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High Performance Long-Term Telemetry Analysis System for KARI LEO Satellite Using Spark Platform

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Abstract

For the stable operation of satellites in orbit, the satellite health monitoring task is one of the main tasks of satellite operations. Satellite health monitoring can be divided into real-time monitoring and long-term trend monitoring. Real-time monitoring observes the satellite's normal operation status for the telemetry received during the real-time communication time, and monitors data within a few minutes or a day. The main monitoring points include database-based abnormal status monitoring and operator’s knowledge-based operation status monitoring. Long-term trend status monitoring is to monitor the performance maintenance status of the entire operating period, and it can be used for evaluation of performance degradation status and early detection of component failures through performance trends for major telemetry. There are several difficulties to be solved in long-term trend status monitoring. First, there are thousands of telemetry points that need to be monitored for each satellite. Second, the amount of data that needs to be processed is bulky because data for the entire period of satellite operation must be handled. Third, the number of operational satellites including satellite constellation is continuously increasing. These three factors greatly increase the size of data to be processed in the satellite control center. In order to deal with the difficulties of processing bulky amounts of data, high-performance data processing and automation of long-term trend evaluation were required. For high-performance data processing, the processing algorithm was improved, and telemetry parallel processing and distributed processing were performed. Parallel processing performs simultaneous parallel processing of the requested TLM as many as the number of logical processors of the computer. It was implemented to distribute data by utilizing the Spark platform, and through this, the amount and speed of processing increased as the number of processing PCs increased. Through this, the number of concurrently processed TLMs is processed as much as the number of PCs and the number of logical processes, greatly increasing the processing speed. Through the implementation and operation of the system, tasks that took hours to process data for the entire period of satellite operation can be processed within minutes. For the processed long-term trend data, performance evaluation was automated through OOL(Out-Of-Limit) database, Trend Index, and outlier detection scheme. In this paper, the concept, architecture, and operation result of a high-performance processing system are described.

Keywords: Satellite Operations, Telemetry Processing, Trend Analysis

1. Introduction

KARI has been operating totally nine satellites including five LEO satellites, three GEO satellites, and one lunar orbiter since the operation of KOMPSAT-1 in 1999. For the stable operation of satellites, monitoring of operation status for satellites and in-orbit performance monitoring is one of the important tasks. The first thing to pay attention in recent satellite operation in KARI is the continuous increase in operational satellites. The second is that the satellite life time in operation is long. In terms of satellite health monitoring, this means that the data to be processed continuously increases. In this trend of increase, there are limits to the increase in operating staffing and budget. Therefore, the operation work should be improved through advancement including integration and automation of the mission operations systems. In addition, considering the mass increase in data processing, the data processing speed is continuously improved.

In the satellite telemetry monitoring system, it is developed based on a multi-mission operation system and is commonly applied to all satellites. The core processing engine dramatically improved the processing speed by performing parallel processing. In addition, when processing long-term period data, it is possible to shorten the processing time of long-term data by performing distributed processing based on the spark platform. In this paper, we introduce the status of satellite operation in KARI, the status of satellite telemetry monitoring system, and the development and operation status of Long Term Trend Analysis System.

2. KARI's Satellite Mission Operations Status

There are two important things to consider in terms of recent satellite operation in KARI. The first is that satellites are operating for a long time, far exceeding their mission life time. As of January 2023, KMOC(KARI Mission Operations Center) is operating a total of 8 satellites, including 5 LEO satellites and 3 GEO satellites. LEO satellite includes KOMPSAT-2, 3, 5, 3A and CAS500-1 satellite. GEO satellites include COMS-1, GK-2A and 2B. Most of the satellites are operating far beyond their Design Life and have been operating for more than 10 years, while KOMPSAT-2 has been operating for 16 years.

L/G	Satellite	Launch	Design Life	Mission Status	Mission Life(Y)	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23
LEO	KOMPSAT-2	'06-07-28	3	Extended	16.5																		
	KOMPSAT-3	'12-05-18	4	Extended	10.7																		
	KOMPSAT-5	'13-08-22	5	Extended	9.4																		
	KOMPSAT-3A	'15-03-26	4	Extended	7.8																		
	CAS500-1	'21-03-22	4	Designed	1.8																		
GEO	COMS	'10-06-27	7	Extended	12.6																		
	GeoKOMPSAT-2A	'18-12-05	10	Designed	4.1																		
	GeoKOMPSAT-2A	'20-02-19	10	Designed	2.9																		

Fig. 1. KARI's Satellite Operation Status

The second is that it is expected that the number of satellites will be increasing continuously. Among them, the number of low-earth orbit satellites continues to increase, and it is expected that 18 satellites will be operated in 2026 and 70 satellites in 2030. Considering these two points, a satellite telemetry monitoring system is needed to be developed. Considering the long-term operation period of satellites, it is necessary to monitor the status of satellites during the entire operation period, and to know the status of a single satellite, it is necessary to quickly process and display long-term data. In addition, it is necessary to continuously upgrade and automate the multi-mission system in consideration of the long-term operation satellite.

3. Satellite Monitoring Concept and Requirement

For stable satellite operation, satellite condition monitoring is an important part of satellite mission operation. KARI made continuous efforts for stable telemetry monitoring. In addition, considering the increase in operational satellites, a multi-mission integrated system was developed. The need for short-term monitoring, medium-term monitoring, and long-term trend monitoring of satellite was considered. In developing the long-term satellite status monitoring system, the speed of data processing was considered considering the increase in satellite operating period.

A. Satellite Monitoring Concept and Key Requirement

Satellite telemetry monitoring largely consists of concepts of real-time, non-real-time and long-term monitoring. Real-time monitoring includes real-time operational state monitoring of satellites during real-time contact with satellites, OOL (Out Of Limit)-based limit violation monitoring, and satellite event monitoring concepts. Functions in the real-time satellite status monitoring system include a function of extracting data from the received satellite status data and delivering it to the user. The extracted data includes GPS data for determining the orbit of the satellite, remaining memory space of the payload for monitoring the imaging time of the satellite, and power and fuel status data of the satellite. The non-real-time analysis function uses stored telemetry to perform analysis in the form of text and plot to analyze the operation status and abnormal condition of the satellite. The plot function visualizes related telemetry in the same time zone to analyze correlation. Telemetry can extract and visualize data from several hours to tens of days for analysis. Long Term Trend Analysis is a function that monitors the maintenance and change of satellite performance during the entire period of satellite operation. Through the extraction of satellite status statistical values, etc., the status of change is monitored through monitoring and plotting. The main requirements derived from the operating concept for this are as follows.

Key Requirement is as follows.

Item	Key Requirement
Real Time Monitoring and Processing	● It should be easy to monitor the operation status of the satellite. ● When an abnormal condition occurs in a satellite, it should be easy for the operator to recognize. ● The setup process should be easy when installing and starting the system.
Post-Processing	● A series of processes of receiving and processing data should be automated.
Offline Analysis	● Multiple telemetry items and telemetry data must be processed in parallel. ● When processing a large number of data, the processing speed must be short.
Long Term Trend Analysis	● Data processing speed should be short when processing long-term data including the entire operation period. ● It should be possible to easily recognize the change in satellite status performance.
Common	● It must be a multi-mission operating system that can be commonly applied to all satellites in operation. ● The operation of the system should be automated to an appropriate level.

B. System Architecture of Telemetry Data Processing and Monitoring

Telemetry data processing and monitoring systems are classified into four groups. The bottom group consists of the "Receiving and Archiving" group that receives and stores data, the "Processing" group that is responsible for DB and processing by satellite, and the Application group that utilizes it. In addition, it consists of the System Management group that has system management functions.

- Application : RT View(Real Time Monitoring), TM Post-Processing, Telemetry Analysis System(Offline Analysis), Trend Analysis(Long Term Trend Analysis)
- Processing : TLM DB, Processing Core Engine, etc.
- Receiving and Archiving : Link Management(to Modem), TM Receiving and Archiving, TM Sort
- System Management : Patch Management, Logging, etc.

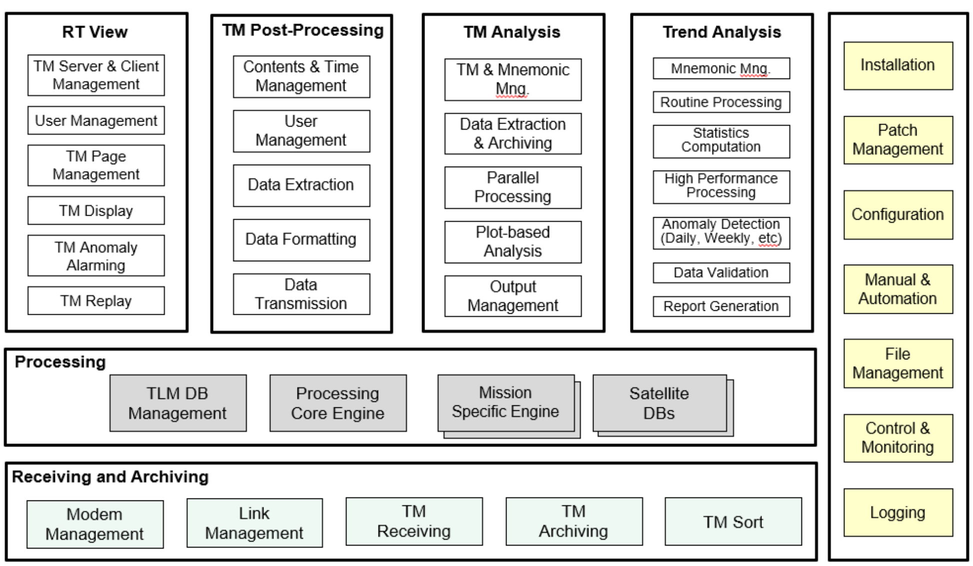


Fig. 2. Architecture of Telemetry Monitoring Applications

Based on this concept, four application software are composed. It consists of RT View that monitors real-time telemetry, "TM Post-Processing" that receives, processes, and delivers telemetry data to users, and TM Analysis that analyze TM offline. Last is the Trend Analysis software for long-term satellite trend analysis. Figure 3 shows the GUI of RT View and TAS. It is a multi-mission system that can perform the missions of KOMPSAT and CAS500 satellites with the same software. The most essential part of the TM system is the Processing Core Engine. The extraction algorithm has been improved to reduce the telemetry processing time, and it has been improved to enable parallel processing during TM analysis. Since it is operated as a multi-mission system that can be commonly used for each satellite, the usage of the system operations is the same, so there is an advantage that user training for new satellites is not required. In addition, when developing a system for a new satellite, development and implementation can be quickly performed, and verification can be performed easily.

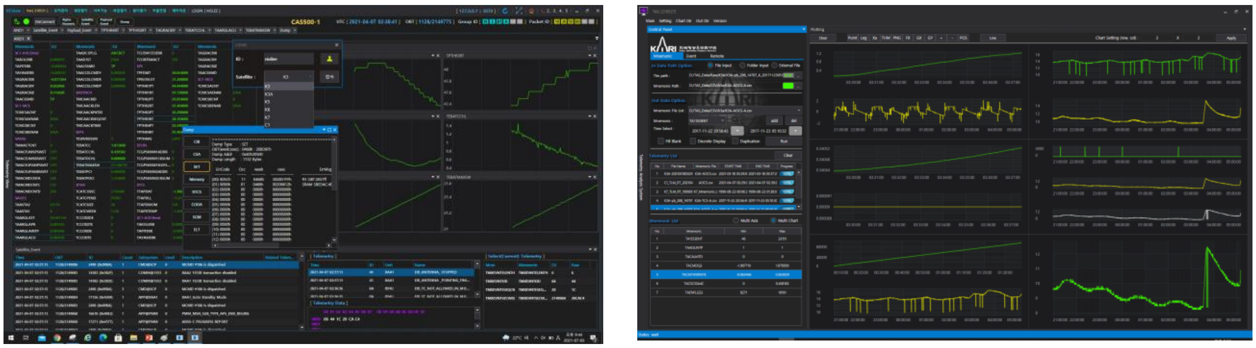


Fig. 3. Telemetry Monitoring Applications(RT View & TAS)

4. High Performance Trend Analysis System

It is necessary to monitor satellite status and performance during the entire period of satellite operation. Since the satellite status must be monitored during the entire period of satellite operation, the extracted telemetry value is enormous. If the extracted value is stored as it is, the storage capacity increases, and if necessary, the processing time increases. In addition, in the case of practical satellites, since the number of telemetry data reaches thousands of data, an appropriate processing method is required. To solve this problem, KARI performed parallel processing in data processing and performed high-speed processing through distributed processing with several computers. In addition, trend monitoring was performed by calculating daily-based statistical values to express the trend of satellite performance over several years. Daily processing is performed on a daily basis, and when a specific telemetry extraction is required, it is necessary to quickly process data from the start of operation to the present point.

A. Key Requirements

The purpose of Trend Analysis system operation is to monitor the performance trend during long-term satellite operation. It will be important to monitor the number of telemetry data as much as possible. The operator will be able to assess the changing trend of the telemetry status compared to the past by systematically monitoring and calculating the report including the plot. The main requirements are as follows.

- Parallel Processing : Parallel processing is performed by each logical processor mounted on the computer in charge of processing for each telemetry.
- Distributed Processing : Based on the Spark platform, processing is distributed to multiple computers, and after processing, it is collected and processed
- Statistical value calculation : Calculate the representative value of the day for trend trend monitoring (Min, Max, Avg)
- Limit Violation Check with alarm table : Limit Violation Check based on OOL (Out-Of-Limit) when processing telemetry data received on the same day
- Trend Monitoring : Telemetry's long-term trend is expressed through the representative values and plots.
- Automation : Automating a series of tasks such as receiving, processing the telemetry data and generating the report file.

B. Parallel Processing of Core Engine

Telemetry point each satellite consists of thousands of data. There are cases in which ranging from tens to hundreds of telemetry are processed for monitoring and analysis. Also, there are cases in which multiple telemetry files are processed. At this time, if a single process is performed, a lot of processing time will be consumed. The KARI TM system increased the processing speed by performing parallel processing as much as the number of logical processors in the computer. By processing using the parallel processing function, it is advantageous when analyzing multiple telemetry numbers using data of several hours or days. By setting "ThreadCount" in the system settings, it is adjusted as much as the number of logical processors the computer has, so that the computer's resources can be utilized to the maximum.

C. Distributed Processing using Spark Platform

When processing of data that is not processed on a daily basis is required, it is necessary to quickly process the data for several years. For fast data processing, each computer performs parallel processing, and a plurality of computers performing parallel processing are placed to perform distributed processing. Distributed processing utilized the Spark platform. Spark is an in-memory, high-speed processing engine for large data and a general-purpose distributed cluster computing framework. Spark has 10 times faster than disk-based and 100 times faster memory operations compared to MapReduce processing. The structure of the system is shown in Figure 4. Trend Commander has a function to monitor system settings and operating status. When a request is made to the master PC, the work to be processed by node is distributed and allocated. After processing is completed at each node, the Master PC collects and completes the data. The processed data is stored in the NAS. To perform data processing quickly, telemetry data is stored in the local disk of each node PC, and SSD is installed to maximize processing speed.

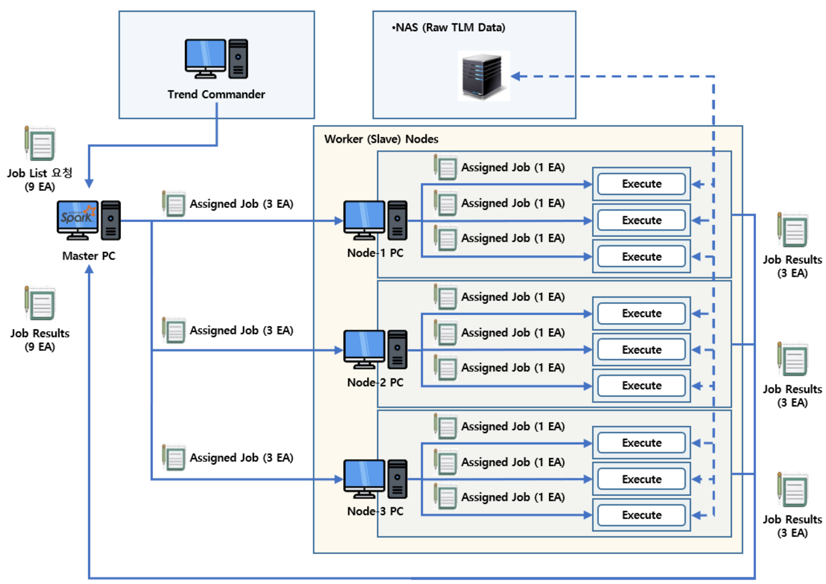
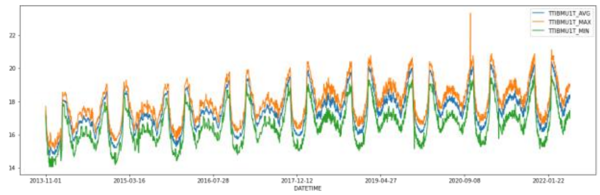


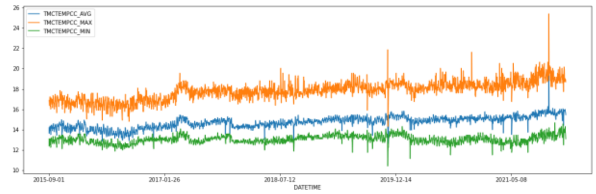
Fig. 4. Architecture of Trend Analysis System

D. System Operations Concept and Result

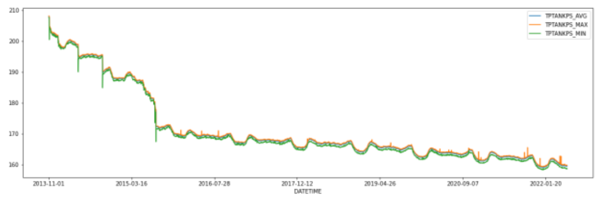
Day-to-day operations are run on an automation basis. Telemetry data is received and stored when communicating with a satellite using a contact schedule. At this time, the Limit Violation Check is performed using the OOL DB. Statistical values (Min, Max, Avg) are calculated and stored for each telemetry item once a day using telemetry stored for each satellite. At this time, the telemetry item for each satellite is a concept of storing and using items that require continuous monitoring in advance in the DB. Therefore, about 200 major telemetry items selected from thousands of telemetry items for each satellite are continuously processed and monitored. Utilize the processed data to create and save a Trend Report once a week or once a month. In the case of non-preselected telemetry, additional processing is required. At this time, the function of high-speed processing occupies an important part. In data processing, invalid data needs to be excluded when trend monitoring and plotting. Figure 00 shows a function that analyzes long-term data and easily checks the validity of the data for a specific date. Figure 5 shows the performance trend for each telemetry item obtained through long-term data processing.



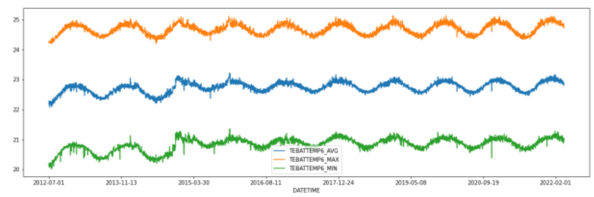
[K5, IBMU Temperature]



[K3A, CEU Temperature]



[K5, Propulsion Tank Pressure]



[K3, Battery Temperature]

Fig. 5. Trend Analysis Plotting

Before the development and operation of this system, it took about 1 minute to process the one day data for one telemetry item. The processing time was drastically reduced through the modification of the processing algorithm, improvement of parallel processing and distributed processing. It was confirmed that it took 50 seconds to process 1 year of data and 2 minutes and 35 seconds to process 5 years of data. It was confirmed that 10 years of data was processed within 5 minutes. Additional time can be reduced by increasing the number of nodes.

Year	Duration	Processing Time(s)
2017	1yr	50
2017~2020	3yr	135
2017~2022	5yr	215

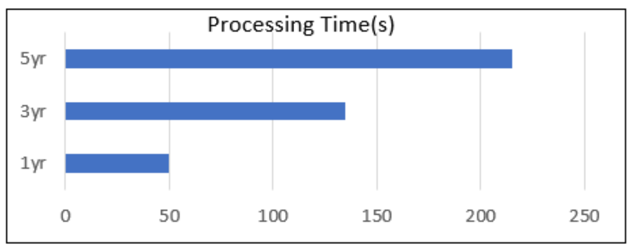


Fig. 6. Performance Assessment of Trend Analysis

6. Conclusions

The satellite status monitoring system was continuously improved by considering the status of satellite operation of KARI, including the increase in the number of operational satellites and the increase in operating period. Through this, the development of a multi-mission operating system commonly applicable to multiple satellites, a parallel processing-based Core Processing Engine that can quickly process and analyze telemetry data, and a spark platform-based long-term data processing at an appropriate time Term Trend Analysis system is developed and operated. Through the development of the TA system, 10 years worth of data was processed in 5 minutes and the results were provided to users. In the future, considering the increasing number of satellites, we plan to continuously improve the system to automate the judgment of satellite conditions based on AI.

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