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Long-Term Trend Analysis System for Low Earth Orbit Satellites

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Abstract

With the New Space Era, the space industry is developing rapidly, and the number of satellites to be operated is also increasing exponentially. As a result, efficient management of satellites has become more important, and for this, monitoring and analysis based on satellite state of health (SOH) data are essential. The Korea Aerospace Research Institute (KARI) developed the Long-Term Analysis system (LTA) to analyse and manage the housekeeping trend of low-orbit satellites in the long term. The system focuses on improving the operational efficiency of satellites by effectively processing and analysing the satellite status data. While existing systems mainly relied on short-term trend analysis, the LTA system enables early detection of satellite anomalies and quick response to problem situations through long-term trend analysis. The system is designed based on the master-slave structure, and the master PC manages tasks centrally, and each node PC processes data independently to maximize performance. In addition, the TM Core is used to increase scalability and optimize performance, and it provides an environment where data can be visually analysed while reducing the consumption of human resources through automatic processing and report generation functions.

It also contributes to the stable operation and life extension of the satellite by checking the periodicity of satellite state changes and analysing defect conditions. In particular, large-scale data can be processed quickly based on distributed processing, and the efficiency of large-scale data management has also been increased through database-based data management. This system also extracts significant patterns in terms of data mining and provides important information for analysing changes in the state and performance of satellites and will be further advanced through continuous functional improvement in the future. This paper details how the LTA system's architecture, main functions, and analysis results contribute to the improvement of satellite operational efficiency.

Keywords: Long-Term Trend Analysis, Long-Term Analysis System, Distributed processing, Master-slave structure

Acronyms/Abbreviations
State of Health (SOH)
Korea Aerospace Research Institute (KARI)
Long-Term Analysis system (LTA)
Korea Multi-Purpose Satellite (KOMPSAT)
Compact Advanced Satellites 500 (CAS500)
New Space Earth Observation Satellite Constellation for National Safety (NEONSAT)
Long-Term Analysis Master (LTAM)
Long-Term Analysis Client (LTAC)
Out of Limit (OOL)
Electrical Power Subsystem (EPS)
X-band Transmitter (XTX)

1. Introduction

The KARI operates multiple low-earth orbit satellites, including the Korea Multi-Purpose Satellite (KOMPSAT), Compact Advanced Satellite 500 (CAS500), and the New Space Earth Observation Satellite Constellation for National Safety (NEONSAT) [1]. Due to the development of the space industry, the number of satellites to be operated is increasing every year, and a systematic management plan to operate them efficiently and stably is essential. Satellites are exposed to harsh space environments with limited lifespans and resources. To ensure the stability, reliability, and efficient management of these satellites, monitoring and analysing satellite status and performance is essential [2]. For this purpose, satellite status data is utilized, which includes information necessary for analysing the satellite's condition, such as temperature, power status, communication status, and attitude control. This data is the only way to know the satellite's SOH. Therefore, the method of analysing satellite status data has a significant impact on improving the stability and efficiency of satellite operations. Until now, much of the research and development has focused on short-term trend analysis. However, as the number of satellites to be monitored is increasing dramatically, research on long-term trend analysis must also be actively pursued.

There are several reasons why long-term trend analysis is necessary. First, it allows for the detection of anomalies by checking periodicity, enabling the prevention of issues before they occur. Second, performance analysis can optimize performance and identify areas for improvement in future satellite development. Third, analysing defect patterns can help develop strategies to prevent similar situations in the future, contributing to the extension of satellite lifespan. To perform long-term trend analysis, an appropriate system must be established. Because the amount satellite status data accumulated during a satellite's mission period is huge, a system optimized for processing and analysing large amounts of data is required. In response, KARI has developed the LTA system for long-term trend analysis. The LTA system reduces human resource consumption through automatic processing of satellite status data, visualizes data through the plot function for intuitive analysis, and enables the systematic organization and sharing of analysis results through the report generation functions. This paper describes in detail the structure, design, and operation process of the LTA system that can produce meaningful results in terms of data mining, as well as the data analysis results extracted by processing the satellite status data actually received.

2. System Architecture of LTA

The LTA system is designed to perform task execution systematically through interactions between the system's various components. This section describes the system components and system design.

2.1 System Components

Figure 1 shows the LTA system, which comprises a master PC, multiple node PCs, four software tools for data processing and report generation, data storage for satellite status data, and a database for processed data. The functions and characteristics of each component are as follows:

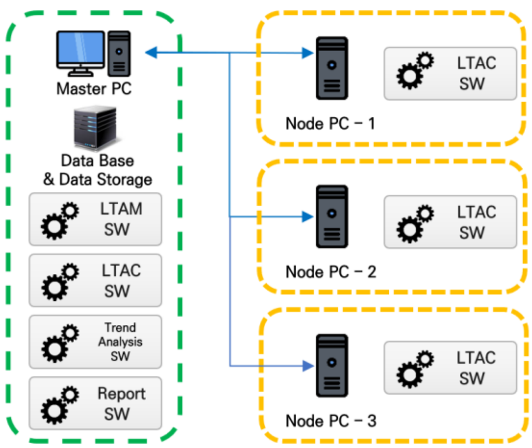


Fig. 1. Components of the LTA system

- Master PC: Master PC is responsible for the management and distribution of all tasks. Through Long-Term Analysis Master (LTAM) software, satellite state data processing tasks are distributed to multiple node PCs and perform important roles such as prioritization, placement, and monitoring of tasks. The advantage of the master PC is its ability to efficiently manage tasks centrally and maximize the benefits of distributed processing.

- Node PC: Node PC performs tasks individually through Long-Term Analysis Client (LTAC) software and processes satellite status data assigned by the master PC. The Node PCs operate as independent devices that perform data processing and are capable of distributed processing. This enables the system to improve processing performance and scalability by increasing the number of Node PCs. Additionally, in the event of a failure, other nodes can take over the processing tasks, enabling a fault-tolerant system and enhancing overall system reliability.

● LTAM Software: The LTAM software runs on the master PC as the central manager of the system. It registers to handle tasks automatically or manually through TCP/IP modules and distributes them to each node. It also performs the function of generating reports based on the results of data processing. LTAM maximizes the efficiency of automation and distributed processing and increases the stability of work through monitoring and management.

● LTAC Software: LTAC software runs on each node PC, processes satellite status data, and stores it in the database through the TCP/IP module. It supports parallel processing to improve real-time processing speed and ensures consistent data storage through smooth communication with the database. Additionally, LTAC software can operate on both the master PC and node PCs to process data.

● Trend Analysis Software: Trend analysis software allows operators to analyse trends based on data stored in the database. This software provides the function to visually express the data desired by the operator using the Plot module, clearly showing long-term pattern changes. This contributes to the analysis of satellite status and performance.

● Report Software: Report software is used in LTAM and trend analysis software in console format. This software searches for necessary data using the database search module and generates plot images and a report in PDF file format. This enhances the efficiency of trend analysis tasks and quickly delivers key information needed for decision-making.

● Data Storage and Database: Satellite status data received from satellites is stored in the Data Storage, and processed data is stored in a PostgreSQL-based database. By using PostgreSQL, the system ensures stable processing and retrieval of large-scale data, and it efficiently handles complex queries. This serves as a reliable storage system for long-term data preservation and analysis.

Figure 2 shows the functions of 4 software described above.

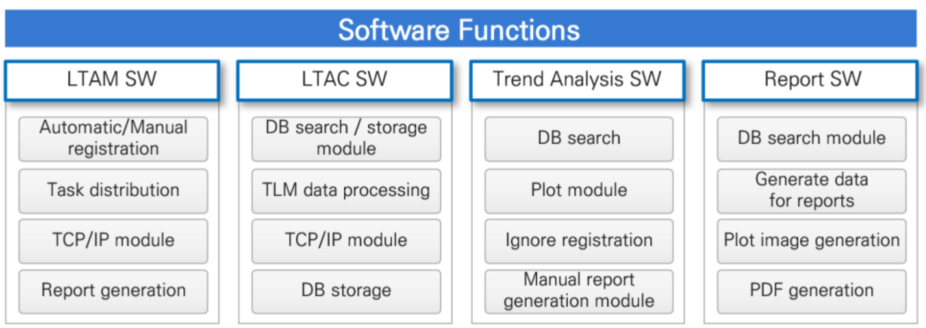


Fig. 2. Functions of 4 software

2.2 System Design

The LTA system processes data based on the TM Core and supports distributed processing of large-scale data through a master-slave architecture. Additionally, the system is designed to operate in stages, from satellite data collection, processing, and storage to report generation and trend analysis. The main design contents are as follows:

2.2.1 Scalability Provision and Performance Optimization through TM Core

The amount of satellite status data accumulated during the mission period is huge. To analyse and process this large-scale data, a powerful analysis engine is required. Accordingly, the LTA system uses the TM Core framework, which plays an important role in data processing and analysis. TM Core is designed to process satellite status data received from various satellites. By standardizing the data processing structure, the system can be expanded simply by adding a library file when a new satellite with a different data format is introduced, without making major changes to the core system. This is possible because the system is built with a modularization, allowing it to adapt flexibly to changes in data formats. As a result, it helps reduce system development and maintenance costs while providing scalability to quickly integrate and process data from new satellites. Additionally, by analysing only the telemetry defined as necessary by the operator instead of analysing all telemetry included in the satellite status data, it contributes to performance optimization by reducing processing time. As a result, TM Core plays an important role in improving the scalability and performance optimization of the system as a core engine that quickly processes and comprehensively analyses satellite status data.

2.2.2 Master-Slave Structure-Based Distributed Processing

The LTA system is designed on a master-slave structure to efficiently process and manage large-scale satellite status data. The master PC manages the entire task, and node PCs independently process data. Therefore, each node can focus only on data processing, which improves processing performance. Additionally, the distributed processing structure ensures that even if one node encounters an issue, it does not affect the tasks of other nodes, thus enhancing the system's availability. Additionally, by using multiple nodes to process data at the same time, processing time is reduced, and the system is easily scalable by adding more nodes if the data load increases. And since the processed data is managed by accessing the database only through the master PC, the network load is reduced, and the possibility of performance degradation is minimized. Through the master-slave structure, the system optimizes data interfaces such as task allocation, data processing, and transmission to maximize system performance and provide scalability to establish an environment that can reliably process various satellite state data [3].

2.2.3 Data Flow and Operation Process

The overall data flow of the LTA system follows the sequence of receiving satellite status data, distributing tasks, processing and storing data, generating reports, and conducting trend analysis. Figure 3 shows the data flow and operation process of the LTA system. In this process, the LTAM software on the master PC is run to open the server, while the LTAC software on each node PC connects to the server. Once the LTAC software on the node PCs is connected, the LTAM software confirms the connection and updates the system's health status. When an operator assigns a task in the LTAM software, it is distributed to the connected node PCs' LTAC software. If no node PC is connected at the time, the system waits until a connection is established.

The LTAM sends tasks to the LTAC, and once the LTAC processes the data, it sends a completion event to the LTAM and saves the processed data in the database. The LTAM then assigns the next task to the LTAC, repeating this process until all tasks are completed. Additionally, the processed data is generated into weekly or monthly reports, and the Trend Analysis software visualizes the data, allowing the operator to intuitively analyse long-term trends.

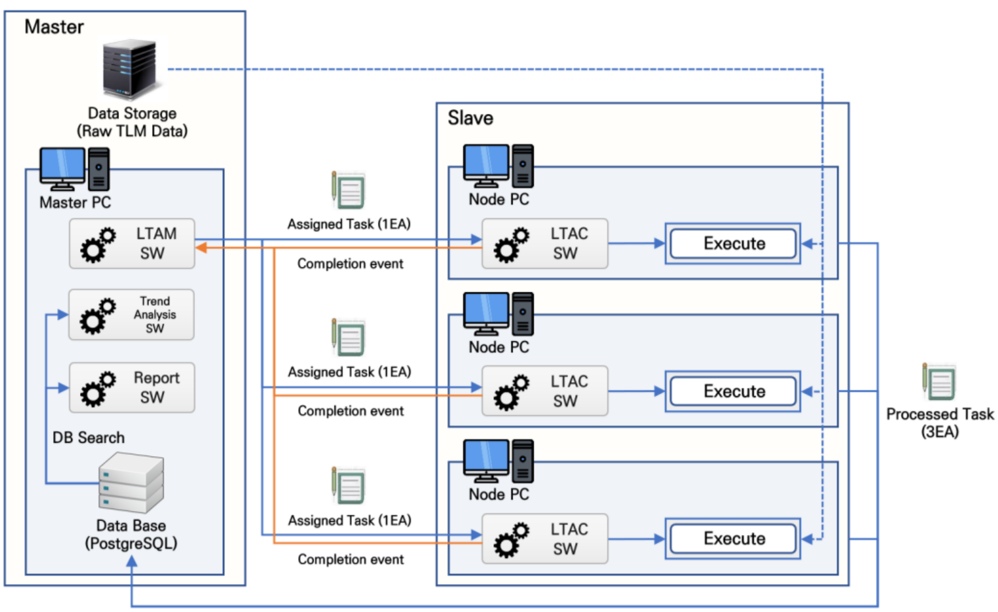


Fig. 3. Data flow and operating process of the LTA system

3. Main Functions of LTA

The LTA system is equipped with various functions that provide operators with convenience, allowing for efficient data processing and analysis. This section describes the main functions of the LTA system.

3.1 Automatic/Manual Processing

To extract the data needed for long-term trend analysis, it is important to process the satellite status data received from the satellite into a format that operators can analyse. The LTA system processes data through TM Core and offers two methods of processing: automatic and manual.

The automatic processing function is performed by adding a telemetry list file that requires analysis for each satellite, setting the automatic processing time and report generation time, and saving the information. The system checks the automatic processing information for each registered satellite and processes data based on the scheduled time. At this point, it processes data from the day before the scheduled time. Reports are generated every Monday and on the 1st day of each month according to the set time. This feature allows operators to avoid the hassle of manually processing data, reducing human resource consumption.

The manual processing function is used when analysing data for a specific period. By inputting the desired processing period and telemetry list file for the satellite, the system distributes tasks and performs data processing. This allows operators to process data immediately whenever needed. By using both automatic and manual processing methods depending on the situation, the efficiency and usability of the system can be maximized.

3.2 Report Generation and Export File

When the operator selects the telemetry that requires trend analysis and processes the data, the processed data is stored in the database in two forms. The first is to store the status data values for each telemetry in chronological order for a set period, and the second is to store the daily min, max, and average values for each telemetry in date order.

Based on the data stored in this way, the operator can generate and export files in CSV and PDF formats. The CSV file is generated by dividing it into a DATA file that stores the telemetry values in chronological order and a STATISTICS file that stores the daily min, max, and average values in date order, depending on the two forms stored in the database. The PDF file is generated in the form of a report file, divided into weekly and monthly, and the weekly report file uses data from Monday to Sunday of the selected week, and the monthly report file uses data from the 1st to the last day of the selected month to create a report file.

The report file includes a plot image generated based on the min, max, and average values through the plot module, which provides visualized data to help the operator intuitively understand the status and performance changes of the satellite and respond quickly. In this way, through the report file generation and file export function, operators can easily check data and quickly review results at any time.

3.3 Trend Analysis

The LTA system was developed for long-term trend analysis, which is the most important function. The system is designed to analyse and judge satellite status changes and performance from the launch date to the present or over a specific period set by the operator. Trend analysis is performed through the Trend Analysis software, which generates plot images based on the min, max, and average values of the selected telemetry over a specified period. This allows operators to monitor satellite status and performance trends, as well as check for failure. In this process, the system refers to the Alarm Table defined in each satellite's database and sets limit values. It uses the Out of Limit (OOL) method to determine whether status data has exceeded the predefined thresholds.

Additionally, for more detailed analysis of specific periods, the short-term trend analysis function can be used. This allows operators to set a period of 1, 3, 5, or up to 7 days based on the selected date. Instead of relying on min, max, and average values, the function provides a detailed analysis using values stored in order of actual time for a specific period. Through trend analysis, operators can detect changes in satellite status, predict performance, and apply the analysis results when extending a mission, increasing the efficiency of satellite operations.

Figure 4 shows the execution screen of LTAM software and Trend Analysis software.

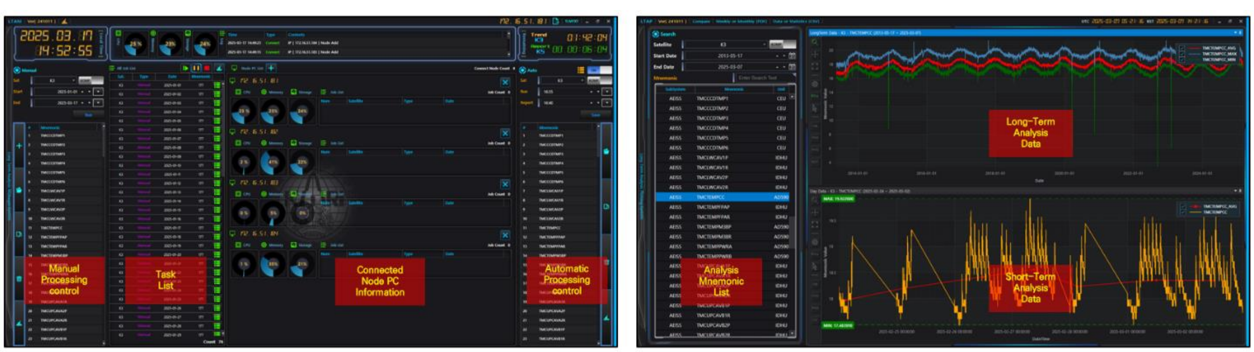
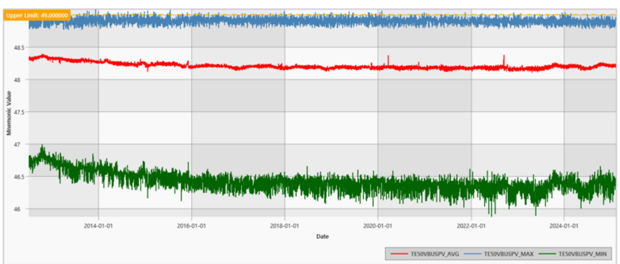


Fig. 4. Execution screen of LTAM software and Trend Analysis software

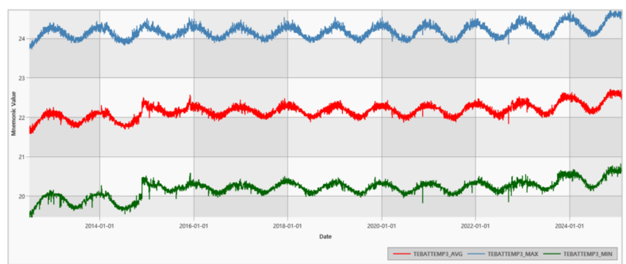
4. Utilization of Trend Analysis Result and Data Processing Performance Analysis

KARI operates various low earth orbit satellites, including KOMPSAT, CAS500, and NEONSAT. For trend analysis, about 150 to 200 telemetry data points are selected for each satellite, parsed, and analysed separately for each subsystem. The data extracted from this analysis is used as important reference material when extending satellite missions. One example is as follows:

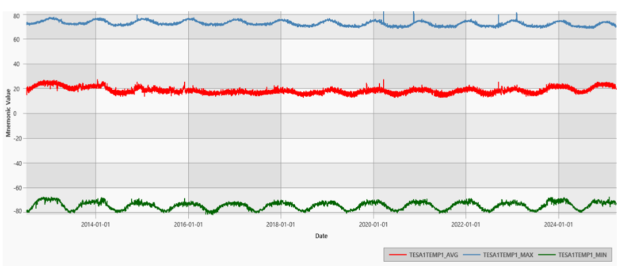
The K3 satellite has been operating for 13 years and continues to operate through ongoing mission extensions even after its 4-year design life time. In order to extend its mission, a complete check of all the satellite's subsystems must be performed. At this time, analysis data about its operational status is extracted to assess the possibility of a mission extension. In particular, since most functions of the satellite bus and payload are performed using electrical energy, the state of the Electrical Power Subsystem (EPS) is important [4]. Figure 5 shows the analysis data of the K3 satellite's EPS, the battery voltage, battery temperature, and solar array temperature. For the battery voltage, it must remain between 32.4V and 49.2V. As shown by the 50V BUS Voltage in Figure 5, the battery voltage's average value remains within this range. The battery temperature also stays within the normal range of 15°C to 30°C. In the case of the solar array, a total of three panels are used, and Figure 5's "Solar Array Temperature #1" and "#2" show the temperature of the first panel. It can be seen that the solar array is also operating normally within the set limit range of -100°C to 100°C. By comprehensively analysing the average values of each component, it was determined that there were no issues in operation, and since the performance of the other power system hardware was also confirmed to be normal, the mission could be extended without any problems.



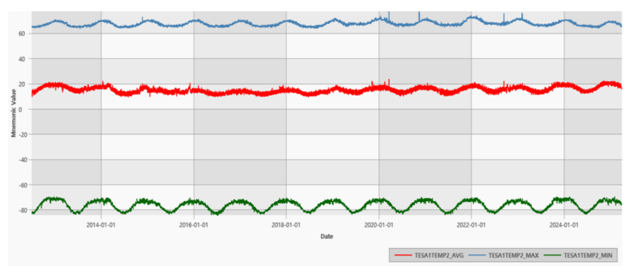
[K3, 50V BUS Voltage, Statistics (Min/Max/Avg)]



[K3, Battery Temperature, Statistics (Min/Max/Avg)]



[K3, Solar Array Temperature #1, Statistics (Min/Max/Avg)]



[K3, Solar Array Temperature #2, Statistics (Min/Max/Avg)]

Fig. 5. Trend analysis data of K3 Satellite's EPS

The trend analysis data extracted from the LTA system helps identify anomalies by checking for periodicity and determining whether the satellite can continue its mission even when issues occur. This data is used to evaluate the satellite's status and performance, playing an important role in extending the satellite's mission. In addition, trend analysis data from the LTA system can also be used to analyse and predict satellite failures and performance degradation. Satellites are designed so that various components operate in an integrated manner, and since they cannot be directly repaired after launch, thorough management is essential. Since failures and performance degradation can have a critical impact on mission execution, it is important to monitor changes in system and equipment performance through regular trend analysis and data mining and to establish countermeasures based on this data. Thus, the analysis and prediction of failures and performance degradation are among the core roles of the LTA system for ensuring stable satellite operations, along with mission extension. Like this, through trend analysis and data mining techniques, it is possible to detect changes in the satellite's pattern and determine if a failure has occurred. It also helps identify which systems need improvement in future satellite development and allows for strategies to be created to prevent the same failure from happening again.

The LTA system not only improves the operational efficiency of the satellite by utilizing the analysis results but also shows high performance in terms of data processing speed and management. Figure 6 shows the data processing time according to different processing periods. The data processing was performed using a total of 4 PCs, including a master PC, and approximately 150 telemetry data points were selected for the analysis. Each PC took about 25 seconds to process one day's worth of satellite status data. Using four PCs, it took about 3 minutes to process one month's data, 38 minutes for one year's data, 1 hour and 50 minutes for three years of data, and approximately 3 hours and 10 minutes for five years of data. Distributed processing minimized the system load, enabling a stable processing speed while efficiently handling the data. Additionally, the efficiency of data management has been significantly improved by directly storing the processed data in the database instead of saving it in a file format. This approach ensures data integrity while enabling real-time analysis and utilization, thereby enhancing the overall performance and reliability of the system. Currently, 8TB of database storage space is secured and operated, and even if the number of operating satellites increases in the future, stable system operation is possible without the problem of lack of data storage space.

Processing Period (Years)	The number of PCs	Processing Time (Minutes)
2020 (1year)	4	Approx. 38
2020~2022 (3years)	4	Approx. 110
2020~2024 (5years)	4	Approx. 190

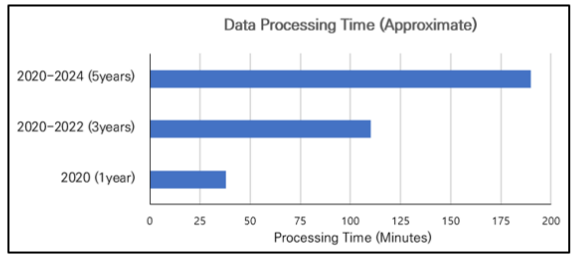


Fig. 6. Data processing time by processing period

5. Conclusions

Long-term trend analysis is a crucial factor in improving the operational efficiency of satellites and extending the mission lifetimes. As the number of satellites that need to be operated will increase rapidly, the amount of data to process and analyse will also increase. The LTA system can support more satellites by reducing the cost of system construction and providing scalability through TM Core and Its distributed processing using a master-slave structure allows for quick and consistent data processing. Additionally, The LTA system through automation minimizes operator intervention, reduces manpower consumption, identify satellite status periodically through report extraction, and enables effective analysis of long-term data trends by using min, max, and average statistics.

In terms of data mining, the LTA system extracts key patterns from large volumes of satellite status data, helping to identify abnormal signs and detect performance changes [5]. It also analyses past defects to respond to problems that may occur in similar situations, contributing to the extension of satellite mission lifetimes.

There are still some functional improvements to be made. Currently, the LTA system does not support the function to apply formulas between statistical values to calculate new data. This function is currently being implemented and is expected to be of great help in long-term trend analysis, applying the function. The LTA system will continue to make continuous improvements, with plans to add AI-based analysis techniques in the future. This will lead to a more advanced system capable of providing more precise trend analysis and predictions.

References

[1] http://www.kari.re.kr
[2] N. L. Crowley and V. Apodaca, "Analysis of satellite telemetry data," 1997 IEEE Aerospace Conference, Snowmass, CO, USA, 1997, 13 – 13 February.
[3] Eduardo Javier Huerta Yero, Marco Aurélio Amaral Henriques, "Speedup and scalability analysis of Master–Slave applications on large heterogeneous clusters," Journal of Parallel and Distributed Computing, 67, 2007, pp. 1155-1167.
[4] So Young Kim, J. -F. Castet and J. H. Saleh, "Satellite Electrical Power Subsystem: Statistical Analysis of On-Orbit Anomalies and Failures," 2011 Aerospace Conference, Big Sky, MT, 2011, 05 – 12 March.
[5] D. N. R. Azevedo, A. M. Ambrósio, "Dependability in Satellite Systems: An Architecture for Satellite Telemetry Analysis," Workshop em Engenharia e Tecnologia Espaciais, São José dos Campos, INPE, 2010, 30 March – 01 April.