beacon from the Daughter Satellite was received on the Kagawa University ground station (JR5YDP) as follows.

Pass: 5:13am - 5:23am (JST), 28 February 2014
Normal frequency: 437.255MHz

```
D3   9A    -2    BC    0A
R4   000   000
D5   FF    FF    25    B6
R6   000   000   0DB
JR5YDY
?2   00112E
D3   93    -3    BC    0A
R4   000   000
D5   FF    FF    24    6
?6   00?   -0-
------
?2   0011C1
D3
```

At the pass of 18:36 - 18:47am (JST) on the launch day, CW beacon from the Mother Satellite was received on another amateur radio station (JD1GDE) in Japan as follows.

Pass: 18:36am - 18:47am (JST), 28 February 2014
Normal frequency: 437.245MHz

```
M3   -1    C1    0B
M4   --0   --0
M5
```

From the CW beacon data, STARS-II was successfully separated from the rocket, and satellite system started. However, it is noted from M2, M4, M6 and R2, R4, R6 lines data that C&DH also started though it should not start just after the separation. According to the STARS-II design, C&DH starting suggests that the solar paddles and antennas were not deployed. Also, CW beacon from the Daughter was much stronger than that from the Mother. The Daughter and the Mother employ Dipole and Monopole antennas respectively. It is inferred that the Daughter antenna could well transmit CW beacon though it was not deployed.

4.2 Housekeeping data by CW beacon

After few days, CW beacon from the Daughter became to be week. It is inferred that solar battery power was low due to its small body. Also, few weeks later, CW beacon from the Daughter could not be received. The reason is discussed in the next section “3.3 decent orbit.”

On the other hand, CW beacon from the Mother became to be strong, and also M2, M4, M6 lines were not transmitted after March 4. It is inferred that the solar paddles and antennas were deployed by re-starting, and then C&DH were not starting because of the same sequence of just after the separation.

Figure 11 shows sample data of solar battery voltage (item 2 in M3 line), supply voltage for satellite electrical devices (item 3 in M3 line), and Li-ion battery voltage (item 4 in M5 line) translated from CW beacon data from the Mother. Nominal voltage of the Li-ion battery is 7.4V, then telemetry data was around 7.4V performing charge and discharge. Solar battery voltage data was over about 8V at sunshine condition, and about 0V at sunshade. It is also noted that Li-ion battery voltage was higher when charging. Supply voltage was 7 – 8V, and it was lower than Li-ion battery voltage at sunshade condition.

Figure 12 shows sample data of supply voltage for C&DH and supply current for satellite electrical devices mainly including communication and C&DH subsystems. Nominal voltage for C&DH are 5V. C&DH can be operated by the command from the ground station. Then, C&DH voltage was 5V and supply current was about 0.3A – 0.4A when it was ON, and 0V and less than 0.1A, which was consumed for the communication subsystem, when it was OFF.

As a result, it can be said that electrical power balance is normal on orbit. And also, ground commanding (uplink) could be received. However, C&DH subsystem could not work due to any troubles, for example, radiation.

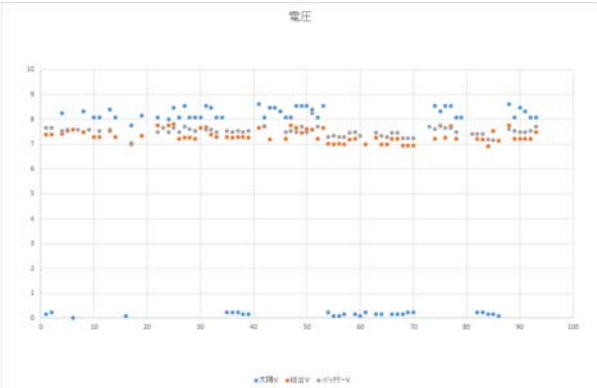

Figure 11. solar battery, supply for satellite electrical devices, and Li-ion battery voltages.

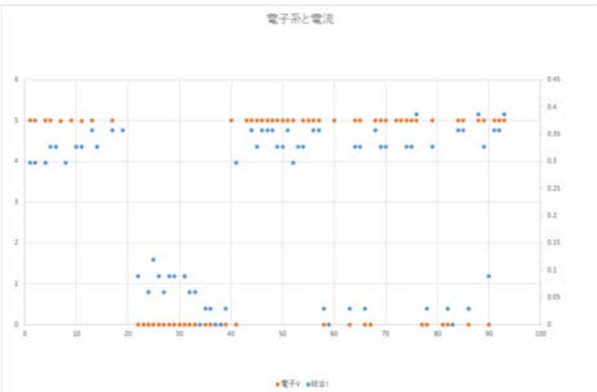

Figure 12. C&DH voltage and supply current.

4.3 Descent orbit

Figure 13 shows orbital altitude of 7 piggy-bag satellites on H-IIA #25, derived from Two Line Element delivered on Space Track Home Page. Also, Table 2 shows Area-to-mass of each satellite. Theoretically, orbital lifetime of a 50kg satellite is longer than that of CubeSat (10cm cubic). Their results in figure 3 shows proper lifetime other than STARS-II. STARS-II lifetime is expected to be longer than Cubesat even when the solar paddles were deployed. As a result, it is inferred from the orbital altitude change that tether was deployed.

Table 2 Area-to-mass of each satellite

Satellite name		
STARS-II	0.0065	Minimum
	0.0124	Paddle deployed
	0.0900	Tether deployed
Shindai-sat	0.0069	50kg
Teikyosat-3	0.0052	50kg
ITF-1	0.0115	Cubesat
INVADER	0.0178	Cubesat
OPUSAT	0.0215	Cubesat
K-Sat2	0.0173	Cubesat

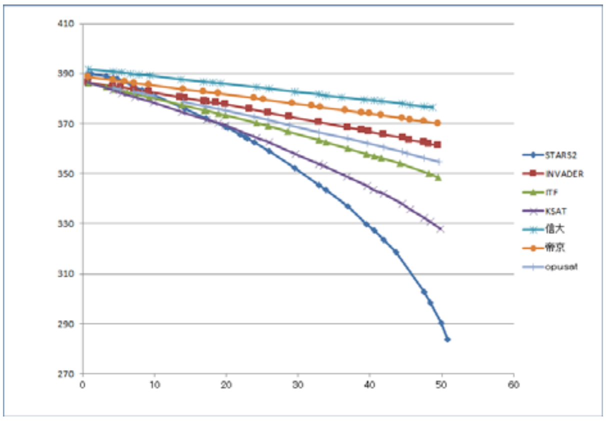

Figure 13. Orbital altitude of H-IIA #25 piggy-bag satellites.

4.4 Optical observation from the ground

Figure 14 - 19 show pictures of optics observation from the ground by astronomical observatories in Japan. STARS-II project organizes astronomical observatory network in Japan in order to observe the Mother and the Daughter satellites for confirmation of tether deployment mission results.

It is noted from figure 14 - 18 that STARS-II appears as one line in a still image. Figure 19 shows one shot of a movie image, and STARS-II appears as one point. Therefore, separated condition of the Mother and the Daughter could not be observed currently (March 2014). As a result, considering the result of orbital altitude change in figure 3, it is inferred that tether was extended once, however it was tangled by rebound. Then, orbital altitude decent was large though it was observed as one object.

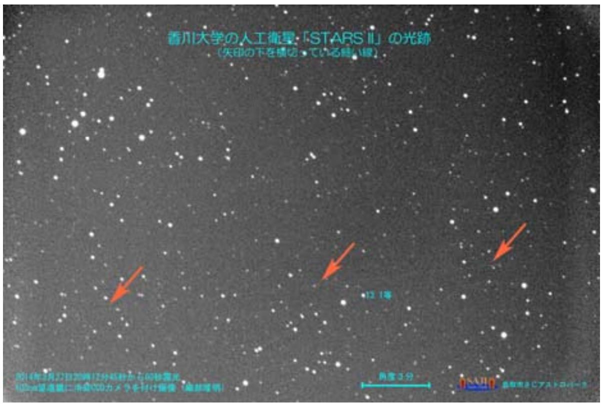

Figure 14. Observed by Saji Observatory.

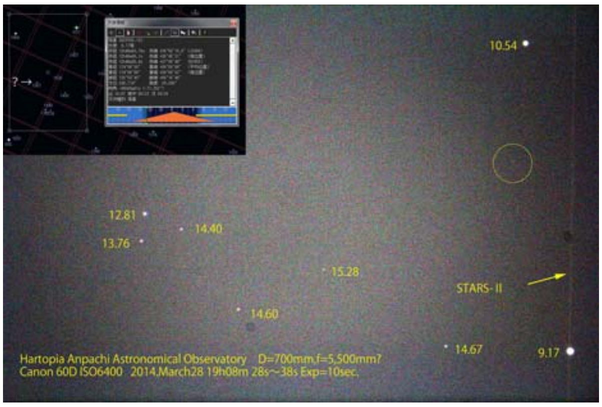

Figure 15. Observed by Heartpia Anpachi.

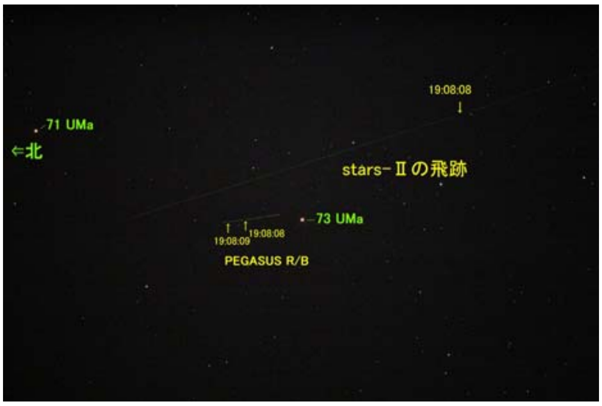

Figure 16. Observed by Usuda Star Dorm.

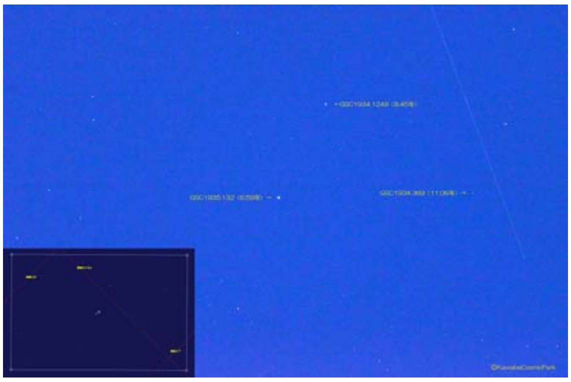

Figure 17. Observed by Kawabe Astronomical Park.

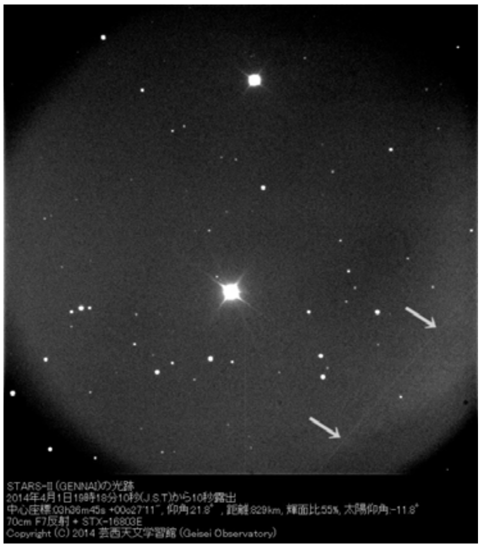

Figure 18. Observed by Geisei Astronomical Observatory.

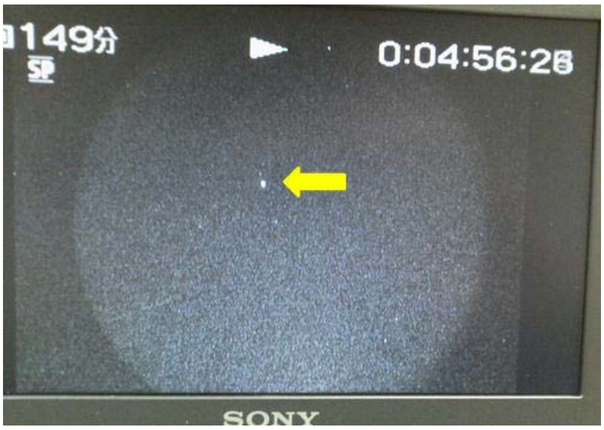

Figure 9. Movie observed by Toyama Astronomical Observatory.

5 Conclusions

This paper reports orbital operation results of STARS-II, which was launched on 28 February 2014, as one of piggy bag satellites by the H-IIA rocket. Unfortunately, STARS-II mission could not achieved perfectly under current status on the mid of April 2014. However, the STARS-II condition can be inferred by telemetries through CW beacons and change of orbit.

It is noted from telemetry data through CW beacon that electrical power and communication subsystems are normal, and also solar paddles and antennas were deployed. And it is inferred from orbital altitude change that tether was deployed. And also, it is inferred from optical observations from the ground astronomical observatory that deployed tether was tangled.

Acknowledgement

Here thanks for cooperation by JAXA-Aerospace Research and Development Directorate to develop tether deployment mission, and by Yamagiwa Lab. in Shizuoka University to develop EDT mission. Also, STARS project deeply thanks to Japanese Astronomical Observatories for optical observation from the ground.

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. Vol. 24, No. 4, July 2001, pp. 827-833.

[2] P. M. Bainum and V. K. Kumar, “Optimal Control of the Shuttle-tethered Subsatellite System.” Acta Astronautica. 7(6), 1980, pp. 1333-1348.

[3] V. J. Modi, P. K. Lakshmanan and A. K. Misra, “On the Control of Teth-ered Satellite Systems.” Acta Astronautica. 26(6), 1992, 411-423.

[4] 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.

[5] Y. Umetani and K. Yoshida, “Resolved Motion RateControl of Space Ma-nipulators with Generalized Jacobian Matrix.” IEEE Transaction on Robot-ics and Automation. 5(3), 1989, 303-314.

[6] M. Nohmi, “Initial Experimental Result of Pico-Satellite KUKAI on Orbit.” ID:923981, IEEE International Conference on Mechatoronics and Automation. Changchun, China, August, 2009.

[7] M. Nohmi, J. Tanikawa, T. Hosoda, A. Uchida, “Evaluation Analysis of the S-520-25 Rocket Experiment for a Tethered Space Robot,” International Symposium on Artificial Intelligence, Robotics and Automation in Space. Italy, Setember, 2012.