4-3 Telemetry and Command Processing System for Experiments

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Two telemetry and command processing systems are being prepared as part of the ground facilities by CRL to monitor and control CRL's onboard equipment of ETS-VIII. One is for mobile communication experiments and another is for time comparing experiments. They have the almost same architecture but databases and amount of host hardware are adjusted for each target telemetry and command set respectively.

So all telemetries and commands are transmitted through TT&C system of NASDA that CRL's T&C systems communicate with ETS-VIII through NASDA's TT&C system. Some of telemetries and commands from/to CRL's onboard equipment which are critical for ETS-VIII satellite system safety are monitored and checked by NASDA's TT&C system too. The other telemetries and commands are simply relayed by NASDA's TT&C between CRL's onboard equipment and CRL's T&C systems.

CRL's T&C system have realtime and non-realtime servers and some terminals. Servers manage the communication with NASDA's TT&C system, process telemetries and commands, and archive telemetry data and command history data. On each terminal, operators can monitor the status of onboard equipment and control them by sending commands.

In this paper, the architecture of CRL's T&C systems and their functions are introduced.

Keywords

ETS-VIII, Eighth Engineering Test Satellite, TT&C, Telemetry and Command, CCSDS, Ground segment

1 Introduction

The telemetry and command processing system for experiments (hereinafter referred to as the CRL T&C system) is a ground facility for monitoring the status of mission equipment which was developed by CRL and put onboard the ETS-VIII, through telemetry, and for editing and transmitting commands that turn on/off the equipment, alter operating modes, and set operating parameters.

In the ETS-VIII system, reception of telemetry and transmission of commands are performed through NASDA satellite control system and GN (Ground communication Network). Consequently, the CRL T&C system does not have an RF segment and is linked to NASDA satellite control system through a network connection.

The CRL T&C system consists of a major shared unit to provide general-purpose common functions, and dedicated units, incorporated therein, to provide processing functions dedicated to specific onboard equipment.

The mission equipment onboard the ETS-VIII developed by CRL comprises (1) a communication subsystem whose objectives are mobile communications and broadcast experiments (refer to "Configuration for mobile communication satellite system and broadcasting satellite systems," Article 3-2 in this special issue) and (2) high-accuracy time comparison equipment (refer to "Time comparison equipment," Article 3-10 in this special issue), for each of which a dedicated T&C system is prepared. Both have the same architecture, except for the contents of target telemetries and commands, a dedicated unit incorporated therein, and hardware scale.

The major shared unit consists of servers, terminals, and databases.

Java was selected as the software development language, while XML was selected for the database definition language; therefore, the system is fundamentally OS-independent.

This paper reviews the configuration and functions of the major shared unit.

2 System configuration

2.1 Basic concept of configuration and its features

The CRL T&C system consists of a major shared unit which provides general-purpose common functions and dedicated units which provide specific processing functions for specific onboard equipment. Dedicated units are integrated into the major shared unit. Since the functions of the major shared unit are defined primarily by the database, it can also be used in other satellites by newly defining a database.

The major shared unit consists of servers, terminals, databases, and a connection circuit with NASDA satellite control system.

Databases are defined by XML in conformity with the NASDA satellite control system. Due to the difficulty of editing XML directly, some tools for building the databases have been prepared.

Several Windows PCs are used as host hardware, and are linked through a LAN to constitute a system. Hardware configurations can be optimized by selecting a number of PCs and adjusting their throughputs according to a processing load. Except for a few tools, the system was developed in Java. Thus, it is fundamentally OS-independent.

One T&C system for communication experiments is implemented in the Kashima Space Research Center, and another system for time comparison experiments is implemented at the Koganei Headquarters. Both have the same configuration except for the scale of the database and hardware, and different dedicated units are integrated into them. Both systems are connected separately to the NASDA satellite control system.

Fig.1 shows the overall configuration of the telemetry and command processing facility for ETS-VIII experiments. The figure shows only the CRL-related portion. Fig.2 shows the configuration of the T&C system for communication experiments. The system for time comparison experiments does not include mobile terminals.

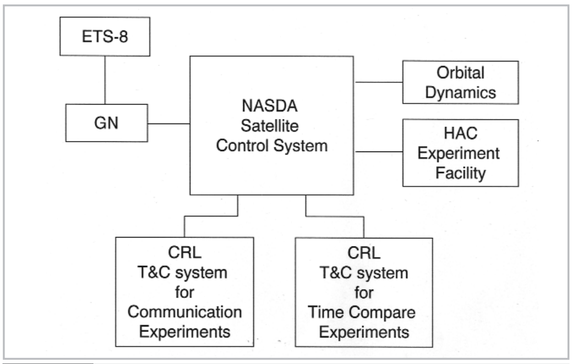

Fig.1 System overview (only CRL-related portion)

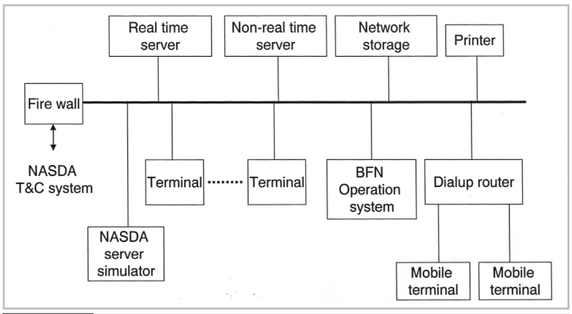

Fig.2 Configuration of T&C system for communication experiments

2.2 Server

The system is equipped with a real-time server and a non-real-time server; the real-time server talks to the NASDA satellite control system and performs telemetry and command processing in a real-time manner, while the non-real-time server reproduces stored telemetries, receives telemetry information and exchanges control information in a batch manner.

A simulator simulates the NASDA satellite control system for development and tests of the CRL T&C system.

2.3 Terminals

The terminal provides a user interface. It displays telemetry results and allows the operator to issue commands. Utility processing such as the building or modification of the databases, is also performed from the terminal. Several operators can log into the system through terminals, and perform operations in specific windows to execute telemetry and command processing functions. All operators logging into the system can open multiple windows simultaneously. For command transmission, to prevent two or more operators from transmitting commands simultaneously, only one operator is given the authority to transmit a command.

2.4 Databases and utilities processing them

The system includes a telemetry database, a command database, and an SOP (Satellite Operation Procedure) database.

The telemetry database defines how to derive a significant engineering value from a raw telemetry data sequence, including the addresses at which each telemetry result is stored, the storage form, and engineering value conversion curves. This database also stores various parameters that define each telemetry view window.

The command database saves information needed to edit commands, such as command names in readable text format, as well as methods for defining command parameters.

An SOP is a kind of script language that describes the operation sequence, e.g., to determine whether the satellite's conditions are adequate for a specific operation, and to transmit a command sequence if no problems are detected. An SOP usually contains definitions of command sequence that are actually transmitted. Condition judgement, branching, calling of a sub-SOP, etc. are possible in SOP execution.

Several utilities are prepared to manage these databases. Databases are constructed, modified and version controlled by operators with these utilities interactively.

2.5 Dedicated units

A dedicated unit is integrated into the major shared unit and provides processing functions dedicated to specific onboard equipment.

In the CRL T&C system, there are two dedicated systems: a BFN operating system for mobile communication experiments (refer to the "BFN operating system," Article 4-4 in this special issue); and a time comparison experiment system.

3 The NASDA satellite control system and the CRL T&C system

3.1 ETS-VIII telemetry and command system

The ETS-VIII telemetry and command system adopts the CCSDS (Consultative Committee for Space Data Systems) protocol. All telemetry and command information are enclosed in CCSDS packets, which are transmitted between the satellite and a ground T&C system. In the ETS-VIII project, only ground facilities of NASDA are permitted to directly transmit commands and receive telemetry information to and from the satellite. Experimental users from CRL and other project member organizations operate the onboard experimental equipment through the NASDA satellite control system. Therefore, the CRL T&C system does not have an RF segment for directly communicating with the satellite, but is instead linked to the NASDA satellite control system though a terrestrial data communication line.

3.2 Overview of the NASDA satellite control system

The NASDA satellite control system is an integrated system that enables a handful of operators to operate multiple satellites.

NASDA satellite control system consists

of a satellite operation control subsystem, a satellite data processing subsystem, a satellite operational planning subsystem, a satellite database management subsystem, and a satellite operation terminal subsystem. These subsystems are connected to a LAN. Further, an orbital dynamics subsystem, satellite development subsystem, GN, SN (Space Network: a satellite control network by DRTS; not used in ETS-VIII), a satellite simulator, participants performing the experiment, etc. are connected to this LAN, taking the appropriate security measures.

The HAC experiment system of NASDA (refer to "High accuracy clock (HAC)," Article 3-9 in this special issue), which is closely related to the time comparison experiments, is also connected to the NASDA satellite control system as one of the experimental participants to perform the experiment by exchanging experimental data with the T&C system for CRL time comparison experiments.

3.3 Connection with the NASDA satellite control system

3.3.1 Network

The CRL T&C system is linked to the NASDA satellite control system through a dedicated router and leased data lines. Since two T&C system users are distinguished—a user of mobile communication experiments and a user of time comparison experiments, two distinct connection points are provided, one for each user. The one is connected to Kashima, the other is connected to Koganei. The CRL T&C system is connected to no other networks, including the internal CRL network, for security reasons.

Digital leased line services are used to implement the connection. A transmission speed of about 128 kbps is assumed.

3.3.2 Telemetry information

Two types of telemetry information are distributed to operators performing the experiment. The one is HK (House Keeping) telemetry, such as temperatures and satellite attitude information which are from the satellite bus system. The other is experimental telemetry from equipment developed by the experiment participants.

The HK telemetry is distributed after being converted to engineering value in the NASDA satellite control system. Because the HK telemetry contains information related to the health of the whole satellite system, it is monitored in the NASDA satellite control system. Thus, CRL can obtain telemetry results that have been converted to engineering value from NASDA. On the other hand, the experimental telemetry is the information specific to the onboard experimental equipment. Since it has no direct effect on the health of the whole satellite system, it is neither converted to engineering nor monitored by the NASDA satellite control system, and is relayed to CRL as is.

Further, the experimental telemetry is divided into two kinds: RIM2 (Remote Interface Module 2) telemetry; and packet telemetry. Here, the RIM2 is one remote interface module for mission equipment out of two RIMs providing compatibility between onboard equipment that have a legacy telemetry and command interface and CCSDS system by hard wired connection.

RIM2 telemetry is from onboard experimental equipment, each having the telemetry and command interface of the conventional RIM format, and comprises raw telemetry data being enclosed in CCSDS packets by RIM2.

Packet telemetry is also from onboard experimental equipment, but each equipment has a CCSDS interface.

Extraction of the experimental telemetry from the CCSDS packet, conversion to engineering values, limit check, etc. are performed on the CRL T&C system. These processing of packet telemetry are generally assigned to a dedicated unit corresponding to the equipment from which the telemetry comes.

Telemetry data is generally distributed in real-time manner. However, when reception fails due to conditions of the CRL T&C system, the telemetry data stored in the NASDA satellite control system can be retrieved in batch manner afterward. Note that the period for which telemetry data is stored in the

NASDA satellite control system is limited.

3.3.3 Command information

As with the telemetry, there are two types of command information.

The HK command is such a command for switching equipment ON/OFF. The CRL T&C system sends a command in readable text format to the NASDA satellite control system, from which the NASDA satellite control system constructs a CCSDS packet and transmits it to the satellite. Since the HK command is likely to affect the health of the whole satellite, the NASDA satellite control system checks its suitability before transmitting it to the satellite.

On the other hand, the experimental command alters the onboard equipment mode and sets its operational parameters. The CRL T&C system construct a CCSDS packet of the command and transmits it. The NASDA satellite control system then relays it to the satellite without checking its suitability.

From CRL T&C system, commands are transmitted in a real-time manner. Although the NASDA satellite control system has various command functions for practical satellite operations, such as transmitting a command automatically at a specified time, it is not assumed that the CRL uses these functions for the sake of the experiments.

3.3.4 Operational information

The CRL T&C system exchanges operational planning information, orbital information, etc. with the NASDA satellite control system in addition to the telemetry and command.

The operational plan is the schedule information for the satellite operation, including an orbit control plan for the satellite, an experiment schedule, etc. Experimental time requests are submitted to NASDA for reserving the satellite operational time, then coordinated and fixed schedule information is returned from NASDA.

Orbital information contains orbit determination results and forecasted orbital information including predicted results of orbit control maneuvers. It is distributed periodically.

A data distribution protocol is used to exchange these pieces of information and to receive the stored telemetry data from NASDA in a batch manner. The data distribution protocol is NASDA original protocol for practical data exchange. With this protocol, control information is exchanged via e-mail first, followed by transferring data with FTP. This protocol is built into the CRL T&C system.

In addition, data exchange to and from the NASDA HAC experimental facility is also performed using this data distribution protocol.

3.3.5 Time synchronization

Since the CRL T&C system is incorporated into the LAN of the NASDA satellite control system, system time of the CRL T&C system is synchronized to the NASDA system by accessing the NTP server in the NASDA system.

4 Configuration and functions of servers

Servers in the major shared unit are a real-time server, a non-real-time server, a network storage, a firewall, and a simulator of the NASDA satellite control system. An overview of the function of each of these components is given below.

4.1 Real-time server

4.1.1 Communication with the NASDA satellite control system

The real-time server executes reception of telemetry and transmission of a command in real-time manner.

4.1.2 Reception, engineering value conversion, limit check, and storing telemetry

The real-time server performs the following operations to telemetry distributed from the NASDA satellite control system. Note that a dedicated unit performs functions except storing telemetry data if the unit is suited to the telemetry. Moreover, for HK telemetry, since telemetry converted into engineering value is distributed from the NASDA satellite control system, only limit checks and storing are performed.

Unpacking of telemetry data packets

Raw telemetry data is extracted from CCSDS packets.

Conversion into engineering value

The engineering value is calculated from the unpacked raw data, and the status information is retrieved.

Telemetry storage

The telemetry data is stored in network storage.

4.1.3 Command processing

Command editing and transmission

A command sequence is interactively transmitted by the operator by executing an SOP through a command processing window on the terminal. The real-time server relays command transmission between the terminal and the NASDA satellite control system. In this relaying, a readable text (character strings representation of command) form of command that is compatible with the NASDA satellite control system is used for the HK command; CCSDS packets, in which commands are packed, are used for the experiment commands.

Verification

When a command is transmitted, the NASDA satellite control system returns an acknowledgement, and the ETS-VIII satellite returns an execution result answer, both as a part of telemetry. The real-time server returns the execution result to the terminal as one of its telemetry processing functions.

Command history management

Pairs of a transmitted command and a result of verification are recorded and stored as a command history into the network storage.

4.2 Non-real-time server

4.2.1 Stored telemetry reproduction

Stored telemetry data for an arbitrary past period is reproduced by the non-real-time server to allow the operator to monitor telemetries using the same display as the real-time telemetry monitor.

4.2.2 Statistical processing of stored telemetry

Fundamental statistical processing is performed upon a set of reproduced telemetry data.

This processing displays moving averages, maxima, and minima, and graphically depicts the correlation between telemetries.

A straight vertical lines placed at the command execution time can be displayed over the reproduced telemetry graphs to confirm whether the command execution is affected by the status of onboard equipment.

4.2.3 Communication with NASDA's system by data distribution protocol

The non-real-time server handles communications between the NASDA satellite control system and the CRL T&C system, except telemetry reception and command transmission, by real-time server in a real-time manner. Two major types of communications are as below.

Telemetry file download

While the CRL system is switched off or down and telemetry data during this period is required, telemetry data is downloaded from the NASDA as a file by the data distribution protocol. Since the downloaded file is saved as an image of real-time transmission, the file is subjected to the same real-time telemetry processing as that for the real-time telemetry stream.

Transmission/ reception of operational information

Operational plans, orbital information, HAC data, etc. are transmitted and received by the data distribution protocol.

4.2.4 Backup of real-time server

In the event of a failure of the real-time server, the non-real-time server will perform its functions for backup. Changeover (starting of the real-time server process) is done manually by the operator.

4.3 Network storage

Network storage stores received telemetry data, command history data, and the database. The prepared capacity is adequate to store all telemetry data received throughout an experiment period, all command history data, and the database data. To ensure reliability, dedicated hardware based on a RAID system is adopted.

4.4 Firewall

A firewall function is implemented to protect both the NASDA satellite control system and the CRL T&C system at the juncture of these systems.

4.5 NASDA satellite control system simulator

The simulator simulates the NASDA satellite control system both for development and testing the CRL T&C system. It distributes pseudo telemetry data for the tests, receives false commands, and performs pseudo transmission reception of operational information by the data distribution protocol.

5 Configuration and functions of terminals

5.1 Configuration of terminals

Several PCs are provided as terminals, on any one of which the operator can execute telemetry processing and command processing. Data is given and received between telemetry and command processing processes on the terminal and those on the servers by interprocess communications.

The Kashima system for mobile communication experiments have several remote terminals that are linked to the Kashima system by PHS (or cellular phone) to enable telemetry monitoring and command transmission even in the field of a mobile experiment. Although there are some restrictions on the line speed of PHS (or cellular phone), adequate performance for experiments is maintained in practice.

5.2 Telemetry processing

Telemetry processing involves displaying telemetry and limit checks of telemetry values. The limit check is the function to issue an alert when the telemetry values falls outside the range which is defined precedentedly and stored in a database. As a value range, the operator can define two range types: the caution (a range that calls the operator’s attention); and the action (variation in the value that necessitates some counter-actions).

The following four types of telemetry view are available.

List view

All related telemetries are displayed collectively in a single window in list form. All values in the window are updated whenever a new telemetry value is received from the satellite.

Time series list view

Several related telemetries are arranged to form a telemetry array on a horizontal axis, and telemetry arrays at different receiving times are stacked vertically, whereby time series variations of related telemetries are shown in table form. The stacked telemetry arrays can be divided along the vertical axis: one stacked arrays are updated in real-time; while other stacked arrays show past data.

Graphical view

Several telemetries are shown in one chart. A single window can have up to four charts, on each chart up to four telemetries can be plotted. While the default graph selection and parameters are defined in the database, they can be temporarily or permanently changed by the operator.

Block diagram view

The configuration of onboard equipment is shown in a block diagram, and at the position of each component, telemetry values corresponding to that component are displayed. The telemetry values are updated in real-time. Results of the limit check are indicated by changing the color of component blocks.

5.3 Command processing

Command transmission is conducted by executing the SOP. The operator calls and executes the SOP appropriate to the required operation from a previously prepared database. Commands to be transmitted are defined on the SOP.

The SOP checks telemetry data and confirms whether the satellite is capable of executing the operation. If so, the SOP transmits a series of commands automatically, or manually step-by-step. The operator can specify whether to perform verification for each step to proceed to the next command after confirming completion of execution.

An authorization mechanism is prepared to allow only one authorized operator to transmit commands exclusively.

5.4 Utility functions

The following utility functions are prepared in the CRL T&C system.

Editing and transmission reception of operational plan

The operational plan is transmitted and received to coordinate the requested experiment time and the orbit control and other aspects of the ETS-VIII satellite system operation.

Reception of orbital information

Orbital information needed to analyze experimental results in detail is received periodically.

Building database

This utility edits and revises the telemetry database, the command database, and the SOP interactively. Since certain database tools were developed using a programming language other than Java, this utility only works on Windows OSs at this time.

Terminal window printing

This utility prints hard copies of the telemetry processing window and the command processing window in the terminal.

Telemetry data file output

The engineering values are output in the form of CSV to enable further analysis of experimental results.

System management

This utility controls hardware configuration, user registration, and so on.

5.5 GUI examples

GUI examples are shown in Figs.3 to 10.

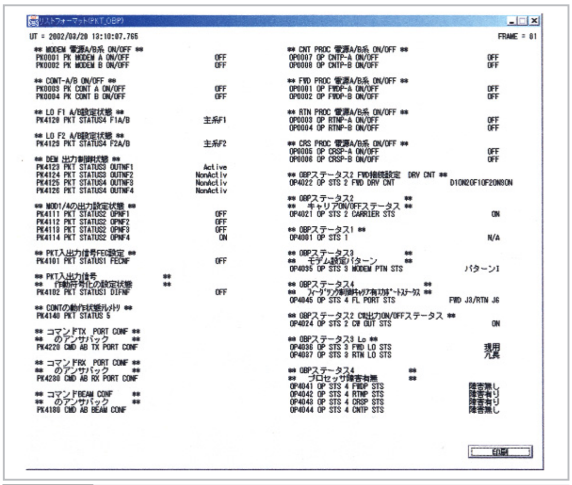

Fig.3 *GUI example, Telemetry list view*

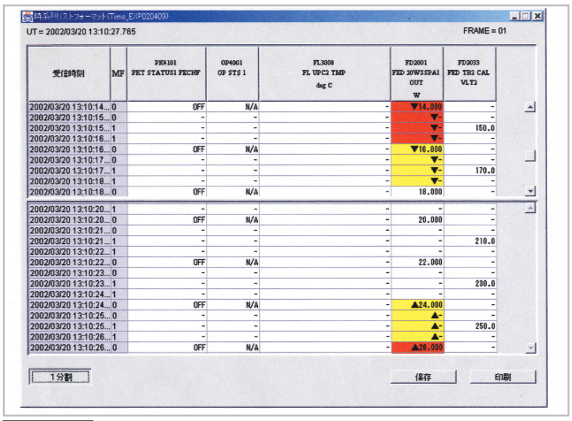

Fig.4 *GUI example, Telemetry time series view*

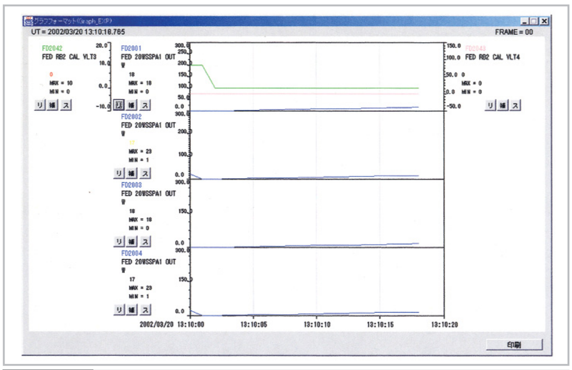

Fig.5 *GUI example, Telemetry graph view*

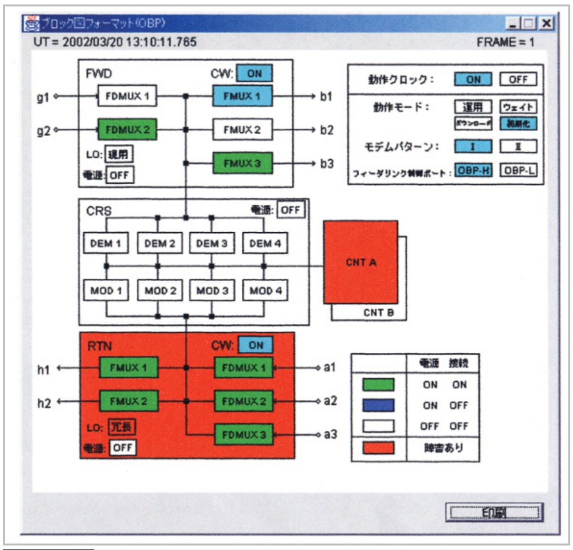

Fig.6 GUI example, Telemetry block diagram view 1

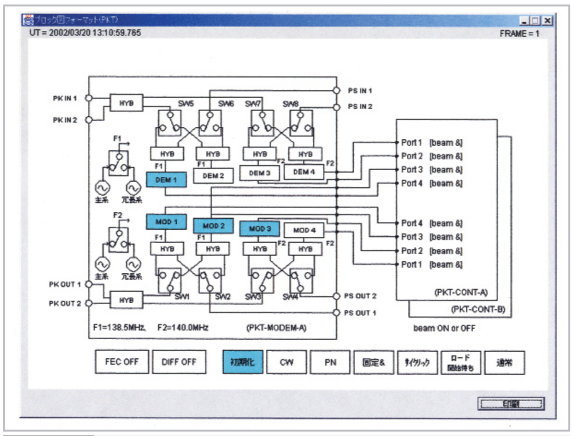

Fig.7 GUI example, Telemetry block diagram view 2

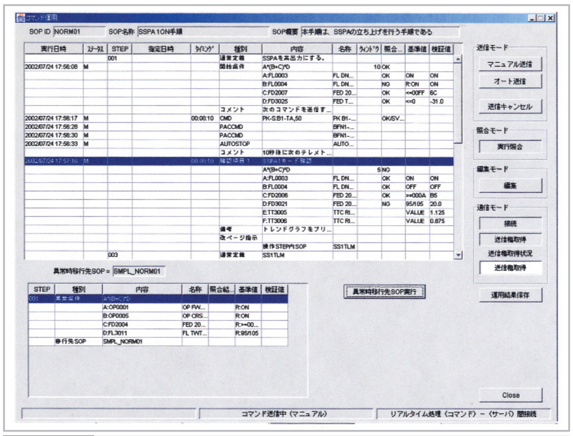

Fig.8 GUI example, Command transmitting window

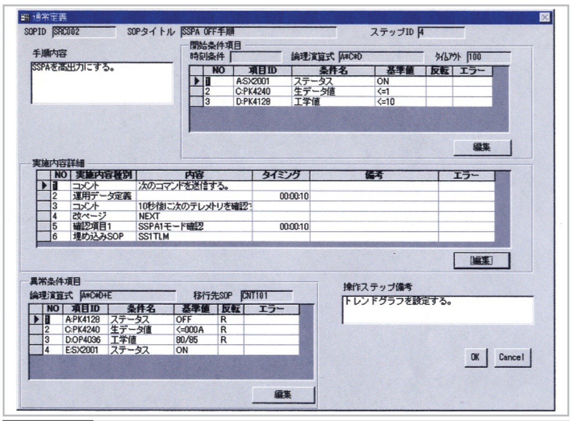

Fig.9 GUI example, SOP defining window

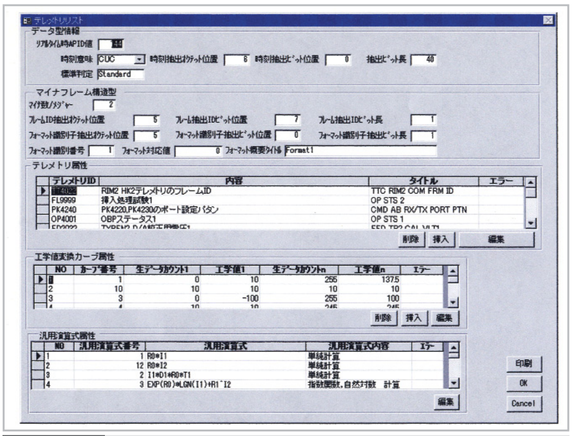

Fig.10 GUI example, Telemetry database editing window

6 Integration of dedicated unit into the major shared unit

Interface specifications between the dedicated unit and the major shared unit were coordinated for each dedicated unit individually, since the number of dedicated units in the CRL T&C system is few. No general-purpose interface specifications were defined.

Fundamental interfaces in the current implementation are as follows.

Telemetry processing

In telemetry processing, from the need for real-time operations, and the need for the capability to display telemetries processed by the dedicated unit together with other telemetries in the same window, a processing program of the dedicated unit was built into the major shared unit and made to work on any terminal. More specifically, a Java class created for the dedicated unit was included in the major shared unit. Since there are some dynamic alterations of the diagrams that represent the configuration of equipment according to the command transmission, the files of the block diagram created by the dedicated unit in each case are accessed via file sharing.

Command processing

Any command transmitted by the dedicated unit is a packet command. Commands registered in advance as SOPs, i.e., commands are previously constructed and filed, are transmitted by normal SOP execution. Command construction is executed on the dedicated unit, and commands are given to the major shared unit by file sharing.

7 Afterword

Development of the CRL T&C system was carried out by placing orders to manufacturers in piecemeal fashion corresponding to areas of development: design work; software manufacturing work based design; and database construction tool manufacturing work. In starting the design work, the author formulated guidelines of the configuration corresponding to a basic design. Manufacturers then gave shape thereto in terms of system implementation and modified the basic design according to its content. The software manufacturing was finished by fiscal 2002.

Hardware, such as host PCs, and OS were prepared by the CRL; implementation of the T&C system for communication experiments and for time comparison experiments (i.e., installation of the software and database construction) are being undertaken with the support of the manufacturers. Figs.11 and 12 show host equipment of the major shared unit for communication experiments installed in the Kashima Space Research Center.

Fig.11 Photograph of T&C system for communication experiments 1

Fig.12 Photograph of T&C system for communication experiments 2

On the other hand, CRL performed interface coordination alongside NASDA to determine interface specifications with the NASDA satellite control system in the early design stage. There was an option to borrow the software system from NASDA to ease interfacing work, but it was finally decided due to the system scale and other factors to develop original system software.

Henceforth, system test, adjustment, and training of operators are planned to proceed in accordance with the ETS-VIII launch schedule. The interface test with the NASDA satellite control system is a major testing milestone and is to be carried forward in close cooperation with NASDA.

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