Development of the Japanese Experiment Module (JEM), KIBO for the International Space Station

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Abstract

Japan has developed its first manned space facility by completing the Japan Experiment Module (JEM), KIBO for the International Space Station. In this development, NEC was in charge of systems including the Inter-orbit Communication System and Robot Arm System as well as the JEM Control Processor, various experiment devices and the Operations Control System. Putting the first priority on the safety of astronauts at the same time as pursuing operability, universality and versatility, NEC developed each piece of equipment by adding new manned space development requirements to the existing space development technologies and by coordinating them into the uniquely Japanese technologies. At present, the JEM is monitored and is operated on 24-hour schedules for performing various space experiments.

Keywords

JEM (KIBO), International Space Station (ISS), JCP, ICS, robot arm, SEDA, MAXI

1. Introduction

The International Space Station (ISS) is a manned space facility of a size equivalent to that of a soccer pitch. It orbits the Earth at an altitude of about 400 km. In the environment that surrounds the ISS, there is little atmosphere, various kinds of space radiation are bombarding the ISS and the gravity is only about one millionth of that on the Earth. The ISS is a facility for conducting experiments, research and Earth/astronomical observations with the objective of advancing science and technology and serving in the contexts both of the present and the future of humankind. With the participation of 15 countries including the USA, Japan, Russia, European countries and Canada, the on-orbit assembly of the ISS started in 1998 and is scheduled to complete in 2011. An image of the current ISS taken from a space shuttle is shown in **Photo 1** .

Japan under the leadership of the Japan Aerospace Exploration Agency (JAXA) developed the Japanese Experiment Module (JEM), KIBO for the ISS. It is Japan's first manned space facility capable of accommodating astronauts for a long period, and it was completed in July 2009 after three component launches. **Fig. 1** shows an external view of the JEM produced by computer graphics.

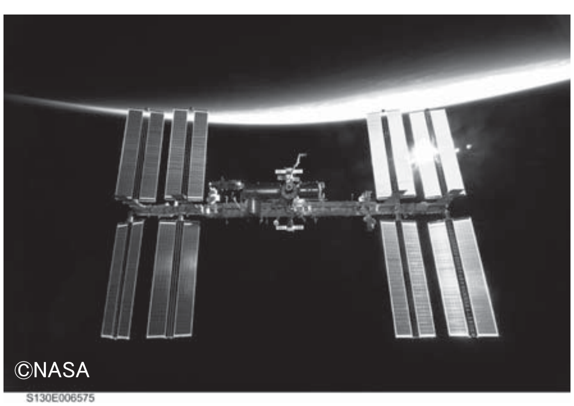

Photo 1 International Space Station.

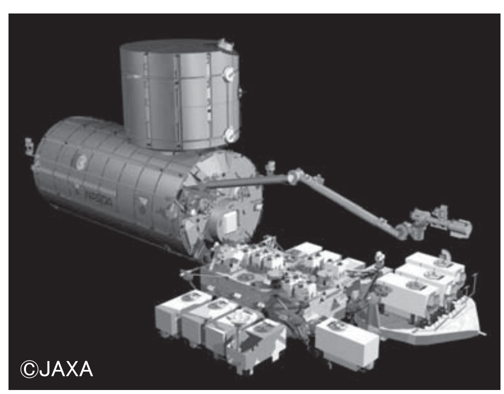

Fig. 1 Japan Experiment Module (JEM, or KIBO).

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The JEM is a complex facility consisting of six separate modules including; the Pressurized Module (PM), the Exposed Facility (EF), the Experiment Logistic Module - Pressurized Section (ELM-PS), the Experiment Logistic Module - Exposed Section (ELM-ES), the Remote Manipulator System (RMS) and the Inter-orbit Communication System (ICS). Among these modules NEC managed the Inter-orbit Communication System and Remote Manipulation System, as well as the JEM Control Processor for coordinating and controlling the entire JEM, various experiment facilities and the JEM Operations Control System installed in the JAXA TsuKuba Space Center (TKSC).

2. JEM Control Processor (JCP)

The JEM Control Processor (JCP) is the main computer of the JEM. Working for 24 hours a day, it operates and controls the entire JEM by intercommunicating with the computer at the U.S. segment of ISS. The JCP has been working without interruption since the startup of the JEM Pressurized Module in June 2008.

The hardware specifications were established in the initial period of development in the early 1990's with; a 32-bit CISC processor, 12M-byte main memory, 300M-byte HDD with an SCSI interface and a total of 3 channels of MIL-STD-1553B network interfaces. The hard disk drive has been replaced by a second-generation drive based on the Solid State Drive (SSD) technology.

The software offers a real-time execution environment and a file system. It also provides services supporting the operations and control of the entire JEM including; various network services such as command and telemetry transmission/reception and file transfer, system operation management that monitors faults and switches automatically to the standby system and the procedure execution environment that enables automatic operation of the JEM.

The features of the JCP are as follows.

(1) Redundant configuration

The JCP adopts the standby redundancy system using a pair of processor units so that, even if one processor unit fails, it is switched automatically to the other one. The two units are installed at distant locations in the Pressurized Module so that the operation of the entire JEM can be continued even in the case of a local incident such as a fire.

(2) Versatile computer system

The capability of file backup and software updating/upgrading on the standby system enhances the operational versatility.

We succeeded in developing reliable infrastructures to support the manned space system by diverting proven technologies in commercial industries to aerospace applications.

3. Inter–orbit Communication System (ICS)

The Inter-orbit Communication System (ICS) is a JEM onboard system to establish the direct communication with TKSC not via the NASA system. **Fig. 2** shows the ISS-Ground communications architecture, in which the ICS provides data for the Japanese space link via the JAXA Data Relay Test Satellite (DRTS, or Kodama). The ICS is composed of the ICS Pressurized Module subsystem (ICS-PM, **Photo 2** Left) that performs baseband data processing and the ICS Exposed Facility subsystem (ICS-EF, Photo 2 Right) that performs RF signal processing and transmission/reception by antenna.

The features of the ICS are as follows.

(1) The high-precision acquisition and tracking subsystem on a flexible structure

ICS achieves high precision pointing to the DRTS at far distance, while it is subjected to a large attitude disturbance due to the ISS as a flexible structure. ICS is able to meet the difficult requirement by processing the ISS time/position / velocity data provided by ISS NASA module, and attitude information obtained from ICS own sensors (inertial reference unit, earth sensor, sun sensor).

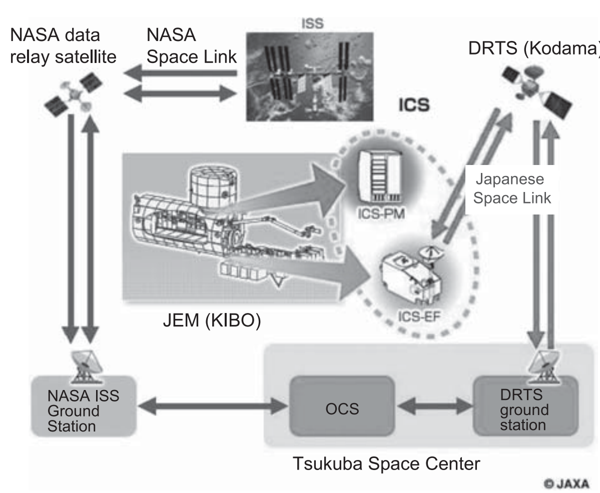

Fig. 2 ISS-earth communication architecture.

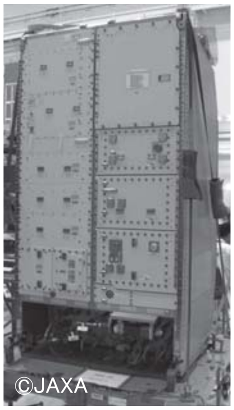

Photo 2 ICS pressurized module subsystem (Left)/Exposed facility subsystem (Right).

(2) Bi-directional multimedia communications

The ICS performs multimedia data communications covering control commands/data, high-speed large-capacity data, and video, audio and Ethernet in full compliance with the CCSDS AOS [*1] protocol, which is the international standard for spacecraft communications.

(3) Extensive use of commercial off the shelf products

The MPEG compression, Ethernet protocol and ITU-T audio conversion are processed with dedicated ICs, but these have not previously been put to space use, so it was decided to use the commercial off the shelf board. As the evaluation data per device was not available, we evaluated the safety at the board or unit level and adopted the internal redundancy system in order to improve reliability.

(4) Manned operation safety technology (Example: RF radiation control)

The critical topic of the ISS is to secure the safety of astronauts. One of the most important ICS safety feature is the RF radiation control as follows.

RF radiation is a necessary function of the ICS. As it may potentially cause damage, such as a malfunction of the astronaut life support system (which could lead to a loss of human life), we adopted the following countermeasures.

1) Mechanical function to avoid the antenna pointing to ISS fixed structure.

2) Radiation is automatically started and stopped based on the operation schedule planned by ground, and is shut down automatically when radiation for inhibited direction is detected.

3) Function for shutting down the radiation with double fault tolerance when an astronaut works in the proximity of the antenna during extravehicular activity.

The technologies used by the ICS will be applied to the future space communication systems for greater distances from the Earth and that are required to provide higher functionality and complexity.

4. Remote Manipulator System (JEMRMS)

The Remote Manipulator System of the JEM (JEMRMS) is the first practical space robot system of Japan designed for supporting the experimentation and maintenance work on the JEM. Japan already has achievements in this field with the Manipulator Flight Demonstration (MFD) test and the ETS-VII (KIKU 7). The JEMRMS is the third space-use remote manipulator system for Japan and all of the remote manipulator systems mentioned above have been developed by NEC.

The JEMRMS is composed of the main arm, a small fine arm and the JEMRMS console. An external view is shown in **Photo 3** and **Fig. 3** .

The main arm is a robot arm with 6 degrees of freedom using six joints that has an overall length of 10 meters and a weight of 780 kg. On the pitch is the end effector for holding the special grapple fixture on each carried payload. It can grapple and carry an object of up to 7,000 kg.

The small fine arm is also a robot arm with 6 degrees of freedom using six joints, and has an overall length of 2.2 meters and a weight of 180 kg. The small fine arm can be operated when it is attached to the main arm and the electricity/communication lines are connected to it.

The main arm has cameras on the wrist and elbow sections, and the small fine arm has a camera on the wrist

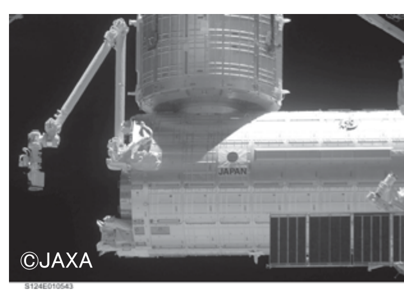

Photo 3 External views of main arm (Left) and small fine arm (Right).

[*1] CCSDS AOS: Consultative Committee for Space Data Systems Advanced Orbiting Systems

Development of the Japanese Experiment Module (JEM), KIBO for the International Space Station

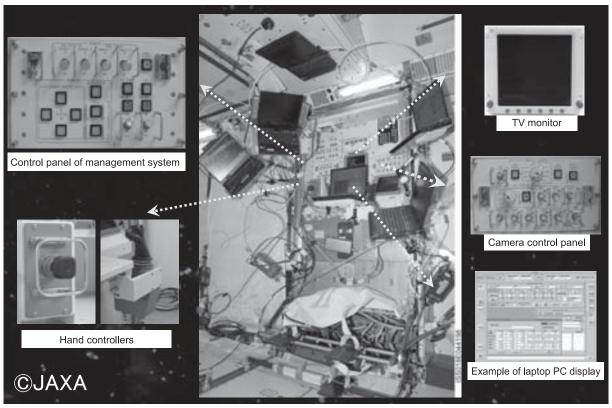

Fig. 3 External view of the JEMRMS console.

section. The astronaut controls JEMRMS by monitoring the camera images from the JEMRMS Console.

At present, the main arm is already in use on the ISS for use in installing experiment payloads and performing maintenance work. The features of JEMRMS are as follows.

(1) Main/small fine arm configuration

The main arm is capable of carrying large structures while the small fine arm is capable of fine operations such as bolt rotation. Combination of the two arms enables application to various operations.

(2) Replaceable system configuration

The risk of in-orbit failure is reduced because the joint mechanism, drive electronics, vision system and end effector of the main arm are designed to be replaceable by extra-vehicular work of an astronaut in the case of failure. A design that was compatible with replacement functions has been unavailable with previous satellites and this innovative design function is ideally suited to a manned space system such as the ISS.

(3) Manned operation safety technology

Just as for the ICS issue, to secure the safety of an astronaut is also the most important issue with the ISS. The JEMRMS ensures safety by enhancing the following two functions.

1) Collision prevention function

To prevent collision, the control system is designed with double fault tolerance.

In particular, in order to keep certain distance between the Pressurized Module and JEMRMS, triple monitoring and shutdown functions are provided. The velocity of the arm's pitch is limited to a safe level by software and the arms are designed not to give excessive impact to other objects in the case of a collision.

2) Object floating prevention function

It would be extremely dangerous if an arm released the grappled object due to a failure and the released object then collided with the ISS. In addition, certainty is particularly required when handling an object. Therefore, the arm is designed so that it is able to release an object only after grasping by the other party is confirmed by three kinds of signals and that three commands must be input to let the arm release an object.

(4) Common designs

The ISS includes three remote manipulator systems including the JEMRMS. To reduce the burden on the operations of astronauts, the control systems of the JEMRMS is designed by extensively adopting common designs.

The technologies established for the JEMRMS will be utilized in future space missions including; the construction of bases on lunar/planetary surfaces, systems for unmanned surveys of planetary surfaces and satellites for collecting space debris.

5. Operations Control System (OCS)

The Operations Control System (OCS) of the JEM enables remote control and monitoring of the JEM from the ground and is installed at TKSC.

Support from the ground is indispensable, so that a limited number of astronauts can conduct a large number of complicated experiments. The OCS can execute all of the controls required for operating the JEM, from support of the experiments conducted on it to the control and monitoring of the equipment, receiving video and voice exchange with NASA. **Photo 4** shows a view of people working on the OCS.

The OCS started operation on the first flight of the JEM assembly mission (March 11, 2008) and currently continues 24-hour operation.

The OCS is composed of about 20 computers, about 100 terminals, three large screens, about 70 audio terminals and other video and network equipment.

The status of the thermal control subsystem, power subsystem, communication subsystem, air/temperature control and life supporting subsystem of the JEM can always be checked via the terminals. In the case of a fire, a drop in pressure or air pollution, the actions to be adopted by astronauts can be indicated via the audio equipment.

Photo 4 JEM operations control room.

(1) Flexible configuration change

Unlike ordinary spacecraft, the JEM receives supply from the ground by using space shuttles or HTV. The configuration therefore changes occasionally following installation of experiment equipment for new experiments or the application of network technologies that have a better performance than previously.

The OCS also changes the configuration as required to meet the new JEM configuration. It performs testing of the database for the next phase and training by efficiently using the standby resource of the redundancy systems that are provided for improved reliability.

(2) Communications with astronauts

The OCS is equipped with a voice data interface for communications with astronauts and a video data interface for monitoring the activities of astronauts. The data subsystem and the voice subsystem are separated to improve the versatility of the means of communications with the ISS.

During the long-term operation of the JEM, the JEM as well as the whole ISS are expected to incorporate new technologies and equipment with higher performances and operability than before. Accordingly, the OCS also evolves continually and accumulates the operations and control system technologies for manned space systems.

6. Space Environment Data Acquisition Equipment-Attached Payload (SEDA-AP) /Monitor of All-sky X-ray Image (MAXI)

The JEM is the venue for various exposure experiments making use of the space environment. NEC developed the Space Environment Data Acquisition Equipment-Attached

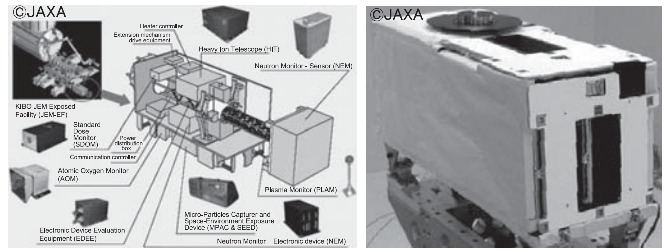

Fig. 4 External views of SEDA-AP (Left) and MAXI (Right).

Payload (SEDA-AP) and the Monitor of All-sky X-ray Image (MAXI) for experimentation on the EF (Exposed Facility).

The SEDA-AP acquires the space environment data using a wide variety of observation instruments that can be expressed as “the space weather reporter”. Its results are expected to support the manned space activities of the future. **Fig. 4** (Left) shows the observation instruments mounted on the SEDA-AP and their external views.

The MAXI observes space using X-rays to clarify the phenomena of space that is not detectable with visible light. In the period from September 2010 to January 2011, the Maxi discovered three cosmic X-ray objects, the flash reports of which were sent to researchers worldwide.

Currently, the MAXI is the sole all-sky X-ray monitor that is available with an excellent sensitivity up to the low-energy X-rays. Consequently, astronomers all over the world are eagerly awaiting its output and expecting it to provide us observation data continuously in future as long as possible.

Fig. 4 (Right) shows the external view of the MAXI.

7. Conclusion

With the completion of the JEM, Japan has acquired an innovative manned space technology. To follow this project, studies have already started into exploration projects aimed at the Moon and at planets such as Mars. NEC will participate in these projects by utilizing/advancing the technologies already cultivated in the manned space development project of the JEM.

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