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Monitoring of Manufacturing Facility based on International Standard Protocols for an Implementation of Digital Twin

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Abstract

Establishment and focus: With the recent acceleration of technology development, technologies for smartization of existing manufacturing plants such as digital twins are being illuminated. This paper introduces existing data collection techniques for digital twins. A Manufacturing Execution System that can improve productivity and help decision making by monitoring production plants in real-time is one of the key technologies for smart factories. The application of digital twin technology for more accurate monitoring is also an important issue. However, digital twin implementations require an integrated infrastructure that can integrate various equipment data from different manufacturers. In this paper, we proposed four processes for collection based on data standards for integrating facility data from different manufacturers. Based on the process scenario, we collected approximately 10,000 data over 120 seconds and showed an average 108ms delay before the data was verified.

System: This paper designs and develops a visualization program that can verify real-time information of facilities using data collection system based on international standard protocols developed for collection and monitoring of data from heterogeneous facilities. To this end, heterogeneous facility data generators are used to collect data based on standard protocols and to calculate the total amount of data collected and the delay time, demonstrating the high reliability of digital twin. This allows a factory to integrate equipment data from different manufacturers and view them in real-time.

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1. Introduction

Along with a emergence of the 4th industrial revolution based on recent acceleration in development of technologies involving sensors, 'Big Data', artificial intelligence, and hardware, the countries having advanced manufacturing technologies are making efforts focused on the development of intelligent factory systems[1]. Existing domestic factories are also trying to integrate and operate system resources of computing and sensors, autonomic control software, and actual physical systems[2-4] thereby the importance of 'digital twin' technology, capable of combining actual physical world with cyber world, is increasing as well[5].

Digital twin refers to a set of set of realistic models capable of simulating actual motions in a virtual environment. Digital twin technology enables an establishment of virtual models and data and an expression of attributes and motions of actual objects, thereby it can be applicable to diverse fields of production and service industries including remote production control, manufacturing simulation, and improvement of productivities etc[6]. Digital twin technologies can also be applicable to the Manufacturing Execution System(MES) that can monitor manufacturing systems and help plant managers based on data of diverse equipment integrated for an embodiment of smart factories.

However, existing studies, focused on an establishment or implementation of digital twin technologies, are yet to get over issues related with actual application of diverse equipment from different suppliers to existing manufacturing factories requiring an integration of necessary data created in different format. Such issues can become tractable by exploiting an International Standard Protocols developed for a collection and integration of equipment data delivered from different suppliers in a factory. Thus, this study presents and implements a system capable of real-time monitoring of the data collected through an application of international standard protocols. Through the presentation and implementation, the infrastructure of data collection and framework thereof based on the application of international standard protocols will be provided to realize the monitoring of real-time data collected.

The methodology proposed in the present study will undergo procedures divided into following four steps: 1) Data Request, 2) XML Analysis, 3) Data Processing, and 4) Visualization. Thereby the real-time monitoring of manufacturing factories will be enabled through analyses, processing, and visualization of data of manufacturing equipment requested and collected through the international standard protocols. As a case study of an application of the methodology presented in the present study, a virtual factory making motors will be simulated. The data of six-axis robot arms and AGV that transfers components to robot arms will be collected in real-time through the international standard protocols and the data will be visualized. The time to completion of analyses for the visualization of collected data from real-time generation thereof will be evaluated and will be examined in terms of the highly reliable implementation of digital twin technology.

This paper comprises following sections. Section two will explain technologies necessary for the data collection from smart equipment in factories. Section three will describe the methodology and system architecture proposed in the present study. The demonstration and performance evaluation of the system presented in the present study will be included in Section 4. Conclusions obtained from the present study will be presented in Section 5.

2. Relevant Studies

Along with an emergence of the trend toward the 4th Industrial Revolution, issues concerning transformation of existing factories into smart ones and the ‘Manufacturing Execution System (MES)’ and ‘Digital Twin Technology’ therefor are being noticed as important relevant technological issues. This section introduces basic concept and technologies necessary for the implementation of MES, digital twin, and MTConnect standards.

2.1 Manufacturing Execution System

Production control systems implemented in factories refer to the software enabling plant managers to save or reduce production costs, to control product qualities, and to accomplish highly efficient production at lower level of cost[7]. MES provides plant managers with

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functions of monitoring and reporting of data collected from equipment installed in factories. MES does not participate in actual production in factories but instead, it enables factory managers to cope with general or special tasks fast and intuitively through an integrated analysis of collected data.

Factory automation became noticeably concerned by people with an advent of the trend toward 4th industrial revolution; this necessitates an improvement of existing MES. However, the improvement of existing MES needs to solve following issues: 1) Absence of an infrastructure capable of collecting integrated data, 2) Insufficient integrated data of workers, 3) Insufficient common frameworks enabling workers and factory managers to do better works through an exploitation of collected data, and 4) Lack of supports to projects and simulations of MES[8].

Authors of the present study previously designed and developed the data collection system according to the 'MTConnect', the international standard protocols, to solve the problem of an absence of infrastructure required for integrated data collection.[9] The present study will design and implement the system capable of intuitive monitoring of the states of manufacturing equipment in a factory based on the data collection system.

2.2 Digital Twin

The 4th Industrial Revolution emphasizes an importance of the transformation of manufacturing industry to cope with rapidly changing markets and advancement of technologies for societies and economy. To fulfill the needs of cost-reduction, improved production efficiency, and changes in manufacturing paradigms such as from mass production to flexible manufacturing systems, the modularization and automation of existing manufacturing facilities enabled to operate by digital control are needed[10].

The autonomous computing technologies developed for an automation of manufacturing facilities and to cope with unexpected problems thereof is also noticed as an important issue. The autonomous control system refers to a system capable of deriving optimal outcomes by spontaneously modifying its own behaviors according to varying environment[11]. To realize an autonomous control of equipment or software, correct monitoring of states thereof is unavoidable. Besides, each entity of doing autonomous control shall be cognitive to the extent available for respective spontaneous controls for behaviors to be selected against created issues.

To implement such functions in automatic manufacturing systems, the very realistic models capable of projecting actual works in reality to a space of cyber world are necessary. The systems and models enabling this projection are referred to as the 'digital twin'. For the embodiment of digital twin in a domain of manufacturing system, a real-time collection of data of manufacturing equipment and sensors thereof and a resulting visualization of such data are necessary.

2.3 MTConnect

The advancement of computing and networking technologies enabled an interlocking of various manufacturing equipment and data thereof in a manufacturing process through the integration of data from diverse equipment and sensors. However, due to the data created in different formats and protocols of respective equipment delivered from different suppliers, there exists difficulties for the integration of such data in factories consist of diverse equipment from different suppliers. MTConnect, the one of scalable communication middleware, was introduced to solve such problems and enable data exchange between manufacturing equipment and application software.

MTConnect does not support robust data security functions supported by industrial standard protocols such as DDS (Data Distribution Service) or OPC (OLE Process Control) etc[12]. However, MTConnect can even model the degree of abrasion of tools (ex. electric drills) used for manufacturing equipment; this qualifies it as an appropriate data collection standard suitable for the digital twin that can project physical world to cyber world as it is. Recently, the OPC-UA standards were established by the cooperation of MTConnect with OPC.

MTConnect is comprised of the ‘Adapter’, enabled to convert data transferred from equipment into standard format, the ‘Agent’, enabled to collect and control data, and the ‘Client’ that requests and receives data. The present study will design and implement a program capable of receiving and visualizing data from the data collection system of manufacturing equipment complying with MTConnect standards.

3. System process and architecture

This section explains the system process and architecture capable of monitoring states of manufacturing equipment.

3.1 System Process

The studies delving into topics of cyber-physical system and digital twin etc. are actively in progress recently for an embodiment and synchronization of physical world into the space of cyber world. To synchronize physical world with cyber world, the technologies, capable of integrating and of highly reliable synchronizing of sensors’ data to be created in an actual physical world, are needed. However, an actual integration of heterogenous data of various manufacturing equipment delivered from different suppliers using respective data transmission methods is difficult. Therefore, this section explains the Step 4 prepared for the implementation of system process providing the visualization and integration of diverse equipment data by using ‘MTConnect’, the standard prepared for data collection to monitor manufacturing equipment[Figure 1].

• Step 1: Data Request

Real-time manufacturing equipment data are requested for a server capable of storing and providing the data complying with ‘MTConnect’ standards. The ‘http’ protocol is used to request for data; ‘MTConnect Agent’ then provides a document in XML format as a response to the request for data. In Step 1, a request for new data continues with the value of ‘lastsequence’ which is provided with equipment data from ‘MTConnect Agent’. The ‘http’ protocol used for the request for data is as follows: ‘http://mtcagentip:port/sample?from=lastsequence’. The XML document returned as a response to the request for data will express equipment data, numbers of data, equipment id., and number of each equipment etc. Figure 2 illustrates the XML data transferred from ‘MTConnect Agent’ in the web[Figure 2].

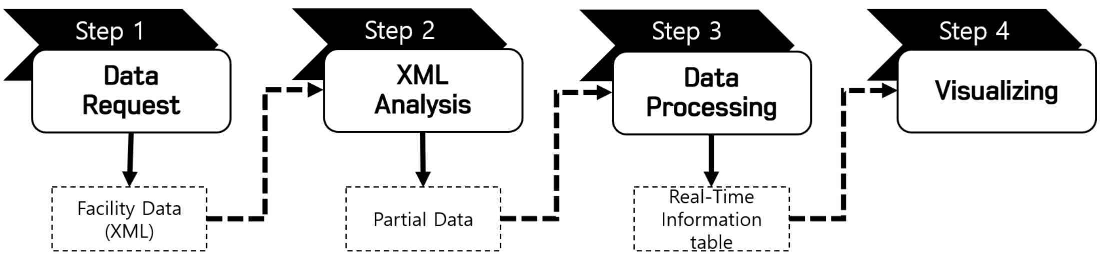

Figure 1. System Process for Visualization

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Device: GFAgie01; UUID: mtc_adapter001

Device : GFAgie01

Events

Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2018-03-09T06:01:09.876048Z	Availability		avail	GFAgie01-dtop_1	15	UNAVAILABLE
2018-03-09T06:01:09.876048Z	EmergencyStop		estop	GFAgie01-dtop_2	16	UNAVAILABLE
2018-03-09T06:01:09.876048Z	AssetChanged			GFAgie01_asset_chg	24	UNAVAILABLE
2018-03-09T06:01:09.876048Z	AssetRemoved			GFAgie01_asset_rem	25	UNAVAILABLE

Condition

Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2018-03-09T06:01:09.876048Z	Unavailable		system	GFAgie01-dtop_3	17	

Rotary : A

Samples

Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2018-03-09T06:01:09.876048Z	Angle	ACTUAL	Aposition	GFAgie01-A_2	1	UNAVAILABLE

Rotary : C

Samples

Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2018-03-09T06:01:09.876048Z	Angle	ACTUAL	Cposition	GFAgie01-C_2	2	UNAVAILABLE

Figure 2. MTConnect data xml shown on the web[13]

• Step 2: XML Analysis

In this stage, the XML document, returned from 'MTConnect Agent', is analyzed. The XML data are then divided into individual ones of manufacturing equipment or of sensors through an analysis. The divided data will be used for further visualization or expressions in graphs in the next steps.

• Step 3: Data Processing

The data of manufacturing equipment or sensors, divided in previous step, are processed in this step for further visualization. Above all, the numbers of data of respective equipment are counted for a certain period of time to figure out how many data were created in a given time (e.g. per second). The data of manufacturing equipment provided therefrom are expressed with separate logs.

• Step 4: Visualizing

This is a final step visualizing manufacturing equipment data processed through previous three steps from Step1 to Step 3. The manufacturing equipment data calculated per each second in Step 3 are visualized to facilitate intuitive recognition of the amount of created data through UIs representing histogram or dots.

3.2 System Architecture

System architecture of the visualization of manufacturing equipment data consists of the following three modules: the 'Data Requesting and Receiving module' to be operating based on 'Machine Data XML', 'Partial Data', and 'Real-Time Information table', which are outcomes resulted from sequential processing from Step 1 to Step 4 with the data collected in real-time, the 'Data Processing Module', and the 'Graphical Presentation Module'. Figure 3 illustrates an overall architecture of manufacturing equipment visualization.

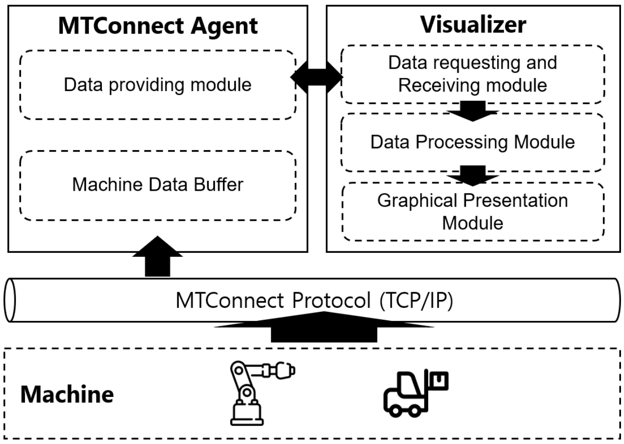

Figure 3. System Architecture

• Module of Data Request and Reception

The 'Data Requesting and Receiving Module' requests for real-time data of manufacturing equipment in a factory and regularly (e.g. at every 30ms) receives the XML document as a return to the request. The XML documents are used for the visualization of data of manufacturing equipment in a factory; the XML documents are transferred to the 'Data Processing Module' for an analysis and processing for visualization. Data collection buffer of 'MTConnect' is a structure of queue wherein respective data, corresponding to each equipment and sensor to be stored therein, will be assigned with separate numbers. 'MTConnect Agent' specifies the number of last data given to the XML document providing information. The module stores the last number of such data (the

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value of lastsequence) separately and the data corresponding to the number next to the stored data are requested when requesting for the next data of manufacturing equipment and sensors. Algorithm 1 represents the pseudo code explaining request for data going to 'MTConnect Agent'

Algorithm 1 Requesting and Interpreting XML Data

```
count ← 0
while true do
    xmlData ← requestData("AgentIP")
    nextSequence ← xmlData.findAttribute("nextSequence")
    while tempData ← xmlData.nextData() ≠ NULL do
        data.add(tempData)
        count ← count + 1
    wait(30)
```

Figure 4. Algorithm for Data Requesting

• Data Processing Module

'Data Processing Module' extracts and counts the data of manufacturing equipment and sensors based on XML documents transferred from the 'Data Requesting and Receiving Module'. The results of extraction and counting of data are reconfigured in the 'Real-time Information Table' and be transferred to the 'Graphical Presentation Module'. Table 1 shows an example of the 'Real-time Information Table'.

Table 1. Information of Real-time Facilities

Machine	Data_ID	Timestamp	Value
AGV	POS_X	12:36:42:4665215Z	1
AGV	POS_Y	12:36:43:0665215Z	1
RV-7FL	Load	12:36:43:1658423Z	LOADED
RV-7FL	POSITION	12:36:44:5365844Z	0
RV-7FL	POSITION	12:36:45:6584211Z	1
RV-7FL	POSITION	12:36:46:6784213Z	2
AGV	POS_X	12:36:47:7531457Z	3
6Axis_arm	J1_ANG	12:36:47:9632544Z	255
AGV_001	POS_X	12:36:48:8698542Z	4

• Graphical Presentation Module

'Graphical Presentation Module' provides factory managers with real-time states of manufacturing equipment presented in an intuitive visualization of data based on statistics obtained from the data processed in the 'Data Processing Module'.

4. Experiment and results

This section introduces a demonstration of the system of monitoring manufacturing equipment data to be presented in the following three-stage processes: 1) Creation of data of manufacturing equipment, 2) Collection of data of manufacturing equipment, and 3) Monitoring of data of manufacturing equipment. A six-axis robot working in an electric motor manufacturing factory and an automated transportation robot AGV runs therein are modeled and the real-time simulation data thereof are created. The data created thereby will be stored in a server in real-time through the MTConnect standards. The monitoring system for manufacturing equipment data in a factory presents users the visualized real-time data of manufacturing equipment in a factory received from MTConnect server. For purposes of evaluation, the time to the monitoring of real-time data in Step 3 from the creation of data in Step 1, will be measured.

4.1 Program Structure and User Interface

The system of monitoring manufacturing equipment data in a factory is a program that outputs the data sequence and data logs of manufacturing equipment based on the requested data after requesting for the manufacturing equipment data to the data collection server that stores manufacturing equipment data created. Figure 5 illustrates the schematized system architecture and processes therein.

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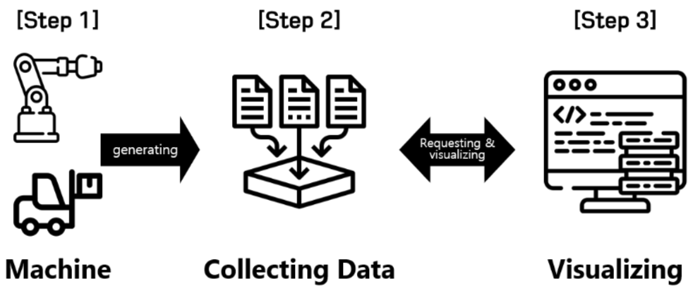

Figure 5. Architecture of Monitoring System

- **Step1: Creation of manufacturing facility data**

First, the data of manufacturing equipment are created based on the scenario of a factory. Through an employment of the data generator of manufacturing equipment, the outcome obtained from previous study conducted by authors of the present study, the data of six-axis robot 'RV-7FL' and of the Autonomic Guided Vehicle (AGV), are created. The data of manufacturing equipment are created to be complying with the protocol of SHDR (Simple Hierarchical Data Representation) that represents the 'time/name of attribute/value of attribute', and will be outputted in the following format: e.g. '2018-04-03T:12:36:42.4665215Z'

- **Step2: Collection of manufacturing facility data**

The data, crated from the data generator, are stored in the 'MTConnect Agent'

- **Step3: Monitoring of manufacturing facilities data**

The monitoring system of manufacturing equipment data requests the 'MTConnect Agent' server for newest data regularly by following processes defined in Step 2 and Step 3 presented in Section 3 before, analyzes the documents in XML format received from the 'MTConnect Agent' server as a response to the request, and visualizes the results of analysis of XML documents through the program UI.

The amount of real-time data created from the six-axis robot and AGV are visualized in histograms and the real-time logs are outputted to users. Following Figure 6 shows the process implemented in the monitoring system for manufacturing equipment data.

Figure 6. Program UI

4.2 Performance Evaluation

For an evaluation of system performance of monitoring manufacturing equipment data, the times to processing and monitoring in the system from creation of respective data, are measured. In Step 1, approximately 8,000 data of six-axis robot arm (RV-7FL) are created with approximately 2000 data of AGV during the period of 120 seconds through undergoing a scenario of manufacturing process defined therefor. Figure 7 shows the graph representing an accumulation of data created during the 120 seconds.

To secure highly reliable monitoring of factory equipment data, the less delay time in the process transferring the data created from manufacturing equipment to the monitoring system would be preferable. A real-time monitoring of manufacturing equipment data in a factory is an important factor for the implementation of 'digital twin' that synchronizes actual manufacturing equipment with the virtual ones. Thus, the delay times in the transference process of the data created during 120 seconds to reach the monitoring system were measured. Figure 8 shows the graph representing average values of

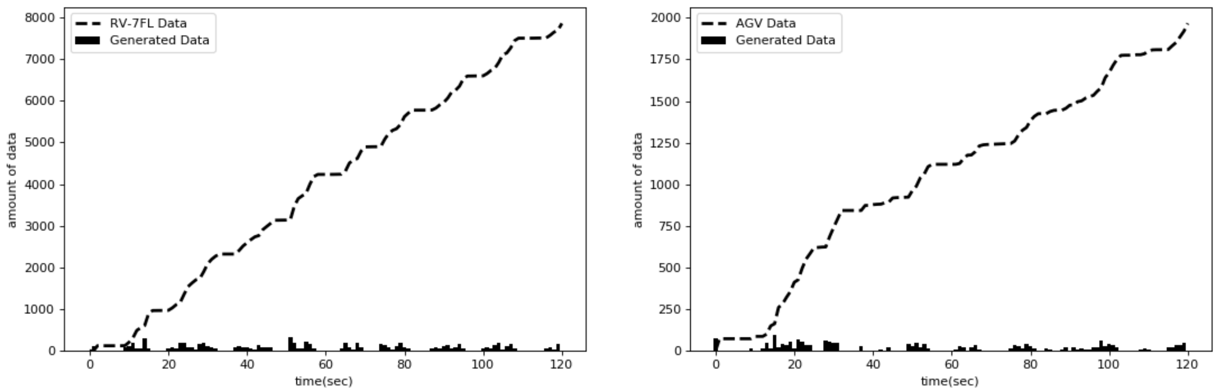

Figure 7. Amount of Machine Data Generated

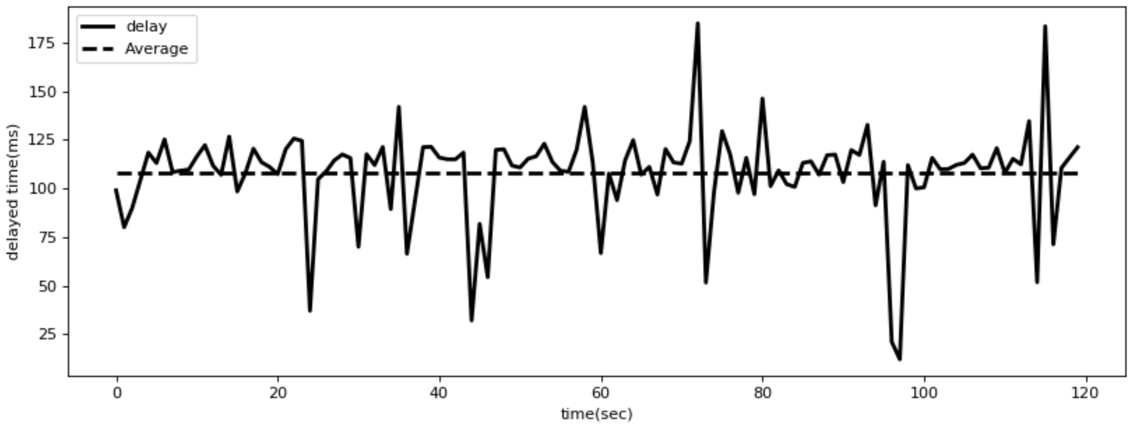

Figure 8. Data Latency

the delay times measured at every second during 120 seconds of the creation of manufacturing equipment data. Average value of overall data delay times was 108ms; the minimum and maximum values thereof were 37ms and 185ms, respectively.

The data created from manufacturing equipment are stored in the 'MTConnect Agent' server through the standard protocols; the Agent server then parses these data in an XML format and transmits the XML document to provide manufacturing equipment data requested by client. The monitoring system of manufacturing equipment data then reinterprets the transferred XML file and presents users contemporary states of the data. Owing to stepwise processes defined for the conversion of data into XML format and visualization of converted XML data, the delay times may increase in accordance with increasing data of manufacturing equipment. Figure 9 presents the graph showing the comparison of the numbers of data created in a second with delay times thereof.

Figure 9 shows the average times of data inquiry decreased in accordance with reduced amount of data. The experiment conducted in the present study demonstrated the data to be created for 300 seconds can be monitored with the delay time of 103ms.

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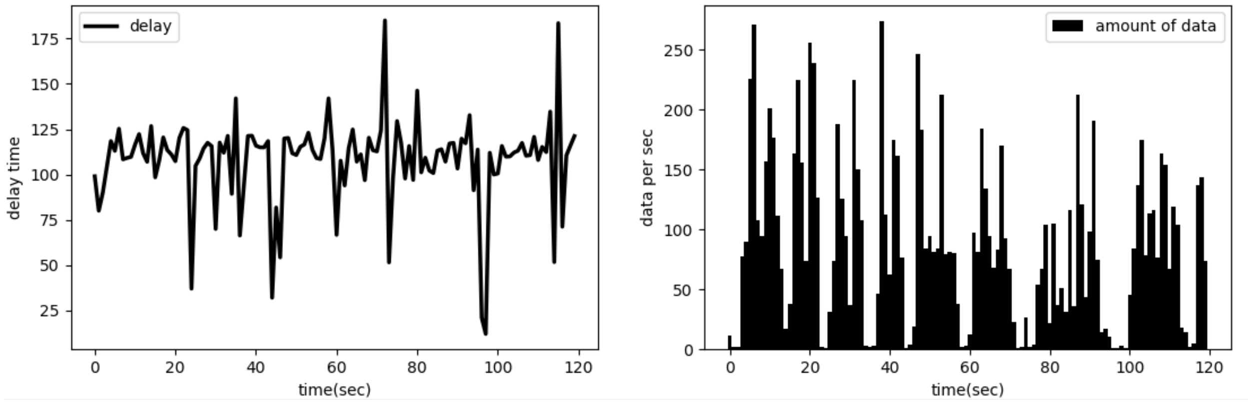

Figure 9. Comparison of data generation time and delay time per sec

This suggests the highly reliable monitoring of manufacturing equipment, which is necessary for an implementation of digital twin, can be secured. Though these are resulted from the data simulation of the only two manufacturing equipment, an actual factory, equipped with more than two manufacturing equipment to be operating synchronously, may encounter big differences in the delay times thereof depending on the amount of actual data created. Thus, subsequent studies, to be focusing on the reduction of delay times of the data created, seem necessary.

5. Conclusions

The present study proposed four step-wise procedures of 1) Data Request, 2) XML Analysis, 3) Data Processing, and 4) Visualizing for an integrated use of the data of manufacturing equipment delivered from different suppliers based on international data collection standards. Through the presented methodology, the real-time data of manufacturing equipment stored in a server with a format based on international standard protocols were identified and monitored. In the perspective of digital twin, the highly reliable real-time update of data would be an important factor for the implementation of correct monitoring of manufacturing equipment data.

However, the process of converting manufacturing equipment data into XML documents, and the subsequent process required for the visualization of delivered XML documents, may affect an implementation of highly reliable monitoring system of manufacturing equipment data in a large-scaled factory comprising diverse manufacturing equipment from different suppliers. This issue can be resolved by receiving the data complying with standardized protocols instead of receiving the data through 'MTConnect Agent' for the visualization system. Besides, an employment of virtual data generator for the creation and collection of manufacturing equipment data in the present study necessitates a validation through the use of actual equipment data. Thus, further studies, focusing on the data transmission module for the implementation of digital twin beyond present data collection module complying with international standards, seem necessary to secure highly reliable data communication.

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