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A Study on Design of Real-time Big Data Collection and Analysis System based on OPC-UA for Smart Manufacturing of Machine Working

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Abstract

In order to design a real time big data collection and analysis system of manufacturing data in a smart factory, it is important to establish an appropriate wired/wireless communication system and protocol. This paper introduces the latest communication protocol, OPC-UA (Open Platform Communication Unified Architecture) based client/server function, applied user interface technology to configure a network for real-time data collection through IoT Integration. Then, Database is designed in MES (Manufacturing Execution System) based on the analysis table that reflects the user's requirements among the data extracted from the new cutting process automation process, bush inner diameter indentation measurement system and tool monitoring/ inspection system. In summary, big data analysis system introduced in this paper performs SPC (statistical Process Control) analysis and visualization analysis with interface of OPC-UA-based wired/wireless communication. Through AI learning modeling with XGBoost (eXtream Gradient Boosting) and LR (Linear Regression) algorithm, quality and visualization analysis is carried out the storage and connection to the cloud.

Keywords: *AI, Big data, Cloud, Data collection and analysis system, IoT, OPC-UA, Smart factory*

1. Introduction

The general system structure of a smart factory, as shown in Fig 1, can be composed of Information Technology (IT) area, Operation Technology (OT) area and communication area. The IT area consists of ERP, SCM, MES, PLM, CRM, etc. and the OT area consists of Machine & Field Device (Sensor, Actuator, Equipment, etc.), Control Device (PLC, PAC, DSC, etc.), Control & Monitoring (HMI: Human Machine) Interface SCADA: Supervisory Control and Data Acquisition, etc.). The communication area can be composed of Fieldbus, Ethernet, OPC, OPC UA, etc. [1]. The latest smart factory trend is the convergence of the latest ICT technologies such as IoT integration and platform, CPS (Cyber Physical System),

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and embedded. Small and medium-sized enterprises (SMEs) are also increasingly adopting big data collection and analysis systems. The big data platform can be divided into the process of data generation, collection, storage, processing, analysis, and evaluation. In order for these steps to proceed effectively, the factory automation and smartization levels corresponding to these should be met, and in particular, the latest network and communication technologies between field facilities are required. Big data collection and analysis technology wired and wireless integrated communication protocol technology including IoT, and AI learning model technology are considered important. As a smart factory project, this research is pushing ahead the smartization of a new connecting rod cutting manufacturing line to improve the productivity of the machining process and achieve high machining precision. This research is to design a real-time manufacturing data collection and analysis system along with a process monitoring system to which an IoT integrated technology based on OPA-UA is applied. time.

2. Smart Factory Network and Data Status Issues

Man The characteristics of manufacturing data information are i) various types of physical and chemical information, unapproved IDs in the first communication data of analog nature, such as RFID, barcode, temperature, humidity and pressure generated during manufacturing execution, ii) a type with large data processing speed and size in mass production systems, iii) HMI/SCADA systems disconnected from external networks, iv) diversity of data formats caused by environmental differences in various machine, v) unnecessary continuous redundant data and increased use of semi-structured data. These characteristics may lead to problems such as the lack of integration technology for real-time driving data and the slow speed of big data [2]. From the point of view of real-time data processing and communication of an old heterogeneous network, technically important characteristics occur such as i) path loss of transceiver distance, ii) half-duplex of transceiver, iii) overhead of physical layer, iv) channel error, etc. Due to this spatial and temporal consistency problems occur because of unapproved IDs in the first communication packet delivery process, and protocol problems may occur because of the movement of the distributed token passing method. In case of avoiding packet collision, there are restrictions such as the use of radio anti-duplex [3]. Comprehensively, the expected communication issues for SMEs are: 1) Linking is not easy when an IT system is already established, 2) it is difficult to collect and integrate data which are generated from heterogeneous systems, and 3) The interface is complex as there are diverse fieldbuses and protocol [4]. It is necessary to study real-time data collection and analysis systems based on the latest communication protocols and networks between heterogeneous facilities and OT and IT areas.

3. OPA-UA based IoT Integration design

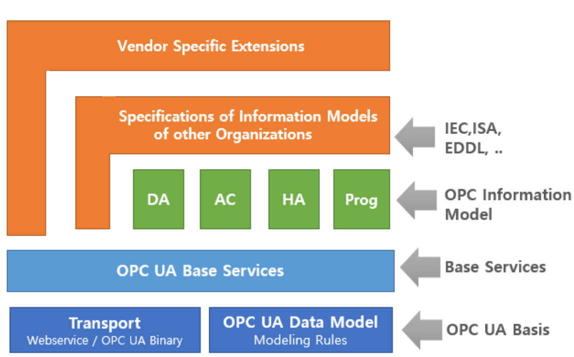

Figure 1. Hierarchical Structure of OPC UA Platform

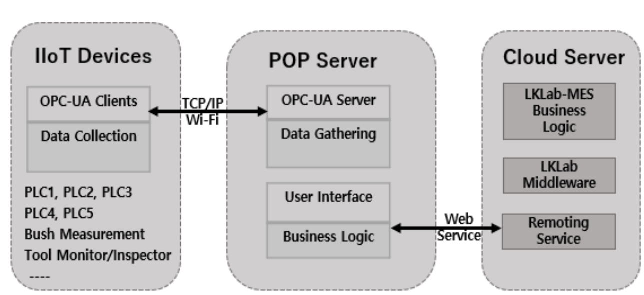

Figure 2. System Configuration

3.1 Concept and Server/Client Design of OPC-UA It can be said that OPC UA
Protocol is the most ideal communication protocol to implement Industry 4.0 because it makes possible to configure independence of the platform and provides a stable communication mechanism implemented in the protocol [5] [6].

Fig. 1 shows the hierarchical structure of the implemented OPC UA protocol. For the effective convergence of SW technology in the manufacturing process, the need for standard-based communication is increasing, and this leads to the attention to OPC-UA. OPC-UA is described in the IEC 62541 standard [6] and enables reliable, safe, and interoperable data exchange between different industrial automation devices such as. PLC, HMI, SCADA, and MES [7]. The platform-independent structure of OPC-UA as show in Fig. 2 provides an environment in which systems of various sizes, from embedded platforms to high-performance systems, can access each other. The OPC-UA information model enables standard communication between systems in different domains by defining and describing the structure and data of the target system in the form of a standard model.[8].

As shown in Fig. 2, the Industrial IoT (IIoT) device was designed to collect data from devices such as 5 PLC of cutting processing machine at the manufacturing site, bush indentation measuring equipment, and tool monitoring & inspection system to OPC-UA client. OPC-UA server in POP (Point of Production) server collects data through wired/wireless network including TCP/IP. The collected data is delivered to the cloud server using web service technology through the user interface (application browser). The transmitted data is classified as middleware, then collected, stored, and processed by LKLab-MES business logic. shows the configuration diagram of the integrated production management for AI Smart Factory Model as an integrated

3.2 OPC-UA based IIoT integrated network design

Based on OPC-UA, communication modules composed of wired and wireless networks such as TCP/IP and Ethernet are utilized, and a contact point IoT integration module of processing and measuring equipment is developed. After constructing a real-time manufacturing data acquisition system by applying flexibility on communication method, it designs a network of real-time data collection and statistical analysis system as shown in Fig. 3. The data generated from the newly introduced cutting processing equipment, bush press-in pressure measuring equipment, and tool monitoring and inspection system are collected by interfacing with the POP server from the OPA-UA-based IoT integrated module. The collected data is stored and processed in the MES in the cloud server, SPC statistical analysis is performed, and then is extended to the data collection

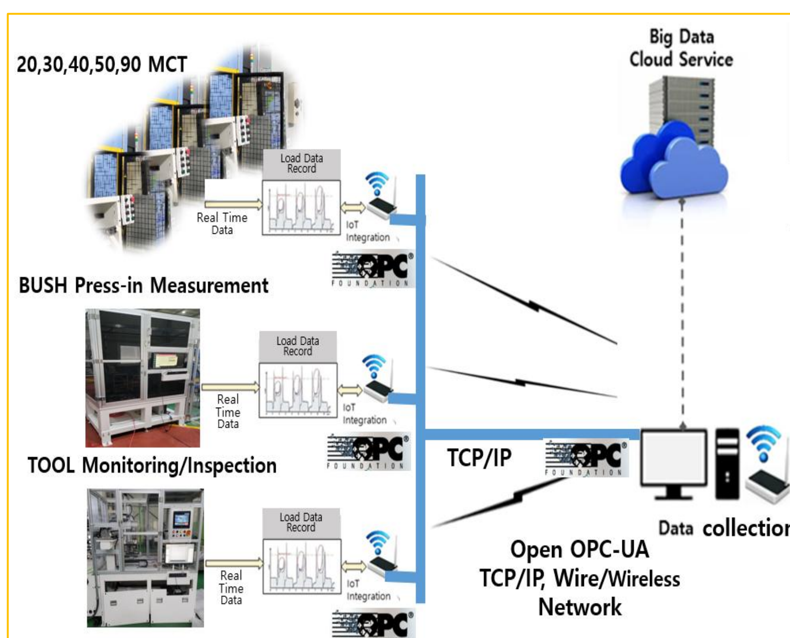

Figure 3. Data collection & analysis system network

and analysis system using AI. Cutting processing information acquires processing data such as dimensional change, tool load, tool life, cutting load, and tool from PLC of each machine. Bush press-in pressure measuring equipment collects bush inner diameter and press-in torque, and tool monitoring and inspection system collects roughing and finishing machining dimensions.

As shown in Fig. 4, the bush press-in pressure measuring system consists of a micrometer, a measuring device, and a measuring system to measure the bush. The measurement system measures the displacement of the inner diameter with the displacement sensor of Linear Variable Displacement Transducer (LVDT). Based on this amount of displacement, the data extracted from the marking information with the position and hole detection function built into the vision camera by PLC and HMI. Then, through MES server and Monitering, data such as press-in torque, inner diameter, and production time are collected by the server through TCP/IP communication based on OPC-UA.

In the tool monitoring and extraction stage, the tool monitoring and inspection system extracts the current applied to the spindle during machining and converts it into a cutting load value as shown in Fig. 5. In the measurement and inspection stage, the measuring equipment is a processing quality measuring system for the production line to measure data such as the large and small ends of the connecting rod, the position of the hole, and the diameter in real time. Finally, cutting load and machining measurement data can be stored and viewed in real time for each tool through wired/wireless communication of Ethernet and TCP/IP based on OPA-UA, and also stored in the server at the same time.

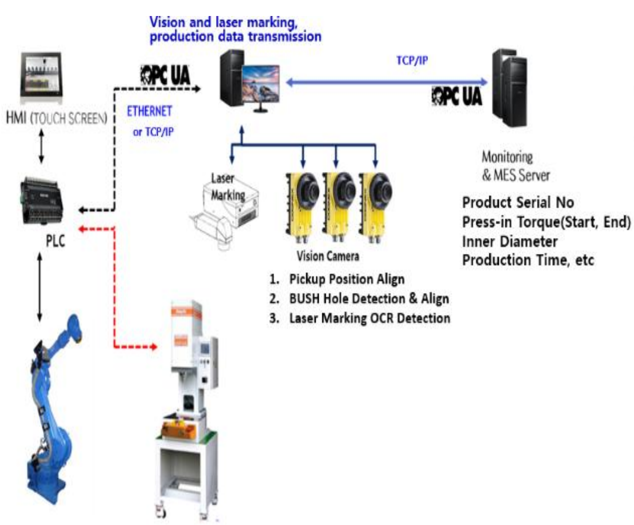

Figure 4. Bush press-in pressure measurement and transmission system diagram

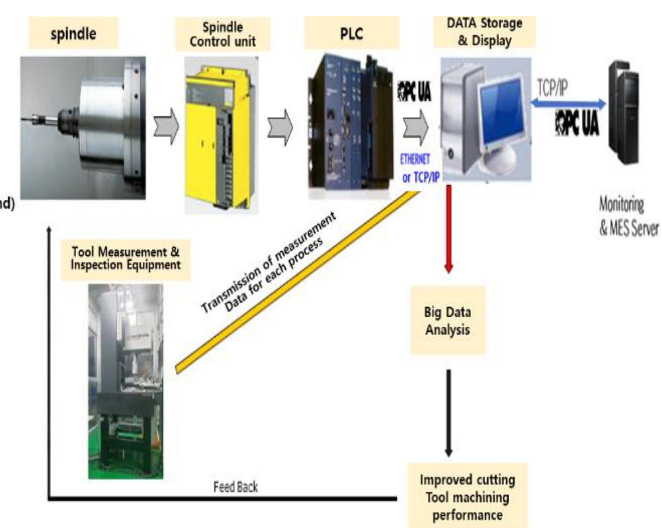

Figure 5. Tool monitoring and inspection system diagram

4. Big data collection and analysis architecture design

4.1 Big data collection and analysis model proposal

The automated manufacturing process and libraries for various manufacturing data are built and used jointly with manufacturing data that is a factor for reducing the defective rate of connecting rods. As shown in Fig. 6, a model is designed as a big data collection and analysis system based on OPC-UA that can be integrated horizontally and vertically by utilizing data from sensors, devices, and applications in the OT and IT areas. First, by introducing of a new bush press-in pressure system, data on changes in bush inner diameter and press-in pressure are collected as manufacturing data which is a factor for reducing bush press-in failure. Second, by introducing a new tool monitoring & inspection system, a smart manufacturing process that collects cutting processing data, cutting tool life data, equipment information and log data is added and built. For data collection and analysis, system model such as manufacturing process data collection and management system, and software development with IoT integration based on OPC-UA is designed. Additionally in connection with cloud computing services, manufacturing data collection and analysis utilization models that apply SPC statistical analysis and AI learning modeling for big data analysis is designed.

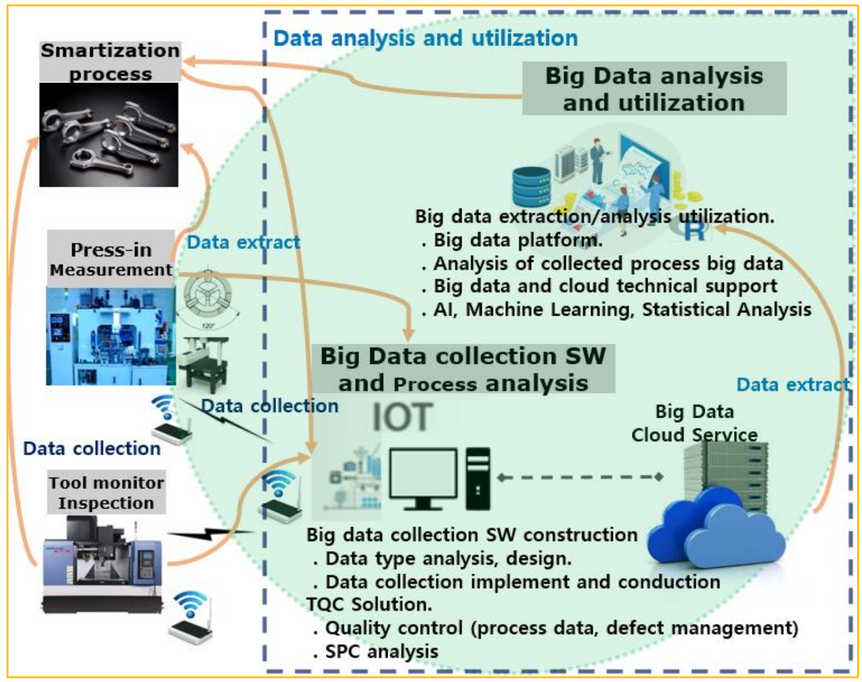

Figure 6. Big data collection and analysis utilization model

4.2 Big data collection and analysis structure design

The big data collection and analysis system structure interfaces with OPC-UA-based wired/wireless communication as shown in Fig. 7 and stores and processes at the Maria Database (DB). The Total Quality Control (TQC) engine is a module that performs SPC statistical analysis. It is a structure that utilizes statistical process control and open-source tools to perform visualization analysis and storage in the external cloud, which proceeds in the order for data collection, storage, processing, analysis, and visualization, and is designed as a manufacturing data utilization model. The data item collection and analysis contents on the MES are processed as described in Table 1, after collecting the data of the items extracted from the three machines /equipment the correlation between cutting load and quality factors, tool life, cutting conditions, bush inner diameter and pressure torque are analyzed. Processing and quality measurement data collection items are designed in the MES system based on a table sheet that analyzes the extracted data such as bush indentation measuring instrument, connecting rod processing inspection results, and vision inspection processing data. The resulting values are used to calibrate processing equipment and optimize and standardize process conditions to control quality and productivity.

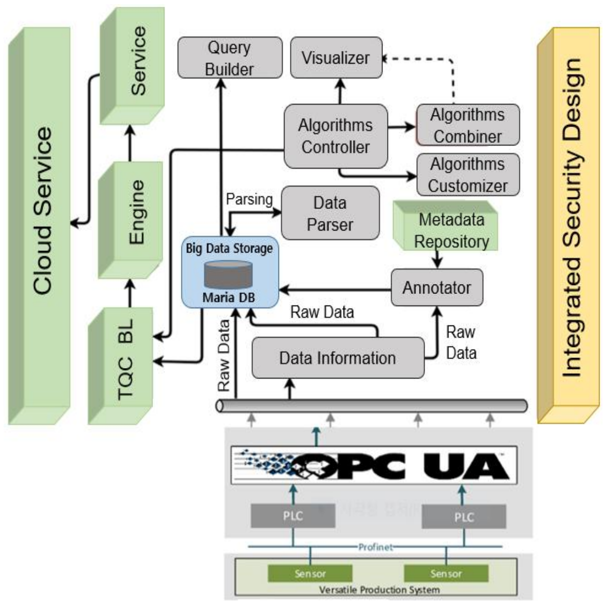

Figure 7. Big data collection and analysis system structure

Table 1. Data collection item analysis result

Classification		Data details
Data Collection	Cutting Processing Machine	Machine/Tool information, dimensions, change amount, tool load, tool life, cutting load, etc.
	Bush press-in Equipment	Bush inner diameter, clamp, press-fitting pressure (Torque)
	Tool test Equipment	Con-Rod machining dimensions (Rod & Cap Bolt Hole, Symmetry, Thickness, Inner Diameter, etc0
Data Analysis	correlation	Cutting load vs Quality factor. Tool life, Cutting conditions Bush inner diameter vs Press in torque

4.3 MES SPC and AI Learning Model Analysis

First, process of data storage, analysis and visualization is shown in Fig. 8. SPC statistical analysis is used for data analysis, which applied mainly for process control such as process capability (CPk), X-bar R control chart, and Scatter Plot. The TQC application based on the MES solution stores, analyzes, and visualizes based on the LKLAB-MES solution, and performs SPC statistical analysis in terms of routine statistical process control. And for the visualization process, open source, and FP(FarPoint) Spread was used as solution.

The second step is analysis of AI modeling. In order to manage the quality and productivity of the machining precision of the connecting rod, the supervised learning algorithms eXtrema Gradient Boosting (XGBoost) and Linear Regression (LR) are applied. XGBoost is a decision tree-based ensemble methodology that uses boosting techniques and can be implemented in a distributed environment, so it is fast and supports both regression and classification problems. LR is used to predict the optimal value of each machine value because it describes the distribution of data well and derives an optimal linear regression model for good product production. How to design and analyze the process of the AI solution is real-time inference. AI solution real-time inference design integrates time based on various

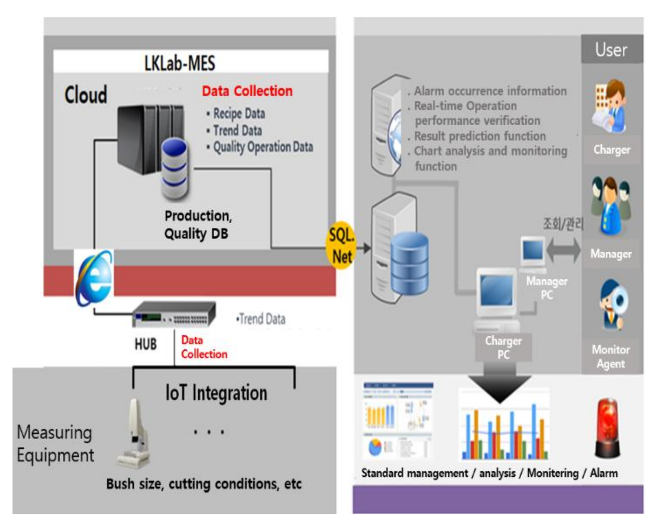

Figure 8. MES Data Collection, SPC Analysis and Visualization

occurrence cycles. After outliers and missing values of raw data are removed or preprocessed, it develops and executes the cause analysis and quality prediction model for each abnormal type and generates an alarm. This result is used to set an action guide according to the alarm, visualize the trend, and uses analyze in detail. Finally, AI determines a good and defective product and classify them by type through inferring the quality data model

4.4 Implications and differences of this research

4.4.1 Implications

First, the machining industry also had a limitation in real-time data collection and analysis research due to network and communication limitations, but these are being gradually resolved with the recent introduction of OPC-UA. Second, due to the limitations of data collection and storage technology, this research conducted sampling oriented SPC statistical analysis, but real-time collection, storage and analysis are now getting possible, so machine learning and AI analysis are being introduced. Third, the latest convergence technology is emerging by combining Edge Computing, Cloud, 5G, and TSN (Time Sensitive Network) with advances in communication technology as IoT integration and platforms.

4.4.2 Differences

First, for real-time big data collection and analysis in the entire IT and OT areas, IoT integration technology was applied by interfacing with the application browser from the POP server to the OPA-UA client/server function. Second, Algorithms such as XGBoost and LR, as a tool of AI modeling analysis, were adopted to improve the processing precision and productivity of the connecting rod, away from the existing SPC statistical analysis. Third, the system was designed to the level of a real-time big data collection and analysis platform in the entire manufacturing area in connection with IoT integration and AI learning modeling technology and cloud.

5. Conclusion

Although many of SMEs have built automation systems, there are limitations in building data collection and analysis systems since real-time processing is difficult due to the lack of data interfaces between different areas such as heterogeneous equipment, OT, and IT. For this reason, most SMEs have introduced the smart factory focusing on IT without prior preparation for problems in the communication and OT areas. But recently, starting with Advancement Project of Smart Factory, the latest communication protocol of OPC-UA is gradually increasing.

In this paper, in order to design a real-time manufacturing big data collection and analysis system, a network was designed with an IoT integration module based on OPA-UA, the latest communication protocol. Then, Database was designed based on the collection analysis table that reflected the user requirements in the cutting processing automation machine, the bush press-in measuring system, and the tool monitoring/ inspection system. the first stage, SPC statistical analysis and visualization were implemented, and the second stage AI model analysis and visualization analysis were designed.

For future tasks, after the big data collection and analysis system based on OPC-UA is stabilized, it is necessary to apply optimized AI learning model. Then it is considering of apply the latest technologies such as edge computing, cloud, 5G, and TSN linked with factory servers. Through the advancement of AI learning modeling, it is necessary to expand and study the model design of the CPS module concept that can be applied to a specific process according to small and medium-sized machine processing companies.

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