The Impact of Communication Protocols within SMART Manufacturing and Their Benefits

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***Abstract* - Industry 4.0 is opening up new avenues for customers and manufactures. This is achieved by offering a larger pool of information to improve the manufacturing process and the manufactured products. However, with new technologies and equipment becoming available, the facilitation of information between customer to developer and products to manufacturing lines becomes a more challenging task. The need for suitable communication is gathered by an appropriate communication protocol. Discussed in this paper is the impact of the communication protocols within Industry 4.0, a creation and test of a newly developed communication protocol, a comparison of the said protocol against existing manufacturing protocols and elucidation of future work for communication protocols.**

Keywords - SMART Manufacturing, Communication Protocol, Simulation, Industry 4.0.

I. INTRODUCTION

Industry 4.0 (I4.0) is regarded as the industrial revolution that will bring about the full customization requested from customers – by incorporating communication throughout the entire production process, from logistics to manufacturing. With the constant communication of a product's life span, developers and manufacturers are able to improve the future quality of products. With communication of the production process, SMART Manufacturing Unit's (SMU's) are able to optimize the manufacturing process, perceive future faults and analyze production in order to bring about re-configurability and forward thinking in SMU's [1].

This paper firstly sums up SMART Manufacturing Units and their Characteristics. Secondly a review of SMART Manufacturing Unit communication protocols is conducted. Thirdly an analysis of a newly created SMART Manufacturing Protocol (SMP) is performed and finally an examination of the SMP is undertaken, in order to compare the effectiveness of the SMP against existing communication protocols.

II. LITERATURE REVIEW

A. SMART Manufacturing

SMART Manufacturing (SM) makes up one of the four pillars of Industry 4.0 [2] and is concerned with the advancement of the manufacturing process. This is achieved by providing intelligent decision making capabilities in real-time. While the other pillars of I4.0 are made up of Internet of Things (IoT) [3], Internet of Services (IoS) [4] and Cyber-Physical Systems (CPS) [5], as seen in Fig. 1. SM differs from the Internet of Things in that SM deals with information of products and production, in order to improve future products and production efficiency. While the IoT is concerned with the communication between devices in order to improve user experience.

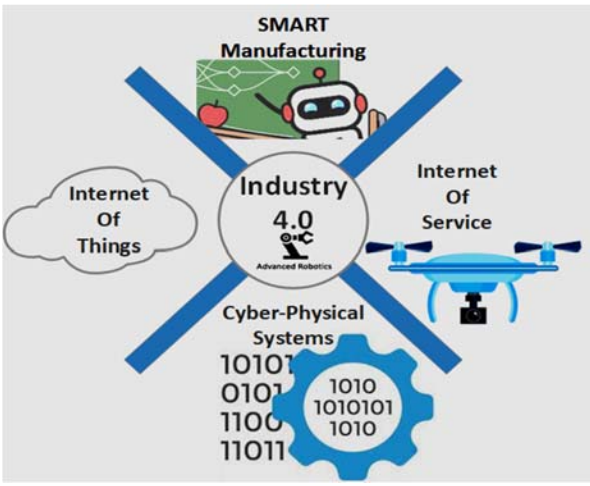

Figure 1: Pillars of Industry 4.0

A1. SMART Manufacturing Characteristics

SM is realized through SMU's only when said units are incorporative of certain characteristics [6]. These characteristics are categorized into; Cyber Security, Cloud Manufacturing, Data Analytics, Composability and Interoperability, as seen in Fig. 2. The main characteristic identified within this paper to realize SM, is Interoperability. The main motive for this decision is the offer of a decentralized enabling factor within the network.

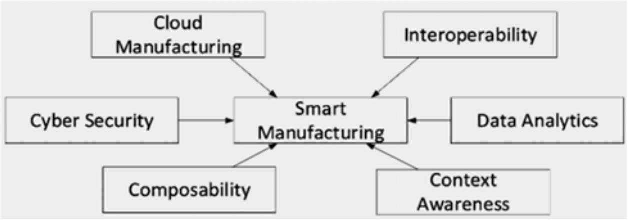

Figure 2. SMART Manufacturing Characteristics

All the defined enabling factors of Interoperability can be summed up in Fig 3. It is worth noting that Cyber Security, Data Analytics and Composability, Context Awareness and Cloud Manufacturing are important factors to consider during SM. However, this study's focus is the decentralized enabling factor and Interoperability characteristic needed in order to communicate information within SM.

a) Interoperability

The enabling factors of Interoperability consist of:

Networkability – the ability of machines to communicate within a system of multiple connected devices.

Integratebility – the ability of machines to be integrated with parts and each other. While this is closely inspected into a machines ability to be able to self-identify the attached machines and sensors in order to provoke a self-programming function.

Distributed – the ability of machines to pass products and data freely to one another

Decentralized – the ability for all machines/data to access all other machines/machines data, within a network and without a central communications hub.

Information appropriateness- the enabling factor for machines to pass useful information within a production line and not just bulk information.

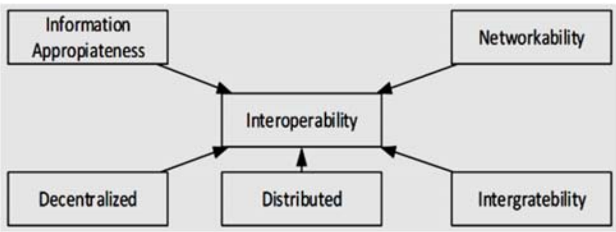

Figure 3. Interoperability Enabling Factors

B. Communication within SMART Manufacturing

Communication within SMART Manufacturing is broken down into three layers [7]. Layer 1 being the communication of the customer to the ordering domain. This is normally hosted on a server or a cloud. Layer 2 consists of communication of orders from the cloud to the production server where organization and optimization [8] can be performed. Layer 3 is contrived by the actual "machines on floor" communication, where individual machines communicate in order to identify; bottle necks, alarms and predictive maintenance to mention a few.

These Layers can be seen in Fig. 4, where the first layer is controlled by the user interacting with a website in order to place customized orders. This layer of communication is usually consisting of protocols such as; Hyper Text Transfer Protocol (HTTP), The Internet protocol suite (TCP/IP) and Internet Protocol (IPv4). This layer is usually separated from communication from the machines by means of an intermediate server. This server, as mentioned previously, is to optimize orders and dedicate tasks to specific machines. Although the server operates in a centralized network, a decentralized network is still needed in order to communicate production information in real-time to avoid bottle necks and avail timely events between machines.

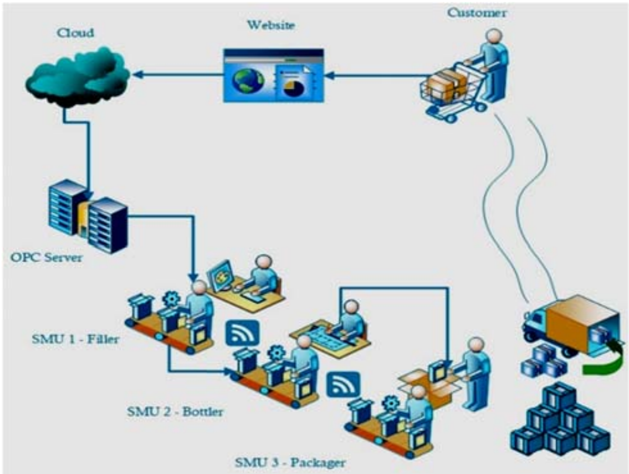

Figure 4. Manufacturing Communication Flow

III. METHODOLOGY

The Manufacturing line used to conduct the tests in this paper, is that of a water bottling production plant. The layout of the water bottling production can be seen in Fig. 5.

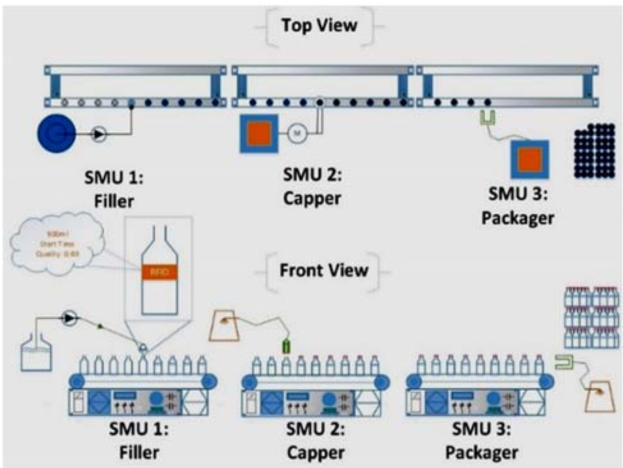

Figure 5. Water Bottling Production Line

The water bottling plant is broken up into three parts, where the first stage of the water bottling plant is tasked with; filling custom sized water bottles, the second stage is the capping of custom sized water bottles and the third, packaging the water bottles to customer orders.

A. SMART Manufacturing Unit Construction

As depicted in Fig. 5, SMU 1 is tasked with the filling of water bottles. The SMU is informed of the bottle volume to fill (in ml) as well as the amount of bottles to fill in all orders. Optimization of the orders are done before production starts, in order to produce the entirety of the order as efficiently as possible, even if out of order sequence is initiated.

SMU 1 also perform image processing on the water bottles, as unique designs and transparency could change the accuracy of which water bottles are filled and the height of the water bottles. This information can then be sent to the other SMU's, as in the instance of the height needed to cap the bottles of SMU 2, or stored directly on the water bottles themselves, as to avoid message queries.

B. Machine Communication

The network structure of the water bottling plant is constructed to have a central server that communicates with the cloud server to retrieve and optimize orders for production. The central server also houses a digital twin component [8] of each SMU, in order to correlate production data. This central server communicates with the individual SMU's through an Open Platform Communication (OPC) protocol.

Although OPC has a large amount of latency issues, particularly when scaling the amount of connections to the OPC server, it still can ensure congruency of information with a hierarchical function. For this reason, the OPC is used as a central server to send order data at the start of production and minimal/non-crucial production data during production in order to correlate the digital twin.

Other communication protocols are then used within the communication of Machine-to-Machine data transfer. The communication protocols tested within this layer are; WebSocket, the constructed SMART Manufacturing Protocol (SMP), HTTP, MQTT, CodeSYS and Profinet.

The SMART Manufacturing Protocol is designed to work with a Siemens S7-1200 module with characteristics inspired by IPv4 addressing scheme, as well as a GET and PUT communication method. The design of the communication protocol can be seen below in Fig. 6. The information of the transmitting SMU is stored in memory of the SMU itself along with all other SMU's attached/needed in the production line.

As a result, whenever an update of information is initiated in memory, a trigger of the PUT method is also initiated. Now this trigger is only tagged with all attached affected SMU's. This states that if information of production only relates to two SMU's within a production line, then at the time the information is updated, only the affected SMU's will be communicated the information, instead of a global variable distributed to an entire network, as such with an OPC tag.

Similarly, with the GET method, all information about the querying SMU and attached SMU's are stored within memory. Therefore, if a decision needs to be taken involving attached SMU's, i.e. a change in production speed of one SMU affecting the attached SMU's, then the SMU is able to collect the information of the attached SMU's, through the GET method in order to make an informed decision and communicate back that decision with the PUT method.

The communicated information has an attached ID request, in order for historical data analysis that may be stored later and an avoidance of miscommunication and solution for message collision. Information that needs to be transmitted or collected is accessed by the stored memory address, within each SMU that can be collected when queried. Multiple address lines may be accessed at once, to reduce the total number of queries. The protocol also incorporates error checking and status updates.

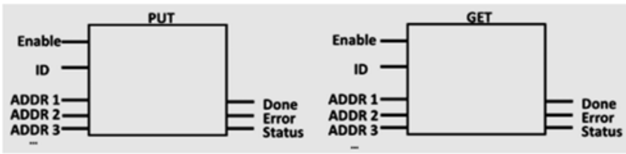

Figure 6: SMART Manufacturing Communication Protocol

C. Product Communication

In terms of product communication outside of the production line, information about the products life span can be stored directly on the product through means of rewriteable RFID tags, detached from a central database [9]. This not only reduces the number of queries through slow latency protocols to central servers, but also allows for SMU to extract product data about the current product by communicating through the product itself.

This is necessary to distinguish which communication needs to be transmitted through which protocols and through which layers. Overall, reducing the amount of information transmitted per protocol and allowing for intelligent decision making of SMU's through optimized information transfer.

IV. RESULTS

This section firstly summarizes the practical application of the SMP and secondly the enabling ability of the SMP to allow for intelligent decision making in SMU's. Finally, a bench test is created and compared against existing protocols used in manufacturing.

A. SMART Manufacturing Protocol Capability

Seen in Table 1. is the communication message sent by both the GET and PUT methods.

During communication between two SMU's, initially the method type is specified in order to determine the direction of communication. This is not to indicate the actual communication protocol used, but rather a distinction between either the GET or PUT method.

The Destination field specifies which SMU to communicate to in the network and not the physical address of information to receive. The destination field incorporates an inspired use of the IPv4 addressing scheme, for network splitting and ease of naming.

The Version field is used to distinguish which type of communication to use. As of date, this communication protocol has only been tested and create on Siemens S7 modules, however an expansion of this protocol, to accommodate multiple vendor processors, can be created and identified within this field.

The header field is used to identify the message query total length. This field can be used to limit the overall size of the message and reduce the transmission time of one message on updates of information or to distinguish between first message contact, when a network device is connected and queries for first time address.

The Body field encapsulates the physical information sent between each message method of each SMU.

TABLE I. SMP MESSAGE

Byte	4	4	4	4	4
0	**Method**	**Destination**		**Version**	
1	**Header Field Name**		**Value**		
2	**Header**				
3					
4	**Footer Field Name**		**Value**		
5	Blank Line				
6	**BODY**				
7					
8					

Within the Body of a message, the Machine Type and Machine Status is specified. This is used along with the data of the queried SMU to identify its function and condition of production. The Machine Type is crossed referenced with a data table for identification and with this, connected SMU's are able to identify parameters such as; If production is able to be completed with the attached SMU's and The overall production speed to eliminate bottlenecks.

With the Machine Status field, attached SMU's are able to determine if; an override in production speed set by factory workers, or if the overall communication to the machine is accessible. This allows for SMU's to create intelligent decisions, during production and for this reason, these fields are added as a template on this communication protocol but may be removed for greater payload transmission. This structure can be seen in Table 2.

B. Communication of SMART Manufacturing Protocol

Since each SMU has stored in memory each attached SMU's data, this leads to a greater use of memory being needed. However as previously stated, each SMU will only need to store each attached SMU in the production line.

This stored memory also reduces the latency and transmission time of each subsequent message, as the dynamic header field allows for reduce message sizes for minimal data updates, bringing the SMP into real-time communication space.

Furthermore, with each attached SMU's data being stored locally, faster intelligent decisions can be made as the need for transmitted information between neighboring devices is not needed, reducing the overall time of decisions.

TABLE II. BODY FIELD ENCAPSULATION

Byte	8	8
1	**MACHINE TYPE**	**MACHINE STATUS**
2	**DATA**	
3		

C. Communication Protocols Results

Table III shows a comparison of each communication protocol, used within a SMART Manufacturing setup, used to convey the same message.

1) *OPC:* currently satisfying a wide enough range of multi-vendor communication, falls off with a higher latency and reduced functionality.
2) *WebSocket:* Being able to transmit respectful payloads per message at a reduced latency, still requires a centralized server in order to facilitate the flow of communication between devices.
3) *SMART Manufacturing Protocol:* The SMP offers a reduced latency with standard payload per message, with error checking and operation in a decentralized fashion. However, as of yet is not able to support multiple-vendor machines.
4) *HTTP:* Used as a staple of communication with most internet applications, offers a low latency and historical messageing logging and compares slightly below the SMP.
5) *MQTT:* Being one of few offering Multi-vendor support, shares traits with OPC as having higher latency with scaling, with no historical messaging logging.
6) *CodeSYS:* Being a lightweight communication protocol between homogenous vendors, which offers great communication latency, however only within a centralized network.

7) *Profinet:* Profinet with its wide use on communication of manufacturing equipment, utilizes great communication speeds, satisfying real-time communication needs, but again only operates in a centralized manner.

TABLE III. COMMUNICATION PROTOCOL ENCAPSULATION [11]

Communication Protocol	Properties						
	Latency (ms)	**Payload Per Query (Bytes)**	**Historical Message Logging**	**Error Checking**	**Decentralized**	**Real-Time**	**Multi-Vendor Support**
OPC	250	32	✓	X	X	X	✓
WebSocket	75	64	X	✓	X	✓	X
SMART Manufacturing Protocol	60	64	✓	✓	✓	✓	X
HTTP	100	64	✓	✓	✓	✓	X
MQTT	210	64	X	X	✓	✓	✓
CodeSYS	120	32	X	✓	✓	X	X
Profinet	125	64	✓	✓	X	✓	X

V. CONCLUSION

With the above tables describing the ability of the SMP being used within SM, enabling SMU's to create intelligent decisions based on the information set, and the SMP allowing for decentralized communication within real-time limits, the SMP becomes one of the most amiable choices within the SMART Manufacturing space.

With the SMP able to operate in a decentralized network, then with the initial startup procedure capturing nearby neighboring SMU's data and finally with the use of the Machine Status field, SMU do not require direct communication with another SMU's, if hardware faults do incur. Instead SMU's are able to query shared connected SMU's, as memory congruency should be updated among all SMU's and therefore are accessible throughout the network.

With the implementation of an OPC server to facilitate assignment of production orders, it is suggested the SMP be used within a decentralized network in conjunction with a centralized network, such as OPC. This is for understanding the hierarchy structure between the SMU's.

If each SMU calculates its own production speed, then each SMU can agree to adhere to the lowest production speed. However, if uncalculated or unforeseeable events occur, then manufacturing workers should be able to directly control SMU's.

With an OPC server being able to communicate within SM, it can therefore be used to overall manually set a desired production speed and force machines to adhere to this condition.

With the Header field instruction, it is possible to limit the size of payloads and therefore a query as whole. This will allow the SMP to reduce the latency and transit time of communication, allowing the SMP to be used in real-time communication for production needs of timely events.

It is however a SMU programmer's duties to ensure congruency of information between SMU's with triggering of methods, as such with all communication protocols. As such the SMP has a trigger attribute, information stored locally on a SMU will only be updated across a network, when an instruction/trigger is executed.

Last but not least, with the SMP having included within its construction a version field, future updates to the SMP could see the support for multi-vendor items.

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