A Ground-Based Operation System for EVA Support Robot Experiments

Atsushi UETA and Mitsushige ODA
Aerospace Research and Development Directorate, JAXA, Japan
e-mail: ueta.atsushi@jaxa.jp, oda.mitsushige@jaxa.jp

Abstract
Japan Aerospace Exploration Agency (JAXA) is developing space robotic technologies to realize a robot to support manned space activity. JAXA plans to conduct a robot experiment to demonstrate locomotion strategy using tethers and an extendable robotic arm with a robotic hand on the International Space Station, Japanese Experiment Module Exposed Facility (JEM-EF) in fiscal year 2011. The experiment (REXJ: Robot Experiment on JEM) will be controlled remotely from a ground-based operation system in JAXA Tsukuba Space Center. The operational system is required to have high safety and reliability to achieve the experiment successfully. In this paper, we report a progress of developing the ground-based operation system for REXJ.

1 Introduction
As one of the KIBO Exposed Facility Second Phase Utilization Missions, an experimental robotic mission named REXJ (Robot Experiment on JEM) is to be launched and conducted at the exposed facility of the International Space Station Japanese Experiment Module (JEM/KIBO). For this mission, the onboard robotic experiment system is being developed and the system proto flight tests are conducted now. The onboard system will be integrated into MCE (Multi-mission Consolidated Equipment), which is the bus system in size of 0.8m × 1.0m × 1.85m, with the other four missions’ equipments on this September after all the tests completed. The REXJ system in the MCE will be installed at the JEM Exposed Facility or JEM-EF (Fig. 1) in the fiscal year 2011 [1].

1.1 REXJ Mission
Purpose of the REXJ mission is to demonstrate some key technologies to realize the Astronaut Support-Robot (Astrobot) which can move inside and outside space facilities and which can support astronauts or conduct tasks instead of astronauts.

Several experiments are planned to be performed in the REXJ mission. The list below shows the experiments in each mission success level.

Minimum success level experiments:
(1) Release of the launch locks and initial operation checks.
(2) Extension of the extendable robot arm. Vibration of the extendable robot arm will be measured when the robot hand and wrist are moved.

Full success level experiments:
(3) The tethered hook is grabbed by the extendable robot arm and then it is attached to the handrail.
(4) Extendable robot arm’s vibration property, positioning accuracy, and the sympathetic vibration with tether and the extendable robot arm are measured.
(5) Releasing and Re-Attachment of the tethered hook from/to the handrail by the extendable robot arm is demonstrated.
(6) Astrobot locomotion using the tethers is demonstrated.

Extra success level experiments:
(7) Cooperative control of the extendable robot arm and tether mechanism.
(8) Extend the extendable robot arm to the outside the MCE and check the vibration caused by the change in the temperature and solar irradiation.

All these experiments will be tele-operated from the User Operations Area (UOA) of the Space Station Operation Facility at JAXA’s Tsukuba Space Center (TKSC) Figure 2 shows the communication path in operating REXJ. For exchange of data and video images between JEM and TKSC, a communication network through the US Tracking Data Relay Satellite (TDRS) system and the White Sands Space Harbor (ground satellite stations) in US is established. In the future, Japan’s own satellite, Data Relay Test Satellite (DRTS) will be used for direct communications between JEM and TKSC.

Fig. 1: JEM-EF

i-SAIRAS 2010
August 29-September 1, 2010, Sapporo, Japan 574
1.2 Teleoperation System

It is still difficult to realize fully autonomous space robot, therefore teleoperation system is necessary technology for space robots. Time delay, limitation of communication and limitation of onboard computational capability are well-known problems for teleoperating robots in space [2]. Especially, time delay is a unique problem for space robots. The time-delay problem causes an operator on the ground not to operate robots in real time (it means that the operator can check how the robot changes its state by commands several seconds after he/she sends the commands) and it leads that operability is extremely lowered [3]. The delay time depends on the communication path. The estimated time is 5-10 seconds in REXJ case (Fig. 2). Several methods have been studied for the problem. One of the efficient ways is a method using predictive simulator or model-based method [4]. In this method, operators use a simulator which models robot and environment numerically and shows the predicted robot’s state by operational commands. It enables the operator to operate the robots easily as if the predicted state of robot were that of the real robot. Although the simulator needs to model the robot and environment precisely of course, there are inevitable errors between the model and the real-world robot. It becomes difficult to operate the robot accurately as the error accumulates.

A ground-based operation system for REXJ applies a predictive simulator for the time-delay problem and a state estimator based on telemetry data which can diminish the errors between the model and the real robot for the modeled-error problem.

This paper reports a progress and challenges in developing the ground-based operation system for REXJ. The next section describes the REXJ onboard system and ground system. The section 3 describes the ground test equipments for verification of this system. The last section states conclusion and future works.

2 REXJ System

REXJ system can be mainly divided into two systems, the onboard system and the ground system.

2.1 REXJ Onboard System

REXJ onboard system will be integrated into MCE bus system and five missions will share the one bus system. The REXJ onboard system (Fig. 3) consists of the followings:

(1) Robot main body

Robot main body consists of a “STEM stage” and “Tether stage”.

(a) Upper stage (“STEM stage”)

The STEM stage houses an extendable robot arm. The extendable robot arm consists of an extendable mechanism called STEM (Storable Tubular Extendable Member), 2 axis wrist joints and a hand with the cameras and Lights. The STEM stage is made of CFRP and its max extended length is approximately 1.5m. Power and signals to the wrist mechanism and the other electrical components are provided through the cable installed inside STEM.

(b) Lower stage (“Tether stage”)

The Tether stage houses a tether reel, a hook and its holder, a motor/latch driver, and a rotation mechanism. The robot main body’s location is controlled by tethers attached to the tether stage. Length of the tethers will be controlled by the tether reel mechanism.

(2) Robot control system

Robot control system consists of a base plate and some components attached to the base plate including a control unit, tether reel mechanisms, hand rails, a camera(LED lights), and launch lock mechanisms for the robot main body.

![Fig. 2: Communication with JEM/KIBO](image1)

![Fig. 3: REXJ onboard system in MCE](image2)
The following images, figure 4 and figure 5, depict the main two experiments, “Grasping Handrail” and “Tether Based Locomotion”.

![Fig. 4: Image of One of Planned Experiments, Grasping Handrail](image1)

![Fig. 5: Image of One of Planned Experiments, Tether Based Locomotion](image2)

2.2 REXJ Ground System

REXJ ground system is at system design phase now. The system has the five main functions, Command Related Function, Telemetry Related Function, Database Function, Operational Preparatory Function and General Function. The each main function has the following sub functions.

(1) Command Related Function
   - Edit of CMD (Command)
   - Send of CMD
   - Rewrite of onboard Software

In this function, the system can load SOP (Spacecraft Operation Procedure), change the parameter, check errors of command beforehand, and send commands. If necessary, the system can rewrite the onboard software.

(2) Telemetry Related Function
   - Receiving of TLM (Telemetry)
   - Processing and Display of TLM
   - NTSC Video Processing
   - Accumulation of Data
   - Distribution of Data to other Network

In this function, the system can receive telemetry and NTSC video data from the high-order ground system, change to engineering values and show in graph. The system can accumulate the data in database and distribute the data to other registered network.

(3) Database Function
   - Database of CMD Data
   - Database of Telemetry Data
   - Searching, Display and Output of Data

In this function, the system can make database of commands’ and telemetry’s data and search the required data from the database.

(4) Operational Preparatory Function
   - Production of ODF (Operations Data File)
   - Production of Macro Command
   - Production of SOP (Space Craft Procedure)

In this function, the system can produce, verify, manage and edit ODF (Operations Data File) for JEM system, macro commands and SOP.

(5) General Function
   - Access to Operational High Order System
   - Management of System
   - GUI (Graphical User Interface)
   - Distribution of Data through Media
   - Print of Data

In this function, the system can access and acquire related data from the high-order ground system. The system has a function of management of the system. Every system has a graphical user interface for usability of operators. Distribute data by media and print data.
Figure 6 shows the functional configuration of this system. Figure 8 shows the hardware configuration of the system. The system consists of three PCs, one for a PC for sending commands, one for a PC for receiving telemetry data from the main high-order system (MCE), and the other for a PC for receiving NTSC video data and telemetry data from the sub high-order system (Multi Protocol Converter: MPC).

High safety and reliability are required for REXJ ground operational system. However, time-delay problem which is unique for space robots makes real-time operation impossible. It means that an operator cannot see how the robot changes its position by every command. Therefore, there is a possibility that a wrong command causes that the robot may hit the wall of MCE bus system or it may get unstable pose. Then, it is required whether the command is safe before an operator sends the command to the robot.

Predictive simulator or model-based control is well known and very strong method for the time-delay problem. The simulator can model dynamics and can display the predictive robot motion by a command (Fig. 7). It enables an operator to know whether the robot “will” change by a command which is planned to be sent beforehand. Then, the operator will make a judgment whether he/she will send the command or not from the basis on the result of the predictive simulator.

It is inevitable that some errors between the real robot and the model happen. It becomes difficult to control the robot using predictive simulator because of accumulation of such errors. However, the simulator can be revised from the real telemetry. For example, if an estimated robot position from the predictive simulator is different from the real position because of accumulation errors, it can be revised from the telemetry data about length of tethers because the position of the robot is specified from the length of three tethers.

![Fig. 6: Functional Configuration](image)

**Fig. 6: Functional Configuration**

**Fig. 7: Graphical Model of REXJ and MCE-BUS**
3 Ground Test Equipment

The efficiency and safety of REXJ ground system needs to be verified for achieving mission successfully before the launch. The Proto Flight Model (PFM) is not used for all the verification points because it is installed into MCE bus system during development of the ground system, and then a ground mockup of REXJ PFM is used for some verification points. In this section, we show the ground mockup which we have developed so far.

Figure 9 and 10 depicts an appearance of the ground mockup. Engineering Models (EMs) of robot hand and STEM robot arm and Bread Board Models (BBM) of MPU, motor drivers, cameras and hook are embedded effectively in the mockup. The mockup has almost the same functions as REXJ onboard system, but all the parts or components are not the same model. The handrail (Fig. 11) has the same shape and size as the PFM but the tether/reel mechanism (Fig. 12) has the same function but has different size, shape and mechanism.

This mockup is used not only for verification test of the ground operational system before the launch but also for training of operators. Even after the launch, if some operations which are not verified on the ground are planned to be conducted, the ground mockup system will be used for verification test of the operations.
4 Conclusions

REXJ Ground-based operation system is required to have high safety and reliability. For that, the teleoperation system must be verified to ensure security and feasibility of operations before the robot launches. So far, we have conducted design study and made prototype models of predictive simulator and ground verification model. Using test and design results of prototype models, we are designing in detail and making ground system for the experiment on JEM-EF.

As future works, we will forward detailed design of the system and develop the system for the launch.

References


