Journal of Engineering and Applied Sciences 13 (3): 643-649, 2018
ISSN: 1816-949X

A Research on Sensor Data Collecting and Processing System for Manufacturing Equipment Autonomic Control based Cyber Physical System

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Abstract: This study introduces sensor data collecting and processing system for autonomic control of manufacturing equipment based CPS (Cyber-Physical System). As emerging the '4th Industrial Revolution' by increasing the necessity of the intelligent system recently, 'Autonomic Control System' also has been the important issue. It is necessary to develop the system collecting data of machines and sensors for the autonomic control system to monitor the target system. But it is difficult to collect data because data formats of machines and sensors of the existing factories differ between each manufacturer. Therefore, this study presents and implements data collecting and processing system that comprise 4 steps by using 'MTConnect' that is standard manufacturing facility data collecting middleware. Through this system, we can monitor the integrated data collected from machines and sensors of each different manufacturer. And using these data, it is possible for autonomic control system to learn machine learning for statistical analysis and better autonomic control.

Key words: MTConnect, data process, agent, manufacturing facility, autonomic computing, system

INTRODUCTION

Recently with the development of 'Bigdata' and 'Artificial Intelligence', the '4th Industrial Revolution' in which technologies are converging has emerged. As having this concept, projects such as 'Industry 4.0', 'Smart Factory', etc., based on the CPS (Cyber-Physical System) are ongoing. To satisfy this need, 'Autonomic Control System' has been important issue. For monitoring the target system on autonomic control system, it is necessary to collect data of machines and sensors. But it is difficult to apply the autonomic control system to the manufacturing factories using machines and sensors of diverse manufacturers because data formats of those differ between each manufacturer (Lin *et al*., 2016; Torrisi, 2011; Li, 2016).

To integrate data from different manufacturer's sensors and machines and to manage the plant, a system with the following processes is required. Data transmission, analyzing and parsing data, storing data, providing data. To apply CPS technology to Smart Factory and reliably synchronize the actual worksite and the virtual space, middleware should be adopted to monitor consumable consumables in the process.

Therefore, this study proposes a sensor data collection system based on 'MTConnect' which is a standard for collecting data of various types of machines and sensors and modeling consumables. As supplementing the database to store with this system, it is also possible to exe-cute the autonomic control based on the statistical analysis and machine learning of the data of machines and sensors.

MATERIALS AND METHODS

Literature review

Smart factory (Leitao *et al* ., 2016; Wang *et al*., 2016; Riedl *et al*., 2014; Park *et al*., 2015): Production paradigm of the manufacturing industry changed from mass production of small goods to small quantity production of many goods. It has made many changes in the environment of the manufacturing industry. To operate system, it is generally needed for person to intervene. However, the large scale system such as the smart factory is beyond the management range of the person and some studies revealed that 40% of system failures were due to intervention of person. Therefore, to minimize the intervention of person, it is needed the autonomic control system and it is also needed to apply this system to the smart factory.

The autonomic control system using goal model and fault tree (Ko *et al*., 2016, 2017): As recently emerging the '4th Industrial Revolution', research of the intelligent systems such as 'Industry 4.0' and 'Smart Factory' has been continued actively. 'Autonomic Control system'

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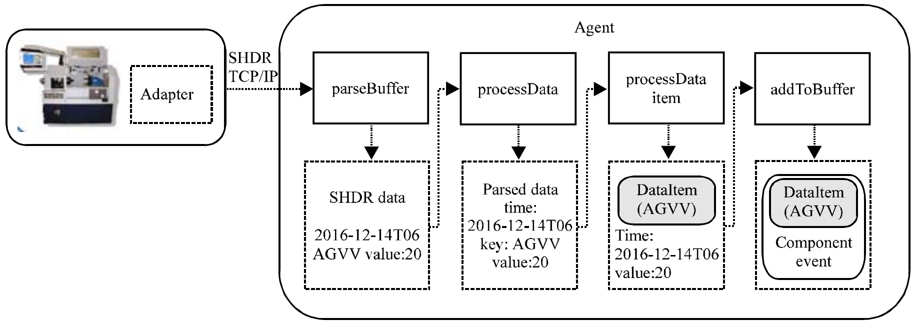

Fig. 1: Data collecting process of MTConnect

Table 1: Comparison of DDS, OPC and MTConnect

Comparisons	DDS	OPC	MTConnect
Integrated data collection	O	O	O
Provide server and client	X	O	O
Provide network security	O	O	X
Supply machine tool status	X	X	O

also has been the important issue for improvement of production and reduction of cost of intelligent production system. Generally, the autonomic control system comprises 4 steps including target system monitoring, analysis, plan, execution.

The autonomic control system using the goal model and the fault tree has advantage that it is easy to structure the entire goal of massive and complex system by abstracting top and sub goals. However, because data formats of manufacturing facilities differ between each manufacturer it is difficult to monitor the entire facilities in the smart factory including various manufacturing equipment. Thus, a standard protocol for integrating data of machines from different manufacturer and a collecting middleware of data of machines for ma-chine learning of machines are required.

MTConnect protocol (Venkatesh *et al.*, 2016): Due to the evolution of the computing environment it is possible to interwork with various manufacturing equipment during manufacturing process. However, since, these services are specialized to the characteristics of the manufacturer and use a manufacturer-dependent protocol it is difficult to collect data of machines of each different manufacturer. To solve these problems, a standardized industrial communication protocol is required to integrate data of machines made by various manufacturer. There are DDS (Data Distribution Service), OPC (OLE Process Control) and MTConnect representatively. Table 1 is a simple comparison of DDS, OPC and MTConnect (Fig. 1).

MTConnect does not support the communication security features supported by other proto-cols. However, MTConnect can provide information on consumables (e.g., cutting tools) used in manufacturing plants. This makes it possible to take precautions before all the consumables of the plant are worn, thereby preventing the loss of productivity due to consumable wear. Therefore, MTConnect is a middleware suitable for CPS architecture for manufacturing environment. In this study, we implement a data acquisition system using MTConnect. In order to adopt the autonomous control system and conduct machine learning of the system it is required to database because large-capacity storage larger than the buffer of MTConnect agent is needed.

MATERIALS AND METHODS

Manufacturing facility data collection system structure and process

Data collecting process of MTConnect: The data collecting process of MTConnect comprises 4 steps as shown in Fig 2, Step 1: parseBuffer, Step 2: processData, Step 3: processDataItem, Step 4: addToBuffer. In this study, we describe the 4 steps of the data collection process.

Step 1; parseBuffer: MT Connect collects data of devices of each different manufacturer by converting them into one common protocol, SHDR protocol. The SHDR protocol is a simple data collection protocol that has low complexity and does not require complex development.

The basic form is ‘ Timestemp|Name|Value’. In Step 1, one of the SHDR string value of the data transmitted from multiple devices stacked in a socket is loaded. This data is formatted as ‘2016-12-14T06|agvv|2’as shown in Fig. 1.

Step 2; processData: In Step 2, the data loaded in Step 1 is split into unit of pipe '|' and parsed. The first parsed data is the timestamp, the second is the ID of the data of device and the last is the value of the data element corresponding to ID.

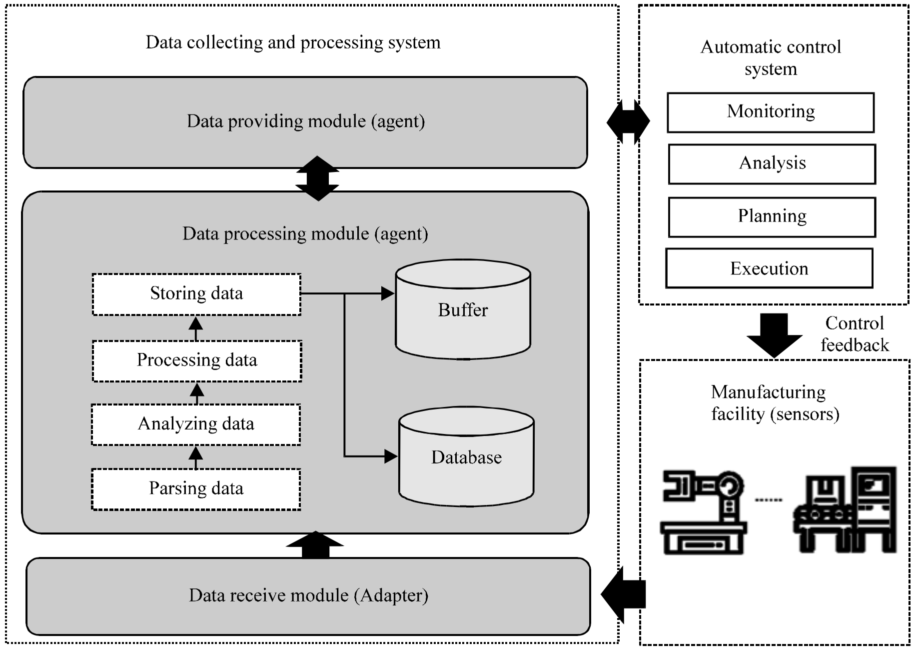

Fig. 2: Architecture of data collecting and processing system

Step 3; processDataItem: In Step 3, the data parsed in Step 2 is converted into a format for storing in the buffer. When MTConnect agent is executed, the data of device predefined as XML format is stored in advance. In this step, reference value predefined in dataItem class is loaded based on Id of the data of device parsed in Step 2. If the ID of data is not predefined, the data is ignored.

Step 4; addToBuffer: In Step 4, the data reconstructed through from Step 1-3 is stored in the internal buffer and external database. Originally autonomic control system receives the data from the internal buffer of the agent. However because MTConnect is designed to provide real-time data of the devices, the structure of the internal buffer of the agent is a queue structure in which the first data is discarded when the buffer is full and new data is entered. Therefore, the past data beyond the range of the buffer cannot be retrieved. It is necessary to store all the data in a separate database that enables statistical analysis of the data of devices and sensors and machine learning for autonomous control.

Manufacturing facility data collecting and processing system architecture: Manufacturing facility data collecting and processing architecture consists of three parts, the 'Data Receive Module', the 'Data Processing Module' and the 'Data Providing Module'. Figure 2 shows the architecture of manufacturing facility data collecting and processing system.

Data receive module: It is a module that receives data transmitted from manufacturing devices and sensors. This data consists of the SHDR protocol such as '2016-12-14T06|agvv|20'. The 'data receive module' sends the received data to the 'Data Processing Module' in the form of a string.

Data processing module: The string-type information of devices and sensors transmitted from the 'Data Receive Module' passes through following steps: parsing the data split the string of SHDR type into unit of pipe (parsing data), inspecting the valid of the parsed data (analysis Data), converting the valid data into the type stored in the internal buffer (processing data), transmitting the data to the internal buffer and external database (Park *et al*., 2015).

Data providing module: The 'Data Providing Module' receives requests to provide the data of devices and sensors to the autonomic control system and the client which is a monitoring program of devices and sensors, converts the data stored in the internal buffer into XML format and sends this data for response. Client requests and responses are based on the HTTP protocol.

Database schema: In this study, we describe the database schema for storing in external databases. In order to process and manage the data transmitted from the devices it is necessary to store the information of the device, data from the device and time-related values. However, if all of

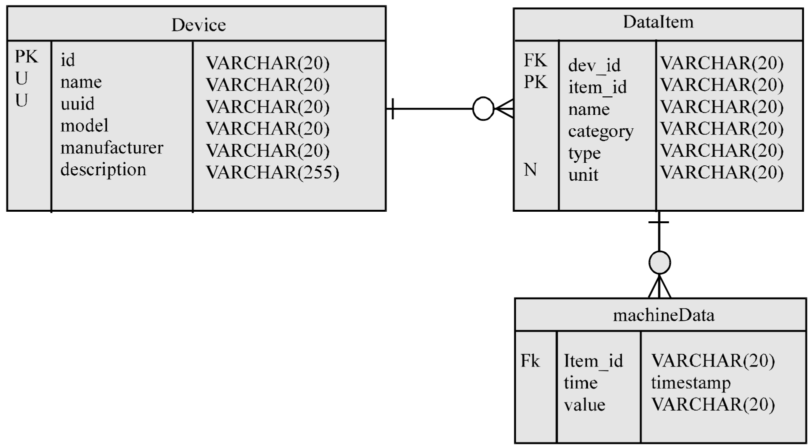

Fig. 3: Database schema for data collecting and processing system

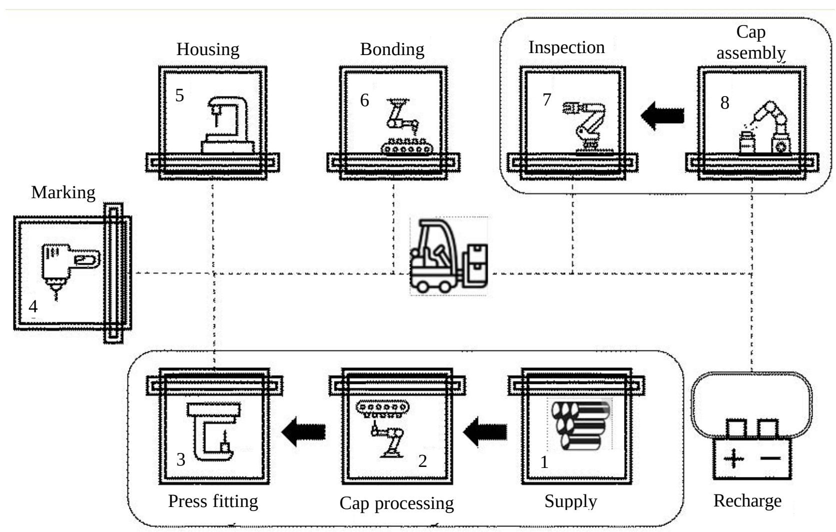

Fig. 4: Factory environment of electric motor factory

the data is managed in one table it is not efficient because the number of duplicate data (the information of the device, DataItem information) increase. Thus, we designed the database schema shown in Fig. 3, to minimize duplicate data. Figure 4 shows the database schema of manufacturing facility data collecting system.

The ‘Device’ table is the table that stores the data of the devices and sensors that the Agent collects data. The ‘Dataitem’ table shows the data which is transmitted from devices and sensors. The ‘machine data’ table shows the values of data transmitted from devices and sensors in real time. The ‘Device’ and ‘Dataitem’ tables store the data based on the predefined the XML file in the MTConnect agent. As the data coming in the real time, the agent inspects the data and stores it in ‘machine data’ table by splitting into ‘id’, ‘timestamp’ and ‘value’. This database schema structure has the advantages that can minimize the number of duplicate data and the load on the DBMS because it stores the data inspected by agent and while storing the data in the database it is not necessary to inspect the data using the foreign key. However, since the data of devices and the sensor are continuously transmitted as long as the device is operated, the data of the ‘machine data’ table is continuously accumulated. This results in longer data retrieval times as the data has accumulated.

RESULTS AND DISCUSSION

Experiment and evaluation: In this study, we conduct a simple data collection experiment based on the data processing system. The experiment was conducted in the following five steps: Step 1; Model the plant layout that produces the electric motors, define the AGV operation for the electric motor production and the data type of the AGV. Step 2; Implement a program (Adapter) that can generate AGV data and confirm data transfer with agent. Step 3 and 4; Adapter generates arbitrary data and confirms whether the generated data is stored in agent and database. Step 5; Generate data on the AGV notion pattern defined in Step 1. Measures the number of data generated, the throughput of the agent and the delay time of the data requested by the client.

Step 1; Definition of AGV's data type: As described in, MTConnect it is necessary to define the data type for monitoring through MTConnect. There are 3 data types: 'Sample' type representing a continuous data value, 'Event' type representing a target (or device) state or simple character data and 'Condition' type indicating the availability of the state and function of the device (Fig. 4).

Figure 4 is the layout of a factory that produces electric motors. One research is done in one process cell (①~⑧). The arrow indicates that result of the operation in the cell can be transferred to the adjacent cell using the conveyor belt. The area where the AGV moves is the same as the dotted line. The AGV carries the components from one cell to another and charges the battery in the recharge zone to charge the battery as needed. The process of producing electric motors is as follows. First, gather the following parts and make one motor in cell ⑧. Output form the sup-ply, cap processing and press fitting (electric motor cap), coil form Bonding and results from housing (motor case). The resultant assembly is inspected in cell ⑦. Finally, the motor is completed by marking in cell ④. Using this program, the AGV data is created virtually.

Step 2; Connection of device and MTConnect agent: For the experiment, we first connected the device and the agent and checked whether the data of the device can be received the data transmitted from the agent.

Step 3; Data collection in database: The generated data can be stored in not only the buffer of MTConnect but also the database. If we use only the buffer of MT Connect it is only possible to monitor the real-time data. But with storing the data in the database, it can monitor old data discarded from the buffer. The accumulated data also can be used as learning data for the autonomic control system.

Step 4; Confirmation of client: The MTConnect Agent delivers the data to the client through the XML document format, so, it can be viewed through the Web browser as shown in Table 2.

Step 5; Performance evaluation: Based on the electric motor generation process described in Fig. 5 and 6, AGV data is generated and transmitted to the agent. The performance evaluation was performed as a result of the client asking the agent for the data. In order to facilitate motor production in the plant layout in Fig. 5 and 6, the AGV must deliver motor components to non-adjacent cells. Therefore, the moving path of the AGV is as follows based on the process cell:

③(pick)→⑧(drop),⑥(pick)→⑧(drop)⑤(pick)→⑧(drop), ⑦(pick)→④(drop)

We repeatedly generated the simulation data that progressed sequentially through this process. The movement path of the AGV is calculated through the virtual coordinates assigned to each cell. Figure 5 and 6 show the number of test data generated for 60 sec.

Table 2: Inquiury through web browser

Timestamps	Types	Sub types	Name	Ids	Sequences	Values
Samples						
2017-02-26T23:34:12.434786	Coordinate	Coordinate X	CoX	x	53	1
2017-02-26T23:34:13.190787	Coordinate	Coordinate X	CoX	x	54	2
2017-02-26T23:34:13.877242	Coordinate	Coordinate X	CoX	x	55	3
2017-02-26T23:34:14.464131	Coordinate	Coordinate X	CoX	x	56	4
2017-02-26T23:34:15.036511	Coordinate	Coordinate X	CoX	x	57	5
2017-02-26T23:34:23.082349	Coordinate	Coordinate Y	Coy	y	60	1
2017-02-26T23:34:23.690753	Coordinate	Coordinate Y	Coy	y	61	2
2017-02-26T23:34:24.270637	Coordinate	Coordinate Y	Coy	y	62	3
2017-02-26T23:34:24.834511	Coordinate	Coordinate Y	Coy	y	63	4
2017-02-26T23:34:25.382876	Coordinate	Coordinate Y	Coy	y	64	5
Events						
2017-02-26T23:34:17.740305	Load	-	L state	Load state	58	Loading
2017-02-26T23:34:20.747800	Load	-	L state	Load state	59	Loaded
2017-02-26T23:34:28.741602	Load	-	L state	Load state	65	Loading
2017-02-26T23:34:29.740265	Load	-	L state	Load state	66	Empty

Device: AGV-001;UUID:001

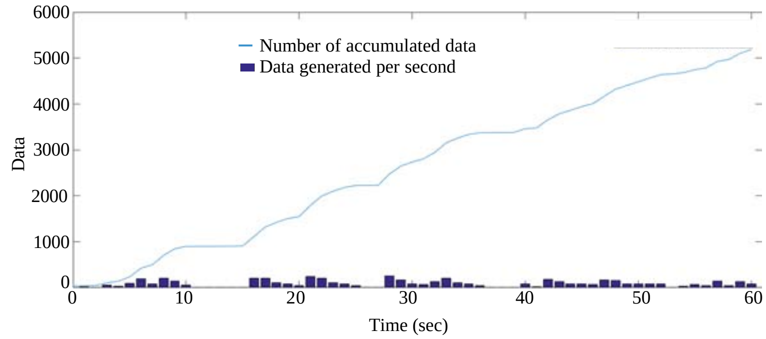

Fig. 5: Simulation data generated for 60 sec

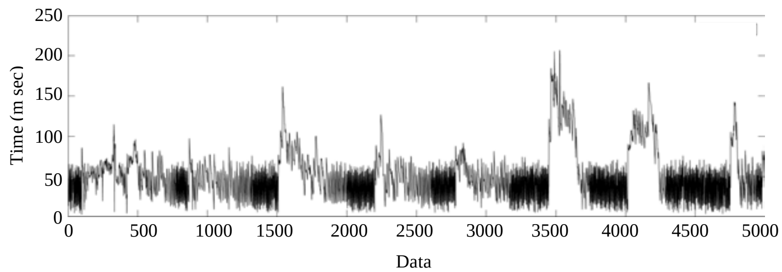

Fig. 6: Delay time of inquired data by client

About 5000 data was generated for 60 sec and a maximum of 248 data was generated per second. Figure 6 is a graph comparing the time when data was generated and the time when the client received data in real time. The client requests the latest data in 20 m sec increments. The query is as follows: http://agentIp:port/sample? from = 'lastseqence+1'. This query is a query that requests the latest data that the client has not received form the agent and the value of 'last-sequence' is replaced with the sequence number of the most recent data received form the client in the client.

The average delay time of the data is 52.1 msec and the maximum delay time is 207.1 msec. Data latency can be a determinant of the reliability of the CPS platform that links the actual workspace to the virtual space. Since, this experiment simulates only the data of the AGV by modeling the virtual electric motor factory it is necessary to experiment to apply AGV and process cell data at once to the actual motor factory.

CONCLUSION

In this study, we proposed and implemented a system which processes the data of sensor using 'MTConnect', a standard manufacturing facility data collection middleware. The existing autonomic control system can detect and cope with the danger through the monitoring of devices and sensors. However, it is difficult to collect data because formats of the data of devices and sensors are different each manufacturer. Thus, collection of the data using standard manufacturing facility data collection middleware enabled us to collect other types of data. In addition, as supplementing the database in MTConnect, it is possible to store past data that was discarded by the internal buffer, perform statistical analysis and machine learning based on all the data made from the devices and sensor. But since the data of the devices and the sensor is generated constantly unless the facility is stopped, the time of the data retrieval becomes longer as time passes. Therefore, we will study statistical analysis and machine learning through the data of devices and sensors based on the Bigdata, improvement of collection method of the data of devices and scaling algorithm and optimization of search performance using table partitioning.

ACKNOWLEDGEMENTS

This research was supported by the ICT and R&D program of MSIP/IITP [R-20150505-000691, IoT-based CPS platform technology for the integration of virtual-real manufacturing facility].

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