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A Study on the Equipment Data Collection and Developing Next Generation Integrated PHM System

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ABSTRACT

This research presents an integrated PHM system for 2,000 rotating equipment units across press, car body, paint, and assembly lines in Hyundai/Kia factories. The system addresses limitations of individual monitoring systems by consolidating vibration, current, robot AI diagnostics, PLC backup status, and operational data. Vibration monitoring utilizes wired/wireless sensors, server storage, and automated analysis for trend detection and fault diagnosis. PLC data monitoring retrieves motor drive information (current, temperature, frequency, etc.) to predict equipment anomalies. Robot monitoring integrates with various manufacturers and tracks operational status, motor load, and alarms for maintenance and lifespan management. The PLC backup solution ensures proper backup functionality. The integrated PHM architecture manages data collection, analysis, diagnostics, reporting, and visualization, enabling comprehensive equipment health monitoring and proactive maintenance.

1. INTRODUCTION

The optimal approach to equipment maintenance in the factory involves a maintenance strategy divided into reactive, preventive, and predictive methods. Among these, predictive maintenance stands out as an effective way to anticipate failures through equipment condition monitoring [Paulina Gackowiec]. It provides timely insights into breakdown causes, which is increasingly vital due to the industrial internet of things. The shift from reactive to predictive maintenance represents an innovative process improvement. In the reactive maintenance method, urgent repairs must be carried out post-failure, degrading maintenance quality and endangering workers. Conversely, predictive maintenance enables preemptive action, preventing factory shutdowns. By monitoring conditions and analyzing root causes in advance, maintenance can be performed proactively, and equipment condition can be evaluated thereafter. Sudhanshu Goel's paper highlights the significant potential of condition monitoring in enhancing operational reliability, machine uptime, damage reduction, and operational efficiency at a lower cost [Sudhanshu Goel]. Equipment incipient faults often exhibit variations in temperature, vibro-acoustic signature, etc. Different condition monitoring techniques utilize dedicated sensing and data analysis tools to analyze specific operational characteristic variations [Figure 1].

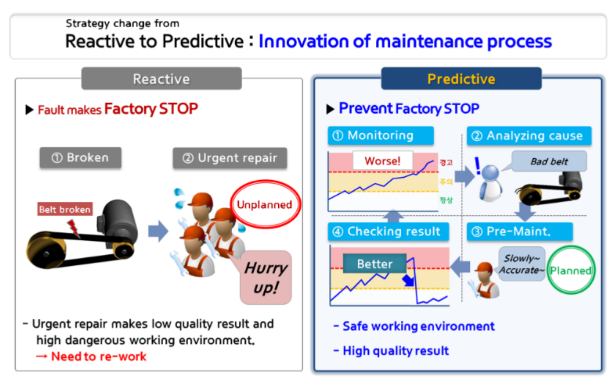
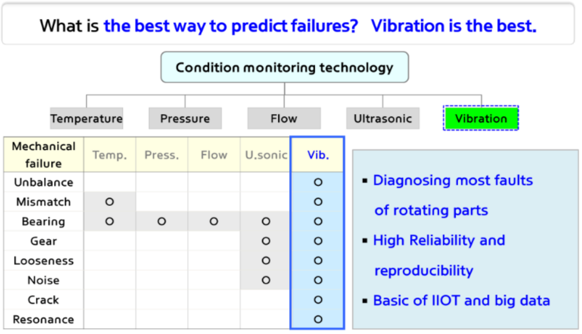


Figure 1. Strategy changes from reactive to predictive

Various sensing techniques such as temperature, pressure, flow, ultrasonic waves, vibration, and acoustic emission can be used to monitor the equipment condition. Among them, vibration monitoring can cover most of mechanical failures such as imbalance, mismatch, bearing defects, gears, looseness, noise, cracks, resonance, etc. [ISO 18436-2:2014] [Figure 2]



Mechanical failure	Temp.	Press.	Flow	U.sonic	Vib.
Unbalance					o
Mismatch	o				o
Bearing	o	o	o	o	o
Gear				o	o
Looseness				o	o
Noise				o	o
Crack					o
Resonance					o

Figure 2. Comparison of Condition monitoring technology

For predictive maintenance, not all equipment is monitored. Instead, sensors, signal processing modules, and servers capable of collecting equipment status data are installed selectively, focusing on those that can lead to extended downtime failures. The primary target equipment includes conveyors, drop-lifters, air conditioner fans, robots, controllers, and communication systems. VMS, or Vibration Monitoring System, monitors vibration data at the equipment's drive in real-time and can predict failures in advance. This system comprises a sensor unit for real-time vibration measurement, a signal processing module, a server for data collection and storage, and a monitoring device for status display. It is implemented on main equipment causing extended downtime failures (downtime exceeding 60 minutes). Over 5,000 sensors are installed in more than 2,000 machines across Hyundai/Kia factories worldwide. All system servers are connected to the company network, allowing authorized executives and employees to access data conveniently from anywhere, enabling real-time monitoring of equipment installed worldwide [Figure 3].

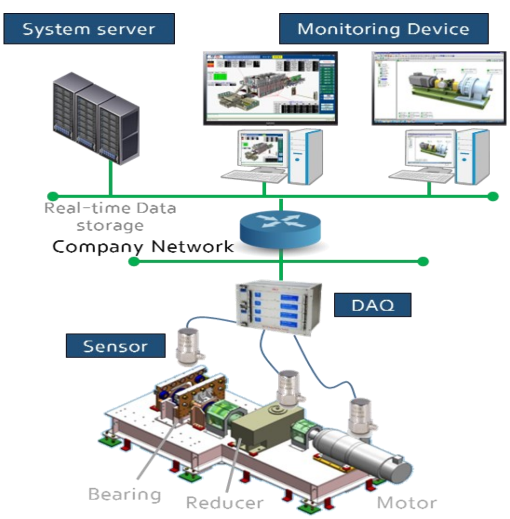


Figure 3. Vibration Monitoring System configuration

Similar to vibration monitoring, an approach to determine the number of shorted turns based on the difference between the phase current of the healthy and faulty machine is proposed [Nandi, S., Toliyat]. Condition monitoring of rotating machinery is crucial for ensuring operational reliability and preventing catastrophic failures. While vibration monitoring has long been the primary method for detecting mechanical faults, current monitoring offers a complementary approach with distinct advantages. Current monitoring is comparatively inexpensive to implement and is well-suited for diagnosing electrical faults in motors and inverters. This system also includes development and application of current-based condition monitoring technology to prevent electrical faults in rotating machinery. Technology for monitoring the current of the equipment's driving unit has been developed and implemented. However, challenges such as slow sampling of current data, the requirement for a large-capacity server, and a lack of diagnostic technology persist. To address this issue, a diagnostic function block capable of current analysis has been developed and deployed. Integrated within the PLC controller's code programs, this diagnostic function block receives various parameters including current, frequency, and control setting values of the equipment's driving unit as input. The output comprises diagnostic results, which are transmitted to the cloud server for analysis. The figure depicting the diagnostic function block is shown below [Figure 4].

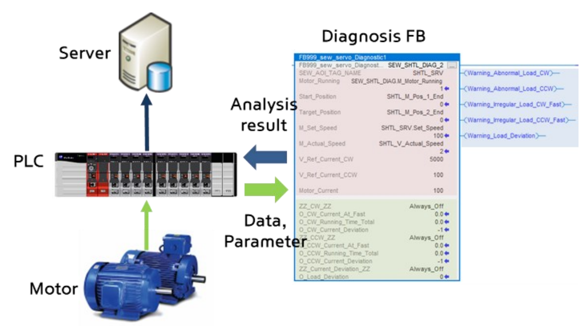


Figure 4. diagnostic function block for current monitoring

The increasing complexity and autonomy of robotic systems necessitate advanced condition monitoring techniques to ensure their reliable operation and prevent costly downtime. Traditional condition monitoring approaches often rely on centralized cloud-based data processing, which can lead to latency issues and communication bottlenecks. Edge computing offers a promising alternative by enabling real-time data analysis and decision-making at the edge of the network, closer to the data source [Niklas Tritschler].

This system involves installing vibration sensors on the motor and reducer of each axis of the robot and applying an autoencoder algorithm to assess anomaly scores. An edge device was developed and utilized as a CMS (DAQ) to gather vibration data from the robot. Figure 5 illustrates the structure of robot vibration diagnosis system based edgeCMS system.

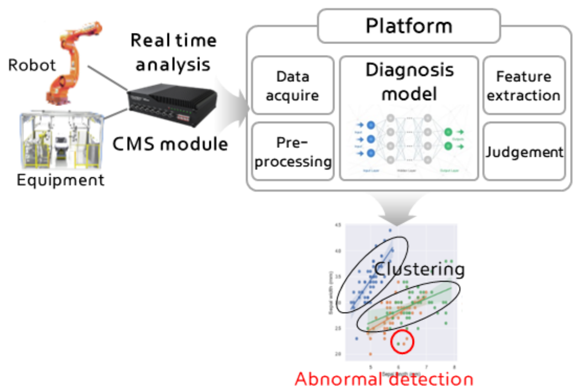


Figure 5. Robot vibration diagnosis system with edgeCMS

To monitor the condition of industrial robots, each manufacturer develops and provides a robot monitoring system. Hyundai(HRMS-Hyundai Robot Monitoring System), Yaskawa(Y-FAI) , Kawasaki(KRDS-Kawasaki Robot Diagnostic System), and Fanuc(ZDT-Zero Down Time system) robots are representative examples. The manufacturer's monitoring system typically displays basic operation information such as model and operation status graphs, along with notification history. It also provides alarm information and component replacement time when the reference value deviates from statistical norms. However, this system lacks failure prediction functionality. To address this, a Robot Predictive Maintenance System (RPMS) was developed. This system utilizes autoencoder models to learn normal states from manufacturer-provided robot monitoring data and identifies deviations from normal states [Figure 6].

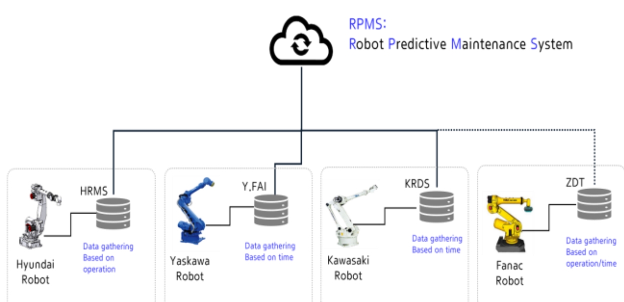


Figure 6. Robot monitoring system

The PLC(Programmable Logic Controller) program backup system is being implemented. It mainly consists of an agent PC managing program change points and a database storing the results. Hyundai/Kia factories employ PLCs from various manufacturers including Siemens, Rockwell, Mitsubishi, Fuji, and LS, and all systems managing program change points of these PLCs are in use. However, to address issues related to ineffective program backup when the agent PC is improperly managed, a cloud-based technology integrating agents and databases has been developed. This technology manages fluctuation points effectively. Figure 7 illustrates the structure of the PLC program backup system based on the cloud.

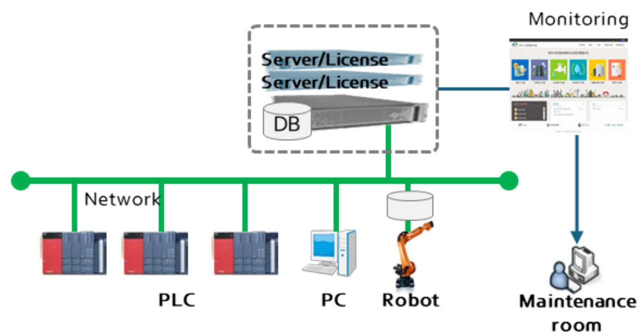


Figure 7. PLC program backup system based on cloud

2. Integrated PHM system

As the equipment monitoring system is currently implemented as separate systems, managing equipment becomes cumbersome. This involves checking multiple individual systems separately to diagnose a single piece of equipment, and there is no comprehensive system for analyzing equipment data. To address these challenges, a next-generation integrated Prognostics and Health Management (PHM) system is being developed. This integrated PHM system, based on existing accumulated monitoring technology and diagnostic expertise, is being deployed in new factories within the Hyundai/Kia company.

2.1. Configuration of Integrated PHM system

The aim of the integrated PHM system is to consolidate equipment failure data monitoring and enhance failure diagnosis and analysis capabilities. The system comprises sections for equipment monitoring, diagnostic report management, fault diagnosis algorithms, and data transmission/reception interfaces.

Equipment monitoring encompasses vibration, drive current, electrical equipment status, PLC program backup status, robot operation status, robot vibration status monitoring, alarm lists, and maintenance history inquiries. Additionally, it enables monitoring of equipment status trends and system resources through trend graphs.

Diagnostic report management is linked with equipment abnormality alarm event management, facilitates automatic report generation and email dispatch of diagnostic reports, and integrates with the prevention task instruction module in ERP(SAP).

The analysis algorithms promote advanced analysis techniques, including time series trend analysis, frequency/pattern analysis, harmonic/rotational speed analysis, automatic vibration state analysis, and automatic failure type determination algorithms that detect sudden state changes.

Utilizing the IoT(Internet of Things) platform and Hyundai/Kia's standard collection module, the system collects equipment state data and offers basic functions for efficient and reliable data management. These include alarm management, equipment registration, device control, data collection, and algorithm management.

Currently, the integrated PHM system monitors equipment/robot vibration status, status of current, control panel status, network switch status, robot status, and PLC backup status. However, it can accommodate new monitoring solutions for equipment condition diagnosis. Figure 8 illustrates the configuration of the integrated PHM system.

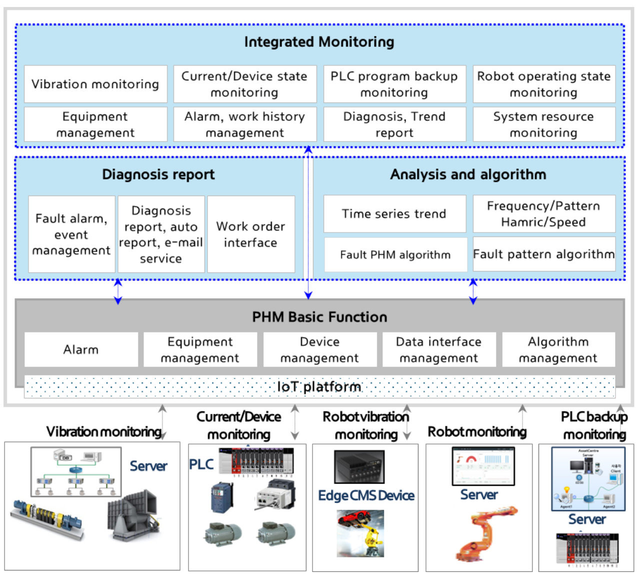


Figure 8. Configuration of integrated PHM system

Several data transactions and signal processing tasks are necessary for the integrated PHM system, including real-time data collection and analysis, CMS(Condition Monitoring System) device control, AI(Artificial Intelligence) algorithm execution, and accounting for network load and security considerations. Consequently, physical servers need to be configured for each factory.

The integrated PHM server comprises a web/app server, a DB(Database) server, and an Factory Talk Linx Gateway server(Rockwell) for interfacing with current and electronic component data. Figure 9 illustrates the configuration of the integrated PHM server.

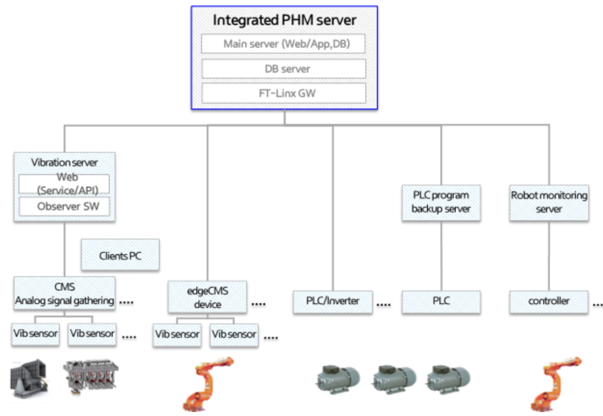


Figure 9. Configuration of integrated PHM server

2.2. Architecture of Integrated PHM system

The architecture of the integrated PHM system is designed to collect, analyze, and present equipment source data. Vibration monitoring, robot monitoring, and PLC backup utilize dedicated servers, with data stored on these servers interfacing with the integrated PHM server via a DB-to-DB interface method.

For collecting current/control panel state monitoring data, PLCs in the control panel gather and analyze necessary data using function blocks. This data is then collected by a dedicated collection server such as FTLinx GW and stored in the integrated PHM's InfluxDB using the OPC-UA protocol. FTLinx GW serves as a collecting tool for Rockwell systems, whereas different servers are required for PLCs from other manufacturers such as Siemens, LS, and Mitsubishi.

Robot vibration data is collected from the edge CMS device, and the analysis result is transmitted to the integrated PHM server through a file collection batch process. As the results from edgeCMS are stored as files, the system must possess the capability to collect and manage files.

The collected equipment status data undergoes backend analysis, including vibration and current abnormality diagnosis, diagnosis notification/report management, equipment status management, external system connection, data collection management, device/alarm management, and visualization data management.

At the front end, functions such as factory map-based equipment management, equipment status management/alarm management, and equipment-based information data visualization are implemented. Further details are provided in Figure 10 below.

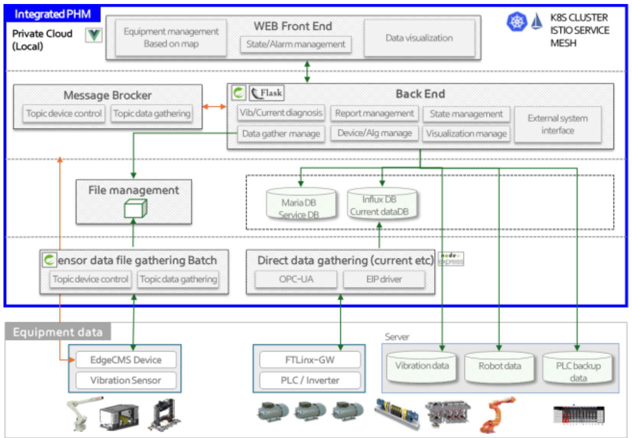


Figure 10. Architecture of Integrated PHM system

2.3. Monitoring contents and user interface

2.3.1. Main integral monitoring

The integrated system encompasses various monitoring purposes and incorporates a user-friendly UI/UX application, incorporating different factors based on a map interface. This enhances efficiency for maintenance engineers. Additionally, AI PHM algorithms are integrated into the system, enabling automatic vibration detection and spectrum analysis, serving as powerful tools. Automatic email notifications of abnormalities further enhance maintenance efficiency.

The main page of the integrated PHM system shows the equipment list, equipment status statistics (normal, caution, warning), daily alarm trends, shop-specific diagnostic result statistics, itemized diagnostic result statistics, and equipment status displayed on a map. Moreover, the system automatically presents analysis results on the main page to improve user intuition. Alarm history, diagnosis reports, action details, and maintenance work management content are also accessible on the main page. Specific and detailed results can be viewed by clicking on each menu. Figure 11 provides an example of the integrated main page.

Figure 11. Main page of Integrated PHM system

2.3.2. Vibration monitoring

The vibration monitoring analysis page configuration presents the average vibration level for each sensor along with the automatically calculated vibration variation. Sensors exhibiting significant changes are highlighted in red. Additionally, the page displays the equipment's vibration trend over time and automatically analyzed results of frequency spectrum analysis. For detailed spectrum analysis, 3D plots and heat maps are provided. Furthermore, the system features automatic generation and emailing of diagnostic reports [Figure 12].

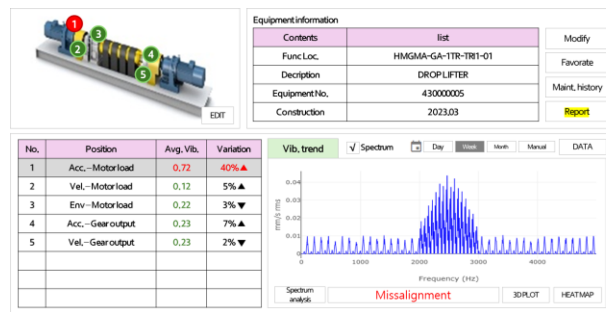


Figure 12. Vibration monitoring page

2.3.3. Current and control panel state monitoring

For equipment current state monitoring, the system displays comprehensive analysis results of parameters such as current data and frequency data from the inverter driving the motor. These values indicate diagnostic results such as load current performance and fluctuations during machine operation. Additionally, the system enables monitoring of elements crucial for the inverter's lifespan, including IGBT, capacitor, and temperature. Sensor data for each location of the drop-lifter equipment, responsible for moving the car up and down, is also presented for monitoring sensor status. Furthermore, the system organizes a page to monitor power, temperature, and lifespan of the main elements in the control panel [Figure 13].

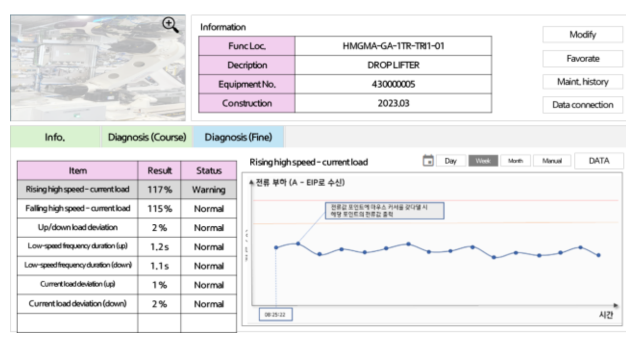


Figure 13. Current/Control panel monitoring page

2.3.4. Robot vibration monitoring

The method for diagnosing the vibration state of robots differs from that of general equipment described earlier. Unlike conventional equipment, robots lack distinct movement patterns and have short constant speed sections, making diagnosis challenging with traditional vibration analysis methods. To address this, a vibration sensor is attached to each axis of the robot, and an AI algorithm, specifically the auto-encoder method, is employed to predict signal outliers. By utilizing an auto-encoder, the difference between normal and abnormal data can be transformed into a health index score, facilitating equipment state trend prediction. The figure below illustrates the monitoring of the robot's vibration status [Figure 14].

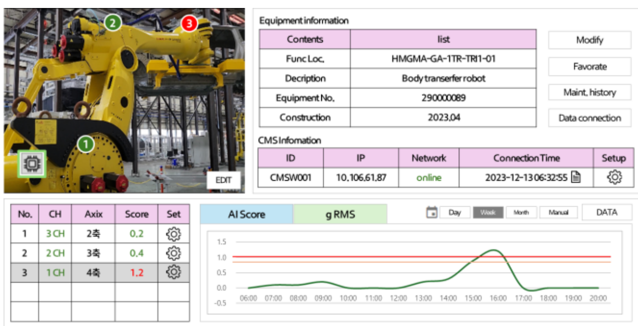


Figure 14. Robot vibration monitoring page

2.3.5. Robot operation monitoring

In the automotive manufacturing factory, there are 600 industrial robots in the vehicle welding factory, 200 in the painting factory, and 100 in the assembly factory. A robot monitoring system is developed and installed in each factory to monitor the operation information and condition of the robots. Since monitoring the operation status, alarm history, and error information of hundreds of robots in individual systems is challenging, the system is configured to initially display key results in coordination with the integrated PHM system, allowing users to review detailed information in individual robot monitoring systems as needed [Figure 15].

Figure 15. Robot operation monitoring page

2.3.6. PLC program backup monitoring

The equipment controller utilizes PLC, primarily employing ladder programs. When equipment operation is altered, monitoring the normality of program backups is managed through the PLC backup status inquiry page. This page displays the location, equipment name, and final backup date, and indicates any communication issues or conditions if backups are not performed. The image below depicts the PLC backup status inquiry page [Figure 16].

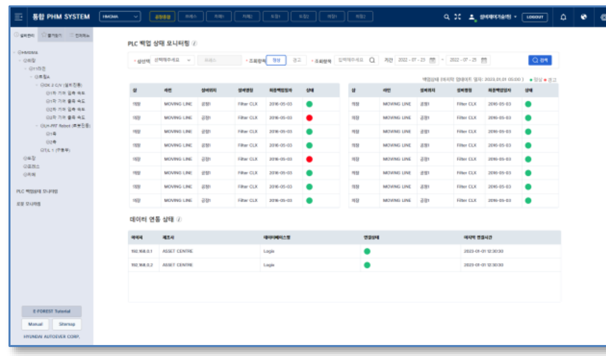


Figure 16. PLC backup monitoring page

3. Practical Application

Various PHM technologies for monitoring and predicting equipment conditions are being implemented in production plants. Initially, an integrated PHM system, integrating these technologies, is being deployed in new factories within Hyundai/Kia. These include the HMGMA Plant under construction in Savannah, Georgia, as well as the Gwangmyeong EVO Plant, Ulsan EV Plant, and Hwaseong EVO Plant in Korea. Subsequently, monitoring will extend to enhance equipment uptime across mass production plants. Equipment monitoring and technical support are facilitated by the Equipment Monitoring Center at Hyundai Motor's Ulsan plant [Figure 17].

Figure 17. Equipment Monitoring Center in Hyundai motor.

4. Conclusion

Vibration and current monitoring are underway for 2,000 rotating equipment units throughout Hyundai/Kia factories.

An integrated PHM system is being developed to streamline equipment management and analysis. It integrates data from various monitoring systems, including vibration, PLC, and robot diagnostics, facilitating trend detection and fault diagnosis. The system architecture encompasses components for data management, diagnostic reporting, and external system integration. We plan to continue activities using the integrated PHM system to efficiently monitor equipment status and dramatically improve downtime.

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BIOGRAPHIES

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