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AUTOMATIC MONITORING AND DIAGNOSTIC SYSTEM FOR INFRARED IMAGING SURVEYOR ASTRO-F

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Abstract

ISACS-DOC (Intelligent SAtellite Control Software-DOCtor), which is automatic monitoring and diagnostic system for spacecraft, has been developed and operated at Institute of Space and Astronautical Science (ISAS) of Japan Aerospace Exploration Agency (JAXA). It aims to rapidly and accurately capture important changes and signals of anomaly during routine operations without the continuous presence of specialists. Three ISACS-DOC systems have been so far constructed for the features of deep or semi-deep space missions. This paper presents overview of the new generation monitoring and diagnostic system for ASTRO-F, which was launched by M-V rocket No. 8 on February 22, 2006 from Uchinoura Space Center. ASTRO-F is a low-altitude earth orbiter different in various aspects from the deep space spacecraft targeted by the past ISACS-DOC systems. There are certainly many items to discuss about the monitoring and diagnostic system. Improvement items based on past experiences can also be considered as issues of the new system. This paper reports the details of the newly developed ISACS-DOC system for ASTRO-F.

1. Introduction

To satisfy the high-grade observation requirements of a scientific satellite, the number of devices per satellite is increasing, software functions are becoming complicated and enhanced, and the number of operating stations is also increasing with the enrichment of satellite operating facilities. To realize accurate and safe satellite operations, the following issues should be resolved.

- Each component has a function to detect and report an abnormality. Because of various abnormality reports, however, visual checks are substantially impossible.
- It is impossible to identify a true abnormality from multiple reports and determine an appropriate action in a limited time.
- It is not difficult to detect an abnormality in each component, but it is difficult to find the phenomenon of influence between components.
- An apparently true abnormality can be detected by a device but a general judgment must be made not only from abnormality information but also from multiple trend information. However, when there is a great volume of information, it is difficult to find and detect abnormal symptoms by human intuition.
- A trained expert may be able to find the signs of fault by experience and intuition, but an operator for regular operations cannot be expected to find such signs.

Under these circumstances, a monitoring and diagnostic system for satellite operations is needed for flexible operations linking satellite operation planning, tracking control, and data processing. Since 1992, therefore, the Institute of Space and Astronautical Science of the Japan Aerospace Exploration Agency (ISAS/JAXA) has been conducting research and development on a ground system for monitoring and diagnosing the status of satellites using AI techniques. This system is called Intelligent Satellite Control Software-DOCtor (ISACS-DOC) [1, 2, 3, 4]. The purpose of ISACS-DOC is to accurately grasp serious changes and abnormality signs during regular operation without experts in the satellite control room to enhance the safety of satellite operations. If the cause of an abnormality cannot be identified from detected signs, it is preferable to consult an expert by presenting the related information and contact address. If the cause can be identified with high reliability, it is preferable to present diagnostic results and solutions.

To do so, information from the satellite to the ground facilities needs to be integrated and visualized. Therefore, ISACS-DOC can be positioned as a system to support monitoring by an operator in regular operation and to support diagnosis by an expert in abnormal operation. From the general viewpoint of satellite control systems, ISACS-DOC is considered to implement ordinary satellite control systems. The main purpose of this system is to improve the probability of abnormality recognition. To achieve this purpose, the system should be independent of existing satellite control systems and should not affect their operations. Independence of existing facilities makes post-launch tuning and trial monitoring and diagnosis easy and more accurate. Especially, the monitoring and diagnostic techniques verified by this system will contribute to the continuous improvement of satellite operation technology through their incorporation into the next satellite control systems.

So far, this system has been applied to the Geomagnetic Observation Satellite GEOTAIL (launched in 1992), Mars Explorer NOZOMI (launched in 1998), and sample-return probe HAYABUSA (launched in 2003). For GEOTAIL, the first ISACS-DOC system was constructed by using a diagnostic expert system construction tool (packaged software MANADESHIKUN). To date, ISACS-DOC systems for NOZOMI and HAYABUSA have also been developed and put into service.

The new-generation ISACS-DOC is being developed for ASTRO-F, which is a low-altitude earth orbiter different in various aspects from the deep space spacecraft targeted by the past ISACS-DOC systems. There are certainly many items to discuss about the monitoring and diagnostic system. Improvement items based on past experiences can also be considered as issues of the next-generation system. The details of the newly developed ISACS-DOC system for ASTRO-F is presented.

2. Infrared Imaging Surveyor ASTRO-F[5]

ASTRO-F is the second space mission for infrared astronomy in Japan. It was launched by M-V rocket No. 8 on February 22, 2006 from Uchinoura Space Center. It is placed in a sun-synchronous polar orbit of 745 km and given a nickname of ”AKARI”, which means a ”light” in Japanese.

The ASTRO-F mission is an ambitious plan to make an all-sky survey with much better sensitivity, spatial resolution and wider wavelength coverage than IRAS (Infrared Astronomical Satellite, launched in 1983 by the United Kingdom, the United States, and the Netherlands). ASTRO-F has a 68.5cm telescope cooled down to 6K, and will observe in the wavelength range from 1.7 (near-infrared) to 180 (far-infrared) micron. By these equipments, ASTRO-F will make a second generation survey which meets current astronomer’s expectations. There are a large variety of scientific targets which will be investigated by ASTRO-F as follows, 1) to understand the formation and evolution of galaxies, 2) to inquire into the formation process of stars and planetary systems. In order to accomplish these aims, ASTRO-F performs the following observations. 1) an unbiased all-sky survey at wavelengths from 50 to 180 microns, and 2) high sensitivity imaging and spectroscopic observations covering more than several tens of square degrees at wavelengths from 1.7 to 180 microns.

ASTRO-F satellite consists of a cryostat and a bus module. A telescope and scientific instruments are stored in the cryostat and cooled by liquid Helium and mechanical coolers. The bus module takes care of house keeping of the satellite, attitude control, data handling, and communication with the ground system. The height and weight of the satellite are 3.7 meters and 952 kg, respectively. The cryostat and the bus module have independent structures so as to decrease heat inflow into the cryostat. Figure 1 shows ASTRO-F(AKARI) which is ready to be loaded onto the M-V-8 rocket.

Figure 1: ASTRO-F (AKARI)

3. Main purpose of ISACS-DOC for ASTRO-F

ASTRO-F is a low-altitude earth orbiter different in various aspects from the deep space spacecraft targeted by the past ISACS-DOC systems. The greatest difference in terms of ISACS-DOC for ASTRO-F is the requirement for high-speed data processing. This is because of the short visible time (deep space spacecraft HAYABUSA: 8 hours, ASTRO-F: 10 min/pass and 4 passes/day) and high transfer rate of telemetry data (HAYABUSA: 16 Kbps, ASTRO-F: 4 Mbps). In other words, a large volume of data needs to be processed in a short time. For high-speed data processing, it is necessary to enhance the system processing performance, to set monitor items strictly, and to set priorities. Therefore, the first purpose of ISACS-DOC for ASTRO-F is to establish monitoring and diagnostic technology for low-altitude earth orbiters.

Knowledge collection and production vital to this system are expected to be more efficient. Therefore, the second purpose is to develop framework of knowledge collection, which consists of knowledge templates about scientific satellites by utilizing the experiences so far, and support system to build knowledge base. Many knowledge bases were previously collected almost manually by experts and those with experience, and then incorporated into systems. This is expected to be automated to some extent. Therefore, we arranged the knowledge already collected and summarized common knowledge into templates to have many diagnostic rules incorporated into systems automatically. These templates and support system to build knowledge base are realized by EXCEL files and macro features of EXCEL, respectively.

4. Features of ISACS-DOC for ASTRO-F

Figure 2 shows operation image of ISACS-DOC for ASTRO-F. ISACS-DOC system gets both telemetry data, real time data and reproduced data, from data distribution server, and monitors and diagnoses them. Diagnosed results are displayed in a monitor and are sent by e-mail. ISACS-DOC for ASTRO-F consists of following 6 functions.

1. Import : the system imports knowledge base and telemetry definition database and extracts telemetry entry, which are required in monitoring and diagnosing.

2. Telemetry reception : the system receives telemetry data in real time, decomposes them to each telemetry entry, extracts status values, converts to physical values and finally creates primary data, according to the telemetry definition database.

3. Monitoring data creation : the system creates monitoring data which are necessary for monitoring and diagnosing, based on the knowledge-base. A filtering procedure and limit check are applied to primary data, creating secondary data. Complex data are created from multiple data: secondary data and complex data, as needed.

4. Monitoring and diagnosing : the system monitors and diagnoses according to the definition of knowledge-base.

5. Display : monitored and diagnosed results are shown through a HTTP server.

6. Notification by e-mail : monitored and diagnosed results are notified by the e-mail after the spacecraft operation or monitoring and diagnosing of reproduced telemetry data are completed.

4.1 System functions

ISACS-DOC for ASTRO-F can automatically monitor and diagnose reproduced telemetry data which are reproduced from the on-board data-recorder and are sorted according to their TI-time (time by the Time Indicator on spacecraft) as well as real time telemetry data, based on the knowledge base. Both data processing are independent and they can be executed at the same time when reproduced telemetry data and real time telemetry data are received. ISACS-DOC for ASTRO-F can also re-diagnose any past data with the newest knowledge base.

ISACS-DOC for ASTRO-F can freely setup cycle of monitoring data creation and cycle of conducting monitoring and diagnosing, and data collecting period, according to features of monitoring data, and monitoring and diagnostic items. Figure 3 shows schematic view of the data collecting period and the cycle of creation of the monitoring data.

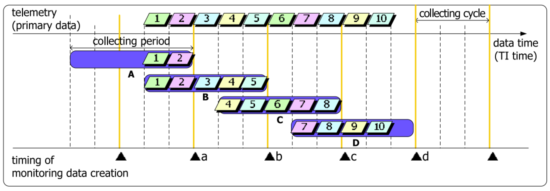

Figure 3: Data processing timing

No dedicated client software is required to check monitored and diagnosed results because a Web based interface is used to show them. Users can check monitored and diagnosed results in anywhere by commonly used Web browser through the network.

Figure 4 shows the main window of ISACS-DOC for ASTRO-F. Detected anomalies are listed in the main part of the window, which is the most important region for ISACS-DOC users. In the left side of the window, there is a list menu for all monitoring items, which show current status of monitoring data regardless of whether an anomaly is detected.

Each listed item is linked to another window (Fig. 5) which shows detailed information: 1) current values of the anomaly data, 2) conditions of anomaly detection, 3) setting values of limit checks, 4) time series plots of not only the anomaly data but also the related other data, which provides valuable clues to an understanding of the circumstances, and 5) messages of anomaly descriptions and the way to response.

Monitored and diagnosed results are notified by the e-mail. Therefore, users can get these results in anywhere.

4.2 Monitoring and diagnosing

ISACS-DOC for ASTRO-F realizes more flexible and effective monitoring and diagnosing than the quick look system of the satellite control system.

Telemetry data rarely have garbled data which are caused by one-bit errors and so on. The garbled data causes incorrect alerts which decrease the reliance on the system. Therefore, a data filtering technique is used in the ISACS-DOC for ASTRO-F. The filter deletes incorrect values in primary data and creates appropriate data as secondary data in order to realize well-established monitoring and diagnosing. Figure 6 shows filtering process

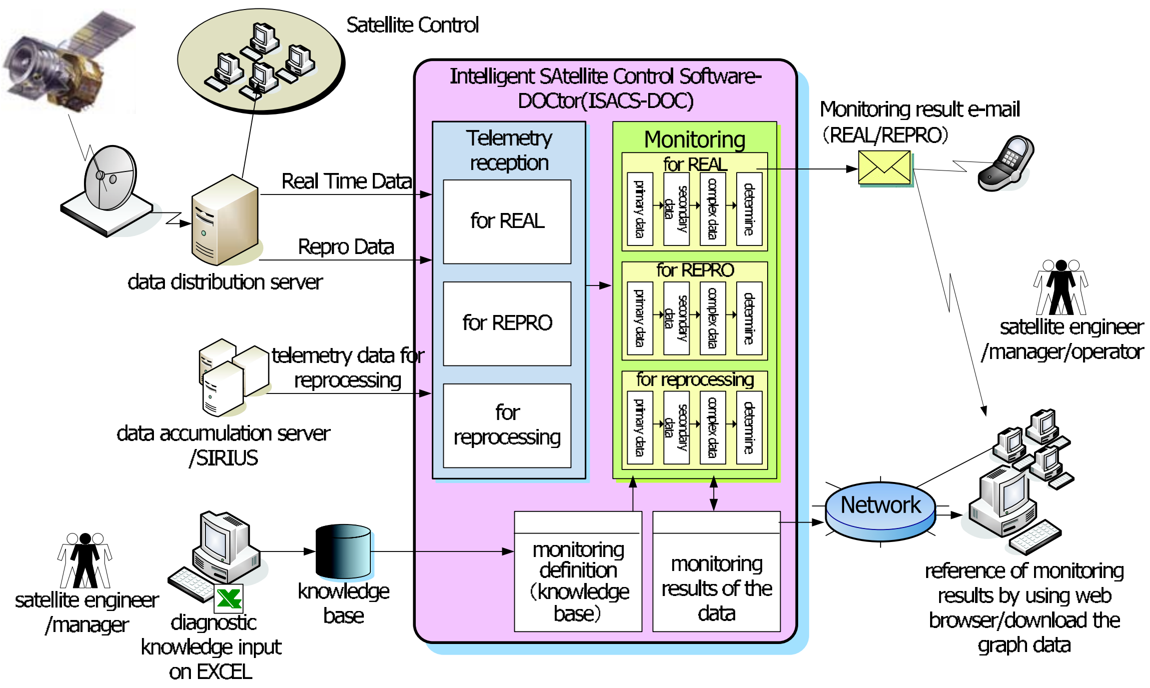

Figure 2: Operation image of ISACS-DOC for ASTRO-F

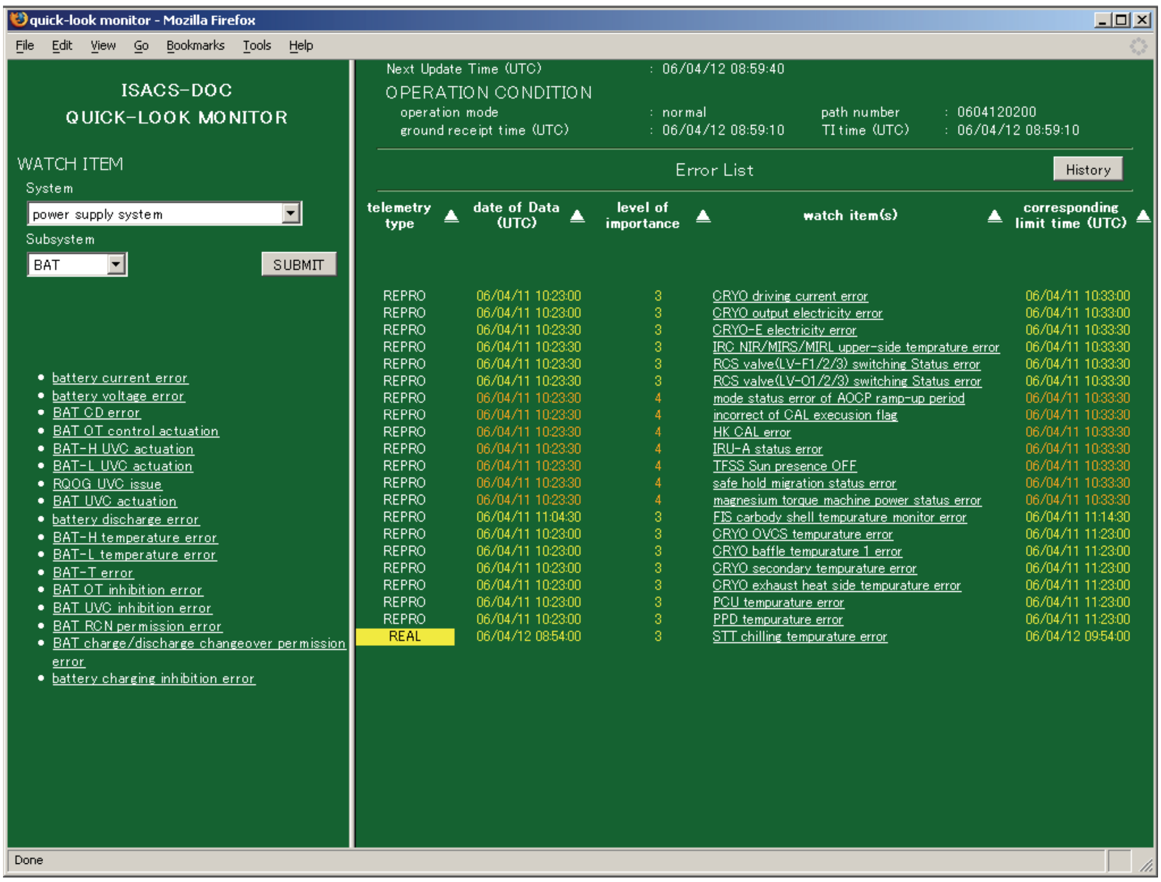

Figure 4: Main window of ISACS-DOC for ASTRO-F

to create secondary data. Secondary data consists of central values which are calculated every collecting cycle. A central value is calculated for each collecting period from the collected primary data according to the filter-

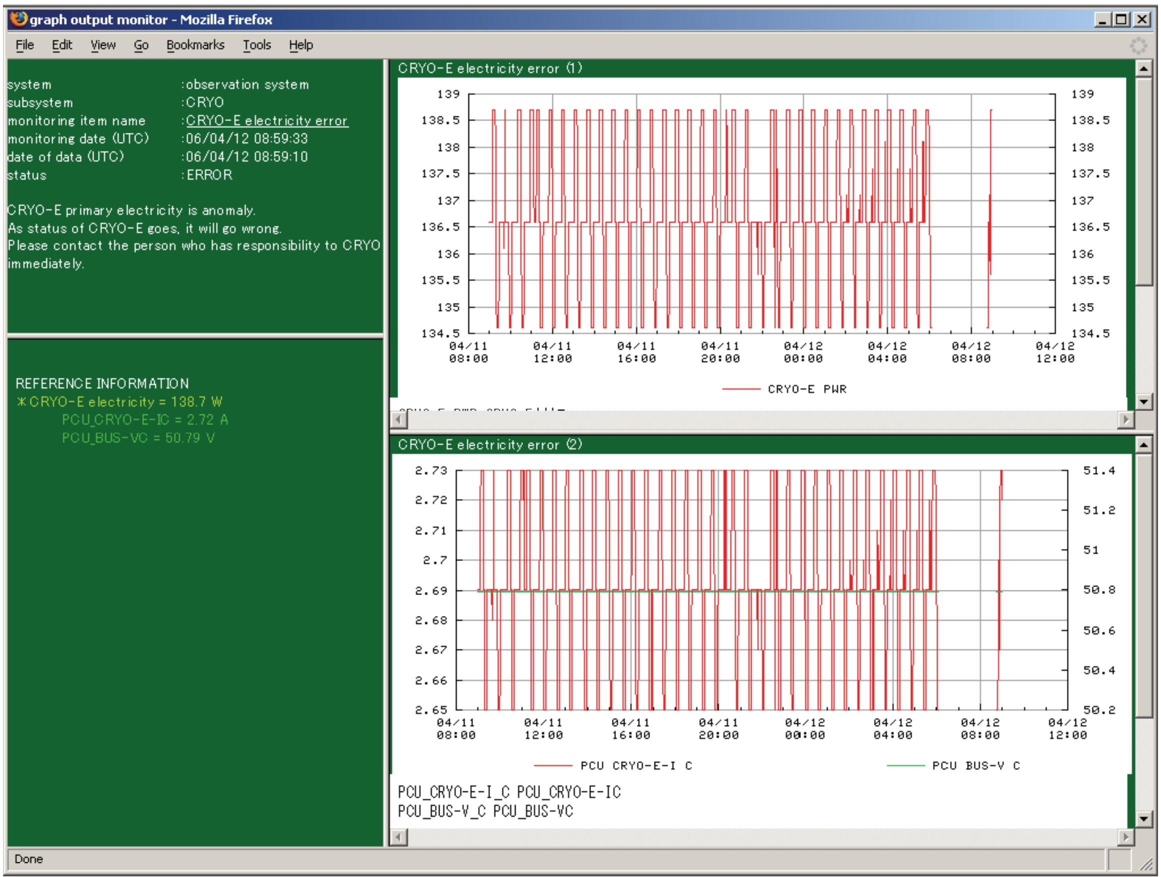

Figure 5: A window which shows detailed information

ing algorithm. Table 1 shows a list of filters which are implemented in the system. In general, the *average2*, an average of collected data except maximum and minimum values, is used for analog data and the *majority*, a mode value of collected data, is used for status data.

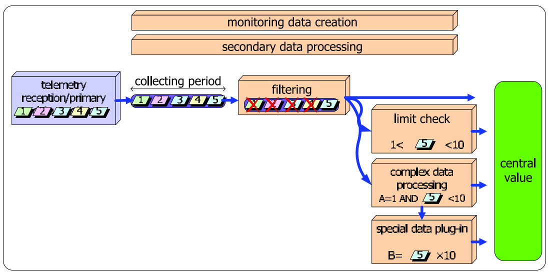

Figure 6: Secondary data processing (filtering)

Complex data are created from multiple data: secondary data and complex data. By using these data, ISACS-DOC for ASTRO-F realizes complex monitoring and diagnosing. The boundary value of the limit check can change according to the current value of specified data. The system can detect continued anomaly by knowing starting time and ending time of specified status. (ex. it should be anomaly if a calibration light source continues to be ON longer than five minutes.) Moreover, the system has following features, calculating expression in a free format as a user intrinsic function, calculation of physical value (ex. electrical power from current and voltage of electricity), predicted value (ex. tank pressure calculation by Boyle-Charle's law), reference of past data (ex. change control of counters), comparison between expectancy and actual showing (ex. difference or ratio between them), and historical trend analysis.

4.3 Knowledge base

The framework of knowledge collection consists of a knowledge templates about scientific satellites by utilizing the experiences so far, and support system to build knowledge base. The framework is constructed by using a software package EXCEL, and collected knowledge are described in templates which are three kinds of EXCEL sheet.

1. Diagnostic input data (status and analog data) : input data which are necessary for monitoring and diagnosing, are defined in this sheet. For example, telemetry name, limit check values, collecting period and creation cycle of data, filtering type and valid/invalid condition.

2. Complex data : new data which are calculated from multiple data, are defined in this sheet.

3. Monitoring and diagnosing definition : monitoring

Table 1: Filters for data processing

Name	Description	data type
head	the oldest data among collected data	analog/status
end	the newest data among collected data	analog/status
maximum	the maximum value of collected data	analog
minimum	the minimum value of collected data	analog
majority	a mode value among collected data	status
identity	a value when all data are identical	analog/status
average1	a simple average of collected data	analog
average2	an average of collected data except maximum and minimum values	analog
average3	an average of collected data except a specified range of data	analog
average4	an average of collected data except maximum and minimum values, and specified values	analog
extraction	extract a specified value	status

and diagnosing items are defined in this sheet. Each entry has conditions of anomaly detection, diagnosing cycle, importance level, time limit for response. It has also the specification of data which are used to draw a graph showing time variation of data, the configuration of the graph, output messages like anomaly descriptions and the way to response. They are displayed in the detail description window.

The knowledge base, which is described in EXCEL files, becomes more easily viewable than previous one. The knowledge already collected are arranged and are summarized as common knowledge into templates to have many diagnostic rules for spacecraft. These templates help to advance the knowledge base which can be used for monitoring and diagnostic system for future spacecraft.

These templates and support system are realized by EXCEL files and its macro features, respectively.

The support system to build knowledge base is realized by using macro features of EXCEL, decreasing input loading of users and having a function to check consistency of knowledge base. The support system automatically imports the telemetry definition database. Several values which are defined in the telemetry definition database, are used as a default value or are displayed as a reference value for data input. Moreover, following functions are realized in order to ensure consistency of knowledge base, format check (required item, fixed word, letter type and number of letters) and consistency check (duplication of entry, magnitude relation of limit values, relation between collecting cycle and collecting period of data, conditional expression for anomaly detection, and lack of required data for diagnosing). They help to build the knowledge base more certainly and efficiently.

The knowledge base is converted to CSV formatted files, which are directly imported by ISACS-DOC for ASTRO-F. Therefore, it becomes incredibly easy to change the knowledge base.

5. Conclusions

The overview of the monitoring and diagnostic system, ISACS-DOC for ASTRO-F was presented. It was a first attempt to develop the monitoring and diagnostic system for low-altitude earth orbiters. Its effectiveness has been proved through the daily operation even in the tuning stage of the knowledge base in the system. Further efforts will continue to enhance the system. ISACS-DOC for ASTRO-F will continue to assist safe operation of ASTRO-F until the end of the mission.

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