A Prefatory Study on Data Channelling Mechanism towards Industry 4.0

Kheng Hui Ng*, Yiqi Tew* and Mum Wai Yip †
* Faculty of Computing & Information Technology, Tunku Abdul Rahman University College, Malaysia.
{ngkh-wt12@student., yiqi@}tarc.edu.my
† Faculty of Engineering & Technology, Tunku Abdul Rahman University College, Malaysia.
yipmw@tarc.edu.my

***Abstract*—Data are increasing in volume, variety and velocity in this Internet of things and big data era. It applies from industry (or manufacturing) process monitoring control to video surveillance analysis to track human and machines activities. Therefore, fast and accurate approaches in data channelling are needed to effectively deal with these big data. This paper presents practical methods to manage and transfer the data from industry manufacturing site to a centralized data processing hub. In this hub, data are transformed into understandable information, which can assist human in understanding and monitoring manufacturing situation autonomously. These data are collected and channelled to desired location for analysis through Open Platform Communication Unified Architecture (OPC UA). Industrial protocols and standards are used to interpret the data channelling methods and tested on several industrial machines. Result shows that size of data and number of OPC UA Client that connects to OPC Server affects the data channelling speed.**

***Index Terms*—Data Channeling, OPC UA, Industry 4.0, RAMI 4.0**

I. Introduction

In this globalization era, there are many factors induce the manufacturing industry to make changes for coping and competing with the competitors. These factors include the development of programming, the introduce of new product and process technologies, the benefits of energy saving, waste and inefficiencies reductions, the requests of customized products, variability in customers demand and so on. Thus, revolution of manufacturing industries has begun once German introduces the title Industry 4.0 (I4) in 2011.

For I4 conceptual implementation, industries are lack of knowledge in collecting, extracting and channelling data from production machines for understanding the production machines' condition. Industries understand that data are very important as they provide meaningful information for making better business decisions. However, data preparation plays an essential role in I4. Fail in preparing data for I4, will fail in implementing of I4 concept. Thus, industry is difficult to fulfil the production deadline whenever unpredictable problem occur in production machine.

Furthermore, I4 carries the purpose to transform the industrial manufacturing via the digitization and exploitation of new technologies. In I4, Cyber Physical System (CPS) plays an important role to link the cyber world computing and communications with the physical world. CPS can be done through installing more IoT sensors and actuators [1]. IoT sensors are sensors that are able to connect to Internet and digitize the value from sensors to Internet [2]. IoT sensors can reduce the communication cost and space by eliminate number of cable [3]. It can autonomously exchange data between machines, initiate activity and independently perform control [4]. With CPS, production system can communicate with each other neither only between Human and Human (C2C) nor Human to Machine (C2M), but Machine to Machine (M2M) [5]. Thus, the decision making no longer make by human because machine can make the decision and perform action based on the decision made by it. Minimize the involvement of workers to operate and validate machine either using speech, type, mouse control or finger touch [6]. Therefore, improving strategies, decision-making and reduce the labours cost.

Operating costs are the expenses for a company to run their business; it is inversely proportional to the revenue of a company. By adopting I4, company able to lower the operating costs. This is because operators able to monitor and control the quality of the product by reduce wastage and rework time to time. Predictive maintenance, which is one of the important features of the I4, can prevent costly repairs and unplanned downtime. Integration of smart machine enable the labour costs to be save, at the same time improve outcome. Real time monitoring can help operators to check how is the condition affecting the production quality. This information is very useful for operators to control the quality of the product, reduce the rejection by customers due to requirements are not meet [4].

II. Data Channelling Structure

The Open Platform Communication Unified Architecture (OPC UA) is an essential conceptual reference for realizing I4 concept in an industry. OPC UA is documented in IEC 62541, proposed by International Electrotechnical Commission (IEC) and OPC Foundation [7]. It specified the standard representation of Programs as part of the OPC UA and its defined information model, includes the details of Node Classes, standard properties, Methods and Events and associated behaviour and information of Programs. OPC UA is developed as a successor to the classic OPC (i.e., Data Access, Alarms and Events, and Historical Data Access) to provide quality information with values and time, alert the user with

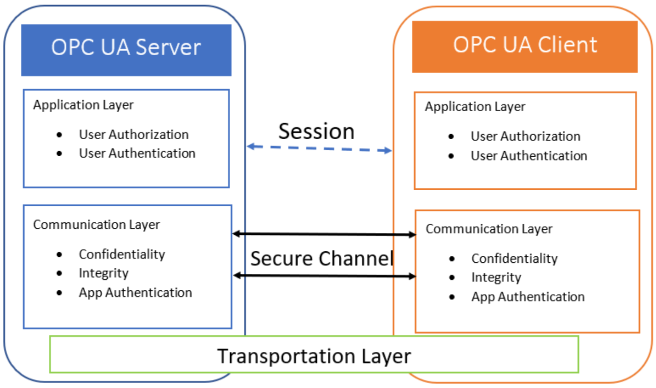

Fig. 1: Architecture Layer of OPC UA

event type message information provided with variable states and state management, and allows users to access the historical data for analysis that connected from different servers. It is one of the core objects for I4 and plays an important by links Integration layer to Information layer [8]. Using OPC UA, the information of machines from the field devices (level 1) is channelled to Human Machine Interaction viewer at Station (level 2) and Manufacturing Execution Systems server at Work Unit (level 3) in the Reference Architecture I4 (RAMI 4.0) [9].

The fundamental layer of OPC UA architecture consists of 2 components: Transport and OPC UA Data Model [10]. Transport defined the way to channelled data by Web service or OPC UA Binary. OPC UA Data Model defined the data type to be channelled. Data types, like object files can be modelled with variables, methods and events. These components are designed to provide the OPC UA base services, that consist of three different stages, application layer, communication layer and transport layer, as shown in Fig. 1. Application layer is to deal with user authentication and user authorization. User authentication is client identification by providing the security password for access. User authorization defines how far or what services the user can access. Communication layer is to provide a more secure channel for application layer to transfer the data from the client to server. Therefore, communication layer consists confidentiality, integrity and application authentication. Confidentiality due to the transfer of data from either client to server or server to client must be encrypted, so that the information cannot be read easily. Integrity is to ensure the information cannot be altered during the transmission. Application authentication assists on deciding either accept or reject the request follow by specific responses.

With these, OPC UA is service-oriented approach with Internet ability to collect and channel data from machine. It provides consistent data for process, alarm and historical data for further analysis. It supports complex data structures that machine able to understand and security implementation with latest standard.

Besides that, Virtual Private Network (VPN) is utilized to

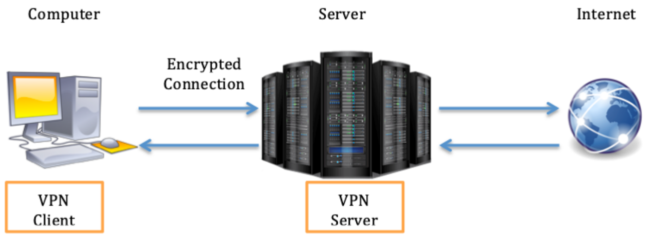

Fig. 2: Structure of VPN

establish a connection between two different networks and providing a service that access to Internet on your behalf. It allows us to access the Internet from non-secure tunnel to an encrypted tunnel thats privately and safely. VPN client that is our own computer encrypt the data before send to VPN server. VPN server send the data to the desire destination before decryption occurs as shown in Fig. 2. VPN is necessary for data channelling as IoT devices such as sensors lack of strong data encryption algorithm due to restriction of resources such as CPU performance, power consumption etc [11]. The more the security demanded, the higher the CPU performance and energy is required [12].

There are a lot of benefits of using VPN to send confidential data especially for enterprise. With VPN, no one can identify where the data send from or send to. This means no one can identify which website you are visiting or what data you are sending and receiving. Furthermore, the data are encrypted before send to desire location. If someone peek the data, the person only can see encrypted information, but not the raw data.

III. Design and Implementation

We conducted the prefatory study in between a manufacturing site, i.e., Kian Joo Can Factory (KJCF) and our research institution. KJCF is a manufacturing company that manufactures food and beverage can and chemical can. In KJCF, there are hundreds of manufacturing machines operate daily and requiring onsite monitoring on the performance of machines. To make sure the machines are operated well, various sensor devices are installed in the machines, along the production lines in KJCF. These sensors data are connected through a data channelling architecture and communication framework, established by using Open Platform Communication Unified Architecture (OPC UA) to send the sensors data (e.g., temperature, pressure and vibration values) to an analytic system to be analyzed. Therefore, analyzing these data can provide preventive maintenance [13] on the machines to prevent unexpected machine failure that cause production loss.

Here, components are set up as shown in Fig. 3. The data from the sensors send to either Programmable Logic Controller (PLC) or Industrial Personal Computer (IPC). If the data are send to PLC, the data is sent to edge computer (indicated as PC) and tagged with identity before channel to Server. However, if the data are direct send to IPC, the data can be tagged in IPC. This is because the processor of IPC is higher

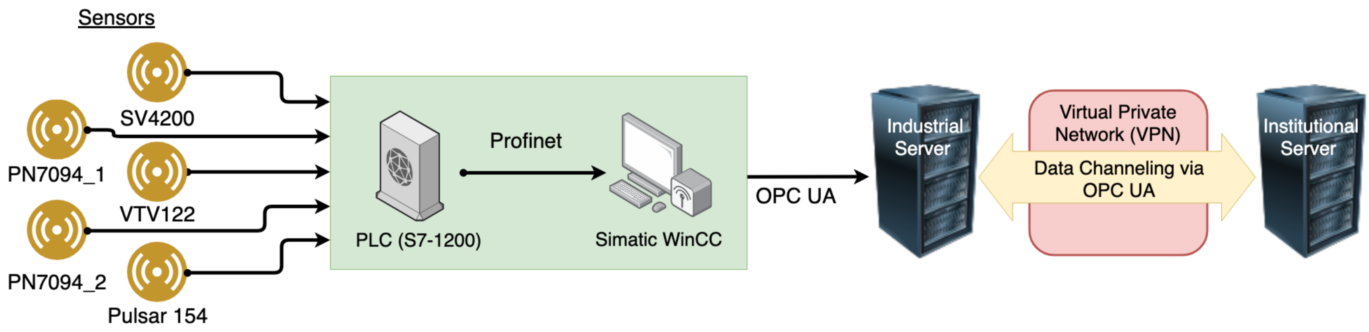

Fig. 3: Components set up for data flow

than PLC. PLC can only work on one task each time. IPC can run Human Machine Interaction (HMI) process, tagging and automation process at the same time.

All data that has been tagged are channelled to server for storing. Then, an analysis system requests the data from server instead of direct request from PLC or IPC. Server only send the metadata to analysis system to make sure the data in the machine cannot be alter.

A. COMPONENTS SETTING UP

A welding machine that used to weld the rolled metal sheet interface to form a can, is selected to install data sensors. There are 5 sensors being used to detect and monitor the condition of the welding machine. Air pressure sensor ($PN7094_1$) is used to detect the pressure generate by air compressor [14]. Chill pressure sensor ($PN7094_2$) is used to measure the air pressure of chiller [14]. Temperature of in-coming water are determined by sensor SV4200 that used to cool down the welding arm [15]. Next, VTV122 is a sensor that used to determine the vibration of the welding engine [16]. Lastly, the current supply to the welding machine is measured by a current sensor that originally install in a static frequency converter (Pulsar154) for monitoring purpose [17].

All sensor data are collected by a PLC called Simatic S7-1200 from Siemens [18]. PLC converts the sensor data into binary form, i.e., 32-bits Float data type. Then, data are channelled to a software called Simatic WinCC using Profinet standard [18]. Profinet is a industrial leading Ethernet standard that link end to end devices and integrate all the processes of machines in industry [19]. Simatic WinCC is a Supervisory Control And Data Acquisition (SCADA) and Human-Machine Interface (HMI) system that used by Siemens to control and monitor the condition of machines [20].

A data channelling architecture and communication framework is established by using OPC UA to store the data to a database server from WinCC. By using the OPC UA open source library maintained by OPC Foundation, a program running on OPC UA based on requirement is developed using Visual Studio IDE in Python programming language. With OPC UA protocol, data are channelled to analytic system that install in a computer. VPN is required to assist OPC UA in providing a more secure data channelling method. VPN enables data encryption before it is sent and data decryption when it is received. This able to make sure all confidential data are not leak to third party during the data channelling process. Furthermore, VPN allows to channel data between different network, from KJCF to an institution, i.e., Tunku Abdul Rahman University College (TAR UC) for analytic purpose as shown in Fig. 3. Here, Forticlient is used for VPN end-to-end encryption of data transmission.

Input: N_n,S_n,L_n
Output: V_{L_n}
initialization ; ;
client ← OPC.TCP URL via VPN ;
client ← connected ;
repeat
  foreach V_n **do**
    N_n ← Get client's node for S_n, L_n ;
    V_{L_n} ← Get Value for N_n ;
  end
  d ← NOW ;
  $T \leftarrow V_{L_n}, d$;
  if *csv file date* ≠ *NOW* **then** create new csv file;
  csv file ← append T ;
until *process stop*;

Algorithm 1: Pseudo code for data channelling

B. DATA ACQUISITION

Algorithm 1 shows the pseudo code for OPC UA client to request data from server via connected VPN. Each data (V_n) request is defined as a session (S_n) with a label (L_n) under a connected node (N_n). Then, each collected data will be tagged with a timestamp (d) and store into the database, e.g., CSV file.

The data that need to be analyzed from the welding machine are temperature, pressure, vibration and current data. These data are read by the sensors that install at particular location in machine. The data are collected and converted to human understandable form by PLC. For example, temperature sensor will send 8 bits data (i.e., 00001001) to PLC, indicates the temperature reading. PLC will need to convert this data into a human understandable form, which is 90°C. Data from PLC are channelled to computer via Profinet and received by

Table I: Average Delays of Time (milliseconds)

No. of PC	No. of program	Test	Delay (ms)		
			1D	3D	5D
1 PC	1 PG	α_1	64	172	321
	3 PGs	α_2	103	338	457
	5 PGs	α_3	170	511	710
3 PCs	1 PG	α_4	101	328	510
	3 PGs	α_5	280	848	1173
	5 PGs	α_6	410	1244	1816
5 PCs	1 PG	α_7	143	447	788
	3 PGs	α_8	400	1328	1948
	5 PGs	α_9	649	2223	3015

WinCC software. Computer with WinCC can channel the data from KJCF to TAR UC's analytic system.

Collections of data from KJCF to TAR UC are done at TAR UC to analyze the time of data channelling between different networks through OPC UA. A study of data channelling time by using OPC UA is done to determine the factors that can affect the data channelling time. Sets of data are collected as shown in Table I. In this table, D, PC and PG indicate Data, Personal Computer and Program, respectively. For example of 3D 5PC 3PG, 3 data are to be collected by 5 personal computers and each computer running 3 data channelling programs. Equation 1 shows all the data V_{L_n} and the time received d for the combination number of 1, 3 and 5 on D, PC and PG, with the label L_n.

$$\begin{aligned}(V_{L_n}, d) = &\sum_{p=1}^{3}\sum_{q=1}^{3}\sum_{r=1}^{3} PC_{2p-1}, PG_{2q-1}, D_{2r-1},\\ \text{where, } L_n = &\text{PN7094}_1, \text{PN7094}_2, \text{VTV122},\\ &\text{SV4200}, \text{Pulsar154}\end{aligned} \quad (1)$$

IV. Result and Discussion

We collected 200 rows of data for each 1 data (chill pressure), 3 data (chill pressure, air pressure and incoming water) and 5 data (air pressure, chill pressure, incoming water, vibration and current) respectively with different number of OPC UA Client include PC and PG connected to OPC Server. Then, we compared these results by plotting graphs with moving average period of 5 collected data to achieve a better graphical presentation for data comparison.

Results of collecting 1, 3 and 5 data with different number of PC and PG are shown in Fig. 4, 5 and 6. Solid lines, dashed lines and dotted lines indicate the data is collecting using 1PG, 3PG and 5PG respectively in each computer. For the beginning of data channelling performance (i.e., number of sensor data < 30), the delay time is increased proportionally to the increment of number of sensor data due to time required for initialization process on multiple PCs and PGs.

Then, the average delays of time for each set of 1, 3 and 5 data are shown in Table I. From the Table I, the fastest time of each number of data channelling is 1PC 1PG (α_1), which is 64, 172 and 321 milliseconds (ms) for 1D, 3D and 5D respectively. Whereas the slowest time of each number of data channelling is 5PC 5PG (α_9) takes 649, 2223 and 3015 ms for 1D, 3D and 5D respectively. In 1PC 3PG (α_2) and 3PC 1PG (α_4) have very closed of time, which are 2 ms differences for 1D, 10 ms differ from each other in 3D, and 43 ms difference for 5D. In 3PC 5PG (α_6) and 5PC 3PG (α_8) have similar 1 data channelling time that is around 400 ms, with the difference of 10 ms. When the number of data increases, the delay time increases, i.e., α_6 and α_8 has 84 ms and 132 ms difference for 3D and 5D respectively.

From the Fig. 4, 5, 6 and Table I, there are a few factors that affect the time to receive data from different network through OPC UA. As the number of data to be channel increase from 1 to 3 and 5, the time of receiving data (i.e., delay time) increase. This is because by increasing the number of data to be channelled, bit rate will be increased. OPC UA server will carry each bit of data to OPC UA client. The higher the number of data, the higher the number of bits that server need to carry, and the slower the time of receiving data. Furthermore, by increasing the number of PG to receive data from the same OPC UA server, it will affect the time of receive data from server to client. This is due to too many requests from clients to server. To allow clients receive data from server, clients will send requests to server to obtain each data. OPC UA server only can handle certain amount of requests each time. Number of PC that uses to channel same data from same server will also affect the time of transferring data. The reason of this happen is because of the number of requests from client to server increase. The number of PC that channel data from same network, increased the number of requests from client to server, the more requests that server need to handle, the slower the speed of server channel data to client. We can conclude that number of data to be channelled, number of PC request data from same server and number of PG request data from same server will affect the speed. Furthermore, the effect on time of PG obtain data is same as the time of PC obtain data. This can be observed from the Table I, 1D 3PC 5PG (α_6) and 1D 5PC 3PG (α_8) have similar data channelling time that is around 400 ms.

However, the causes that affect the time of receive data via OPC UA is not limited to the 3 factors mention above. For example, the hardware specification (e.g., CPU processing speed) of PLC has limit the speed of data channelling. Moreover, networking specification (e.g., Internet speed or bandwidth, router transfer speed) could be another factor to limit the data channelling speed as well. In our next step, we would like to propose an application of data channeling for calculating the effectiveness of factory production. Overall Equipment Effectiveness (OEE) is considered to calculate the productivity of the production floor in order to reduce wastage of operating cost of product [21]. It is measured based on 3 indices: Availability Rate, Performance Rate and Quality Rate. Our proposed OPC UA data channeling mechanism will provide a near real time data, as a part of important variables that is required to calculate the OEE for improving the efficiency of manufacturing production line.

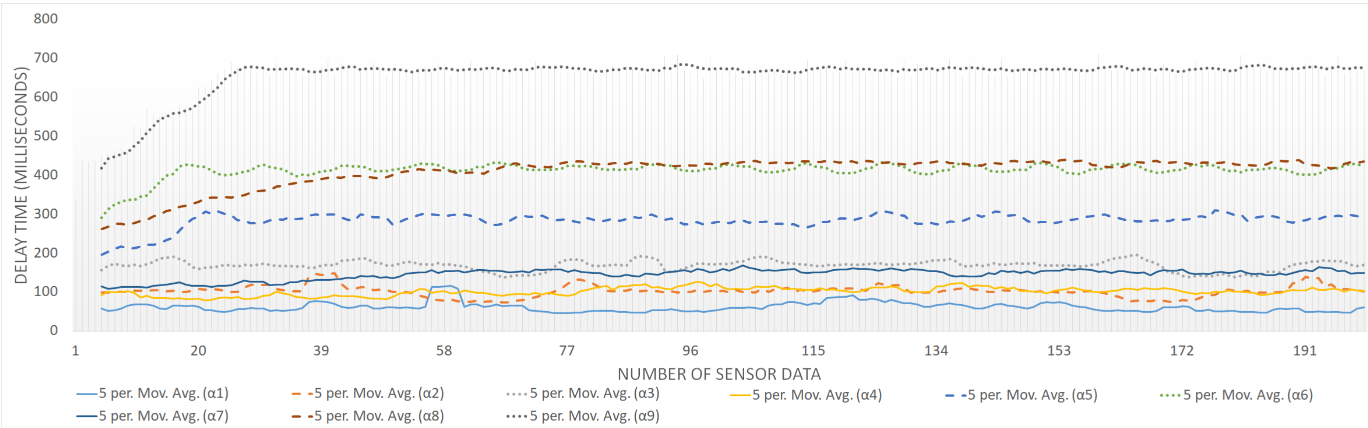

Fig. 4: Performance of 1 Data Channelling

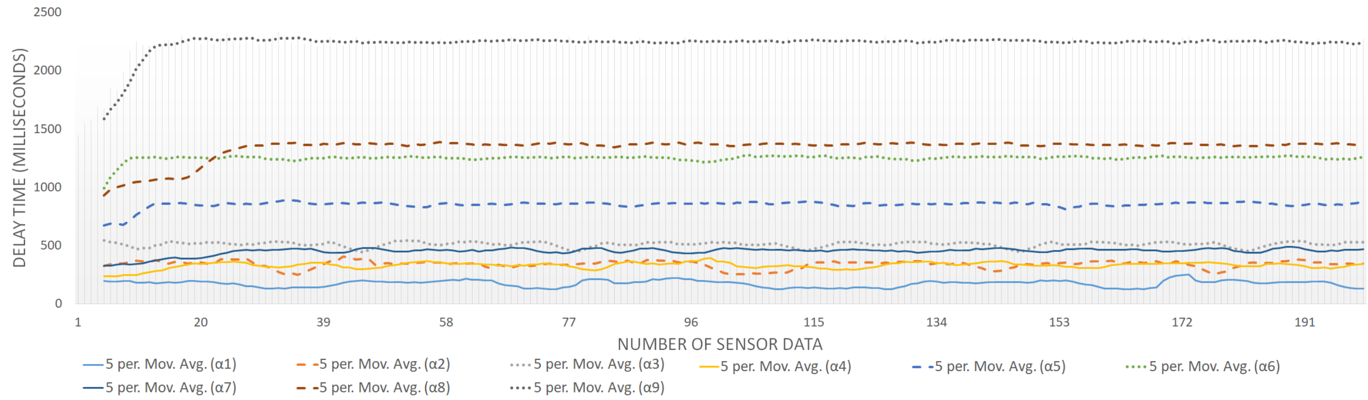

Fig. 5: Performance of 3 Data Channelling

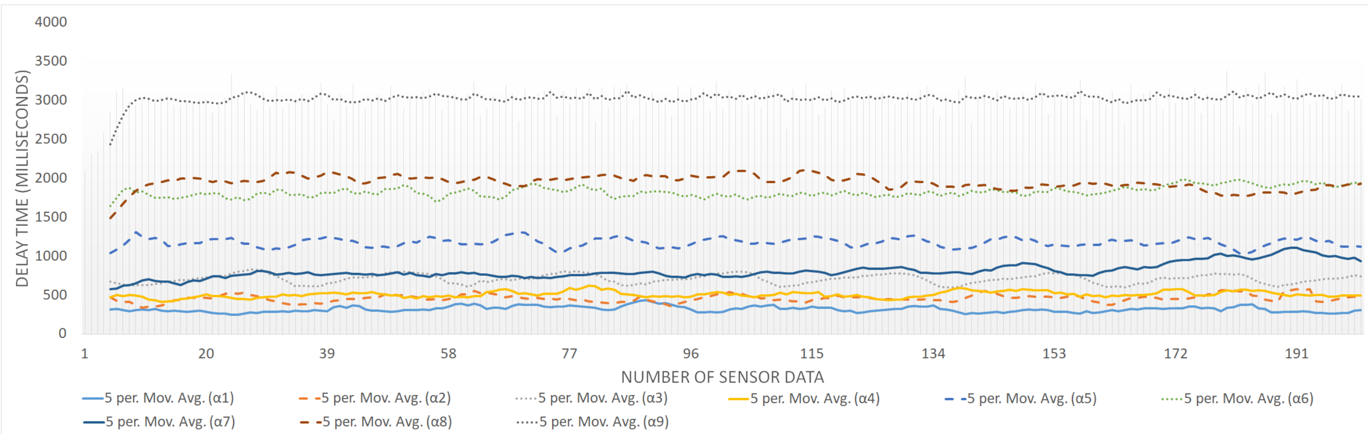

Fig. 6: Performance of 5 Data Channelling

V. Conclusion

This paper revealed the details of data channel from one network to another via data channelling architecture, i.e., Open Platform Communication Unified Architecture (OPC UA) to serve Industrial 4.0 such as predictive maintenance. A few factors that will affect the data channelling speed are determined. These factors are size of data and number of OPC UA Client that connect to OPC UA Server. Number of OPC UA Client connect to OPC Server refers to number of PC and PG (OPC UA Client) that collect data from machine (OPC UA Server). In future, we will continue extensive work on optimizing real time data channelling mechanism to support near real time data responses for more accurate machine predictive analysis under Industry 4.0 implementation. We will also work on defining all the sensor data (lowest layer) by tagging them with asset identity for supporting analysis in upper layer of RAMI 4.0 [22]. With these implementations, a better data management can be established with data asset identity that consists of details of the data such as data ownership, functions etc.

ACKNOWLEDGMENT

This paper was written under the project title Implementation of the Data Channelling Architecture in Industry 4.0 funded by Kian Joo Can Factory Berhad for industry-academia collaboration in implementing Industry 4.0.

REFERENCES

[1] Ragunathan Rajkumar, Insup Lee, Lui Sha, and John Stankovic, "Cyber-physical systems: The next computing revolution," in *Design Automation Conference*, June 2010, pp. 731–736.

[2] M. Babazadeh, S. Kartakis, and J. A. McCann, "Highly-distributed sensor processing using iot for critical infrastructure monitoring," in *2017 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Dec 2017, pp. 1065–1074.

[3] Y. Sheng, C. Li, J. Wang, H. Deng, and Z. Zhao, "A novel pruning model of deep learning for large-scale distributed data processing," in *2015 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Dec 2015, pp. 314–319.

[4] Marina Crnjac, Ivica Vea, and Nikola Banduka, "From concept to the introduction of industry 4.0," vol. 8, no. 1, pp. 21–30, March 2017.

[5] A. Paul and Y. Chin, "Graph based orange computing architecture for cyber-physical being," in *2013 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference*, Oct 2013, pp. 1–5.

[6] A. I. Niculescu, L. F. D'haro, and R. E. Banchs, "When industrial robots become social: On the design and evaluation of a multimodal interface for welding robots," in *2017 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Dec 2017, pp. 083–089.

[7] *Technical Report*, vol. 1, International Electrotechnical Commission (IEC), IEC Central Office, 3, rue de Varemb, CH - 1211 Geneva 20, Switzerland, 2 edition, 10 2016.

[8] Florian Pauker, Thomas Frühwirth, Burkhard Kittl, and Wolfgang Kastner, "A systematic approach to opc ua information model design," *Procedia CIRP*, vol. 57, pp. 321–326, 2016.

[9] Wolfgang Dorst, Carsten Glohr, Thomas Hahn, Frank Knafla, Roland Rosen, Thomas Schiemann, Friedrich Vollmar, and Christoph Winterhalter, *Implementation Strategy Industrie 4.0*, 04 2015.

[10] Gantner Instruments GmbH, Montafonerstrasse 4, 6780 Schruns Austria, *Communication Protocol OPC UA*, 8 2018.

[11] J. Choi and Y. Kim, "An improved lea block encryption algorithm to prevent side-channel attack in the iot system," in *2016 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Dec 2016, pp. 1–4.

[12] P. S. Munoz, N. Tran, B. Craig, B. Dezfouli, and Y. Liu, "Analyzing the resource utilization of aes encryption on iot devices," in *2018 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Nov 2018, pp. 1200–1207.

[13] Ernnie Illyani Basri, Izatul Hamimi Abdul Razak, Hasnida Ab-Samat, and Shahrul Kamaruddin, "Preventive maintenance (pm) planning: a review," *Journal of Quality in Maintenance Engineering*, vol. 23, 05 2017.

[14] IFM Electronic GmbH, "Pn7094 - pressure sensor with display," https://www.ifm.com/my/en/product/PN7094, 2016, [Online; accessed 15 June 2019].

[15] IFM Electronic GmbH, "Sv4200 - vortex flowmeters with display, type sv," https://www.ifm.com/us/en/product/SV4200, 2015, [Online; accessed 15 June 2019].

[16] IFM Electronic GmbH, "Vtv122 - vibration transmitter," https://www.ifm.com/my/en/product/VTV122, 2016, [Online; accessed 15 June 2019].

[17] Soudronic AG, "Static frequency converter pulsar," https://www.soudronic.com/services/upgrades-and-conversions/static-frequency-converter-pulsar, 2017, [Online; accessed 15 June 2019].

[18] Siemens AG, "Basic controller simatic s7-1200," https://c4b.gss.siemens.com/resources/images/articles/dffa-b10053-03-7600.pdf, 2017, [Online; accessed 15 June 2019].

[19] PROFIBUS Nutzerorganisation e.V. (PNO), "Overview of profinet - the leading industrial ethernet standard," https://www.profibus.com/technology/profinet/overview/, 2017, [Online; accessed 15 June 2019].

[20] Siemens AG, "Simatic wincc v7," https://c4b.gss.siemens.com/resources/images/articles/e20001-a820-p810-v2-7600.pdf, 2016, [Online; accessed 15 June 2019].

[21] X. Zhu, "Analysis and improvement of enterprise's equipment effectivenessbased on oee," in *2011 International Conference on Electronics, Communications and Control (ICECC)*, Sep. 2011, pp. 4167–4171.

[22] E. Tantik and R. Anderl, "Concept of the asset administration shell as a software-defined system," in *2018 Fifth International Conference on Software Defined Systems (SDS)*, April 2018, pp. 52–58.