ISACS-DOC: AUTOMATIC MONITORING AND DIAGNOSTIC SYSTEM FOR SPACECRAFT

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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 ISAS/JAXA (Institute of Space and Astronautical Science of Japan Aerospace Exploration Agency). It aims to rapidly and accurately capture important changes and signals of anomaly during routine operations without the continuous presence of specialists. Three ISACS-DOCs have been so far constructed for the features of deep or semi-deep space missions. Development of a next generation ISACS-DOC has just started for low earth orbit satellite. This paper presents overview of the next generation system as well as what we learned through the development and operations of the three previous systems.

Key words: monitoring and diagnostic system; spacecraft; anomaly.

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) (Hashimoto et al. 1997; Hashimoto et al. 2001; Hashimoto et al. 2003). 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). Fig. 1 shows the ISACS-DOC system configuration for NOZOMI. With three computers, this system realizes the following two key functions:

1. Data collection function: Data necessary for monitoring and diagnosis is automatically collected from various data distribution devices of the ISAS/JAXA ground control system in real time through a network. From this data, the diagnostic files necessary for diagnosis are created. The data varies widely from orbit data, latest real-time telemetry data, and attitude data to ground station status data. In Fig. 1, the computer called WS is in charge of this function.

2. Monitoring and diagnostic function: For actual diagnostic work in another computer (PC-1 in Fig. 1), diagnostic information files created in function 1 are automatically transferred to this computer. With a satellite-related knowledge database necessary for diagnosis, this computer diagnoses transferred diagnostic information files and displays various information.

Another personal computer (PC-2 in Fig. 1) copies all the data from PC-1. PC-2 can be operated anytime to see the results of monitoring and diagnosis on any past data.

Fig. 2 is an example of abnormalities diagnosed by ISACS-DOC for HAYABUSA. The pressure of a hydrazine tank was lower than the expected value and leakage of He gas was suspected in this case.

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. This paper summarizes the operational knowledge about the monitoring and diagnostic system ISACS-DOC that has been researched and developed and applied to actual scientific satellite operations. The issues and overview of the next-generation system are also described.

2. KNOWLEDGE ACQUIRED SO FAR

This section gives the operational knowledge acquired from the three ISACS-DOC systems developed so far and describes necessary future improvements.

2.1. From Fault Diagnosis to Monitoring

ISACS-DOC was first developed as a fault diagnosis system using an expert system that could indicate several causes of fault with their possibilities. When ISACS-DOC was actually used, however, the presentation of several causes of fault confused the operators and prevented early solutions. Therefore, instead of diagnosis, reliable detection and the presentation of related information and actions were found to be effective. During operation, it is important to present accurate information, such as what is abnormal and what can be done. Identifying the cause of an abnormality with high accuracy is also effective for executing a diagnosis and presenting its results. Since the character of the system has changed from diagnosis to monitoring the following modifications were made. First, the knowledge structure was changed from Fault Tree Analysis (FTA), which is popular for diagnosis and has a deep hierarchical structure , to the flat Decision Tree, which is suitable for monitoring. The new structure was found to be effective. In addition, the diagnostic system was changed from manual data input using an interactive system suitable for diagnosis to automatic data input. ISACS-DOC was also modified to automatically process all data and present an abnormality report to the operator as early as possible.

2.2. Diagnostic Data

Data for diagnosis is now acquired and stored uniquely by ISACS-DOC. At the beginning of development, ISACS-DOC needed to acquire, convert, and store data uniquely because such foundations as EDISON (an engineering database)(Honda et al. 2003), were not established. Now that such foundations are established, linkage with them is necessary. Since diagnostic data itself requires ground station data as well as satellite telemetry data, the total handling of information from satellite to ground will effectively realize more accurate monitoring.

2.3. Linkage with Simulator

The abnormality detection technique proved to be very effective not only by the mere limit check of status information and measured values but also by comparison with simulation data. Since there are a lot of difficulties in simulator development, however, it is risky to totally rely on the simulator. Therefore, we think that ISACS-DOC should not have a simulator but an interface for a simulator and other external modules for switching to an external module as required.

2.4. Notification to the Operator

The monitoring and diagnostic system now has a function of immediate notification to the operator by an alarm display on the monitor screen with an alarm tone. The alarm notification function by e-mail, which is now in test service, requires further study on the result display method and the alarm clearance timing.

2.5. Knowledge Production Techniques

Now, various knowledge production techniques have been proposed and are in use. The main techniques are data mining, automatic learning, semiautomatic learning, and model-with-meaning diagnosis, as well as a rule base

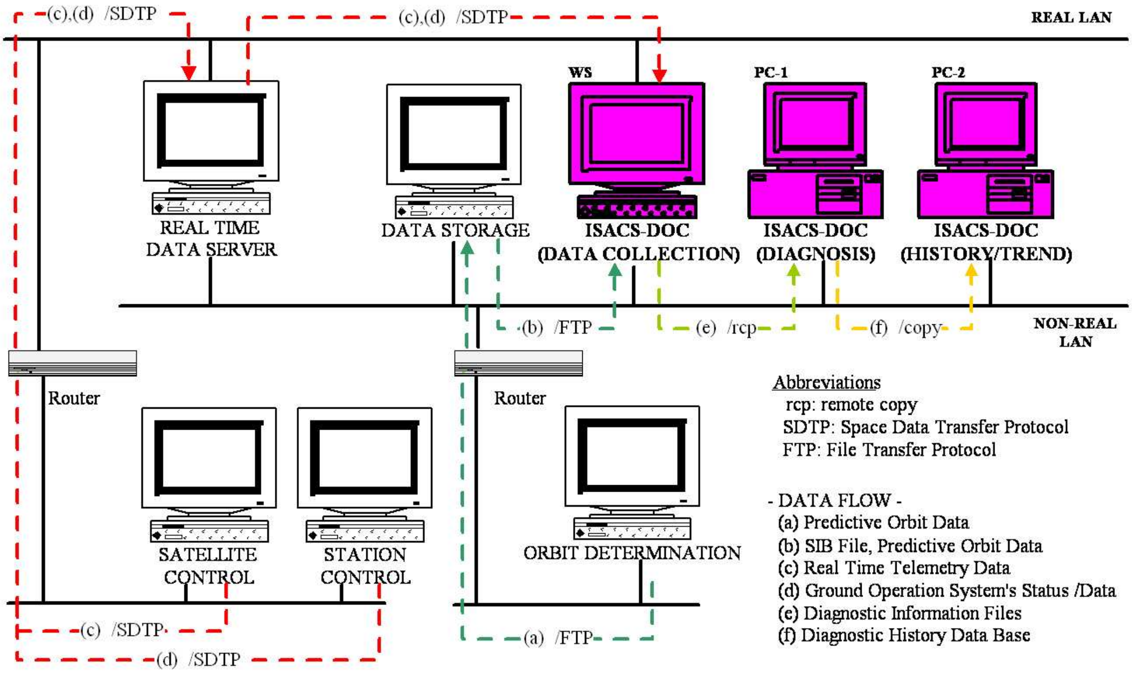

Figure 1. ISACS-DOC system configuration for HAYABUSA

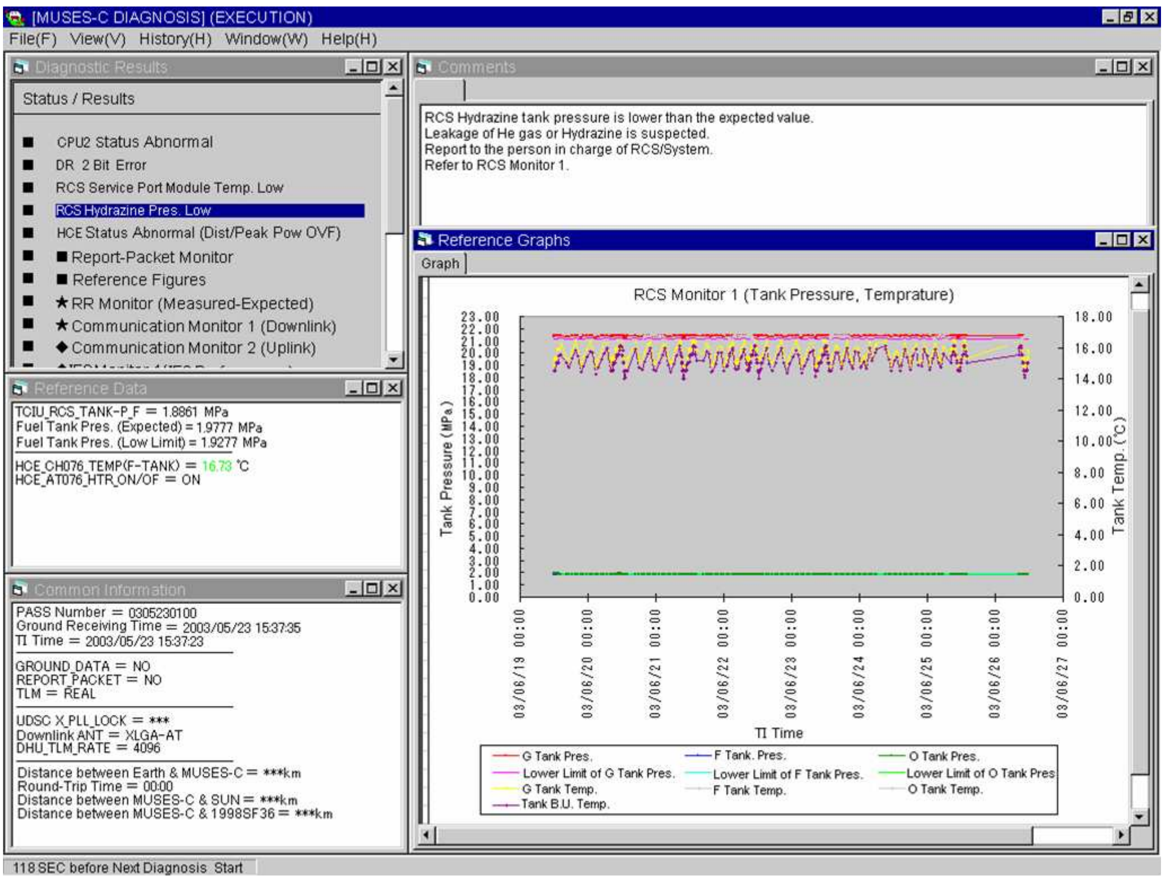

Figure 2. A diagnosed result of RCS abnormality

using the diagnostic tree. As the result of surveying these techniques, we think the currently adopted rule base is the most effective under the special situations of satellite monitoring and diagnosis (the greatest feature is the very small number of samples).

2.6. System development

Now, a total of two ISACS-DOC systems are in service. The oldest system for GEOTAIL has been in service for more than 10 years. The system is expected to work for GEOTAIL for another decade, until the satellite is put out of operation. In the worst case, not the satellite itself but the life of the ground facilities may be significant. At system development, due care should be taken in the selection of the hardware, OS, and development language. It is important to develop a system that allows stable operation and maintenance in a comparatively long span of about 10 or 20 years.

This system is aimed at the actual application to a satellite. A system difficult for an operator to use is put out of service in the end. The operators' opinions are very important. Therefore, the conventional policy of spiral development that improves a system by repetitive design, manufacture, and verification will remain necessary also in the future.

2.7. Significance of This System

Based on the experiences so far, the purpose and significance of the system are reviewed. First of all, 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.

3. ISSUES OF THE NEXT-GENERATION SYSTEM

The next-generation ISACS-DOC is being developed for ASTRO-F, which is to be launched in 2005. ASTRO-F is the second space mission for infrared astronomy in Japan and it has a $67cm$ telescope cooled down to $6K$, and will observe in the wavelength range from 1.8 (near-infrared) to 200 (far-infrared) micron. ASTRO-F will be launched into space by a M-V rocket. 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 next-generation system.

3.1. Support of the Earth Orbiter

The greatest difference in terms of ISACS-DOC 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 (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 may be necessary to enhance the system processing performance, to set monitor items strictly, and to set priorities. To enhance the system processing performance, parallel processing will be implemented. Regarding the priority setting, the top-priority item will be processed by real time and dealt with on the same pass if possible. Items of other priorities may be processed offline and dealt with on the next pass. Processing a large volume of data in a short time will demand high-speed processing by the system and have a great impact on operation. This is because the operator does not have enough time to judge an abnormality and take action, even when the system notifies the operator of the abnormality by a warning. Therefore, the system may need not only to give a mere warning but also to have strong linkage with the satellite control system, such as the automatic preparation of an emergency action command.

3.2. System Arrangement

For next-generation system development, we are planning hierarchical data processing and module configuration. Hierarchical levels are prepared for various conversions from telemetry data and data processing, and the data is defined on each hierarchical level to clarify the role assignments of modules in the system and strengthen the linkage with other systems by using modules of the common infrastructure.

3.3. Knowledge Production Techniques

Knowledge collection and production vital to this system are expected to be more efficient. Therefore, we are considering the preparation of knowledge templates about scientific satellites by utilizing the experiences so far. 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 are thinking of arranging the knowledge already collected and summarizing common knowledge into templates to have many diagnostic rules incorporated into systems automatically.

4. CONCLUSION

Regarding the satellite monitoring and diagnostic system ISACS-DOC that has been developed and operated by ISAS/JAXA so far, this paper introduced knowledge acquired especially during development and operation. The conception of the next-generation system based on these was also introduced. This is our first attempt to support an low earth orbiter with ISACS-DOC, and various issues are anticipated to occur. However, we will continue the research and development for a better system.

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