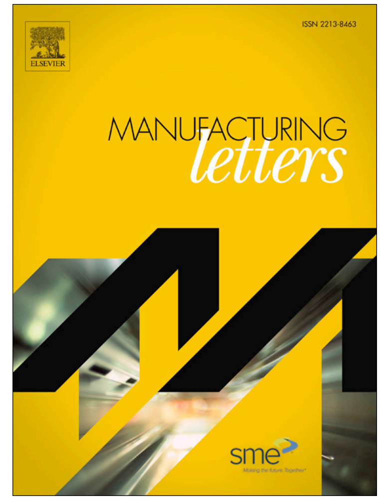

Letters

Standard Connections for IIoT Empowered Smart Manufacturing

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Standard Connections for IIoT Empowered Smart Manufacturing

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Abstract

The use of Industrial Internet-of-Things (IIoT) and related technology is propelling manufacturing into a new era in the fourth industry revolution characterized by ubiquitous connectivity. IIoT allows new and unprecedented interactions amongst hardware, software, and humans. Adopting the capability of IIoT with artificial intelligence tools, manufacturing systems become smart – with unprecedented gains in production agility, quality, and efficiency. One of the key enablers of the IIoT empowered smart manufacturing is connectivity and integration standards. In this paper we review the current IIoT standards used in manufacturing, present a new IIoT standards landscape for the smart manufacturing paradigm, and describe some of IIoT standards gaps.

Keyword: Smart manufacturing, Standards, Industrial Internet of Things, Artificial intelligence

1. Introduction

Major, technological innovations are always a catalyst for improving both manufacturing processes and the products they create. Figure 1 shows roughly the time periods when 4 such innovations began. Historians call these time periods "Industrial Revolutions".

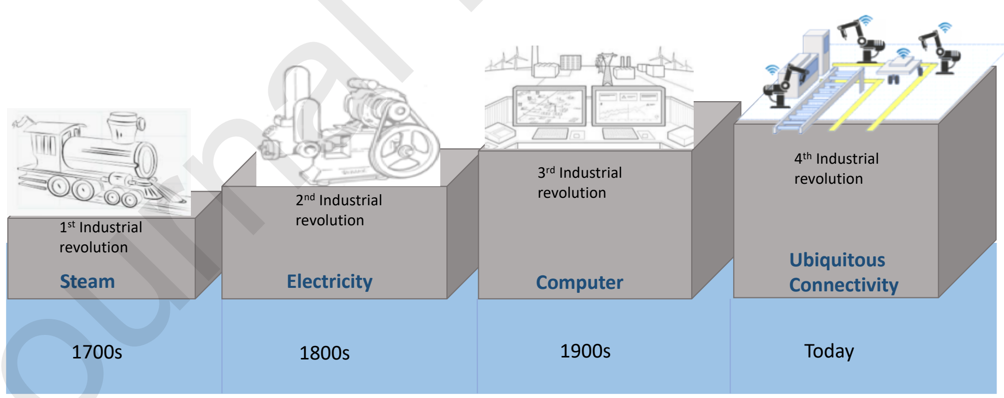

Figure 1. The Four Industrial Revolutions

1.1 The Four Industrial Revolutions and Smart Manufacturing

The first, two Industrial Revolutions were driven by new technologies that could generate steam and electricity. New machines that could change matter into steam (1700s) or electricity (1800s) became widely available. Other machines used that steam or electricity to drive numerous, physical, manufacturing tasks. With electricity, more of the physical tasks previously performed by humans could now be automated using machines.

The third industrial revolution was driven by both new, automated, physical technologies and the first generation of information technologies (IT) that included, sensors, machines, and software

(1900s). Electronics enables the conversion of analog signals in the real-world into digital signals, called data, in the newly evolving information world. Machines can transmit and receive data; software can interpret that data and to automate tasks previously performed only by humans.

The recent explosion of new communications and sensor technologies (today) has enabled ubiquitous physical connectivity among intelligent devices, machines, sensors, and actuators. This connectivity, called the Industrial Internet of Things, IIoT, is fundamentally changing the way we manufacture goods. A similar explosion of new data analytics technologies, especially, Artificial Intelligence (AI), has enabled widespread access to cloud-based analytical services. Both technologies have provided the foundations of a fourth industrial revolution. The ubiquitous physical and informational connectivity is expanding manufacturing to a global smart ecosystem, named smart manufacturing. Smart manufacturing has the capabilities to produce high quality products and to adapt quickly to changing conditions both inside and outside an enterprise.

1.2 Manufacturing Standards

Staring from the second Industrial Revolution, two needs arose: measurements and standards. The earliest needs focused on how to measure physical properties such as length and weight, and connect different machines physically. During the third Industrial Revolution, standards were developed to measure more material properties other than weight and length, as well as to connect various computing units and represent the information of real-world objects. By the end of the 1900s, information-based standards between 1) machines, 2) humans and machines, 3) computers and machines, and 4) humans and computers were abundant. These standards provided the foundation for the new concept - Smart Manufacturing.

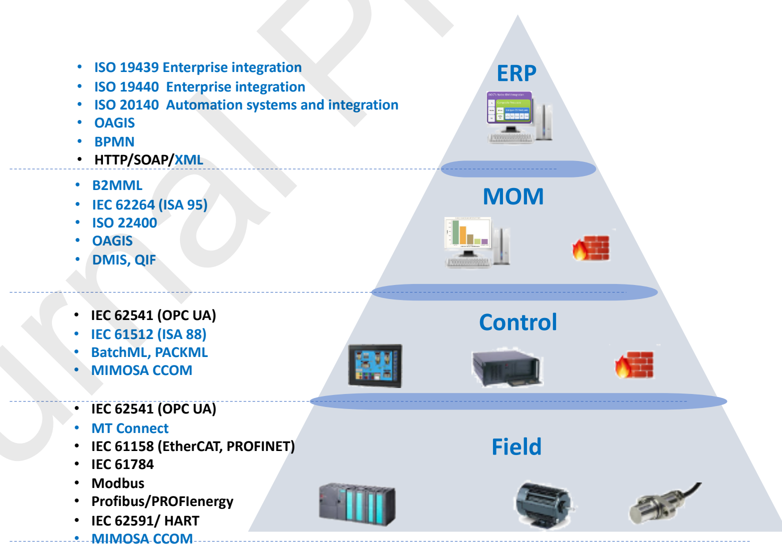

Figure 2. Initial Manufacturing Integration Standards Landscape (Adapted from [1])

2.0 Overview of Current Manufacturing Integration Standards

In the late 1900s, information technologies began to capture, transform, communicate, represent, and analyze information. These functions were formerly only executed by humans. Soon after these technologies became commercially available, standards flourished. Figure 2 shows a multi-layer standards landscape, which was based on the ISA-95 hierarchy [3]. This landscape organizes IT-related and manufacturing-related standards developed by national, regional, and international standards development organizations (SDOs). Some standards were developed specifically for the process industries; others for the discrete-parts industry. IEC TC65 [2], on the one hand, focuses more on the standards needed for operational equipment involved in manufacturing – the lower layers in the ISA-95 model. ISO TC184 [4] focuses more on the standards needed for the IT-related functions at the upper layers of ISA-95.

Representative standards needed to enable information integration and software interoperability both within and across each layer are listed at the left of Figure 2. The integration standards come in groups: communication protocols, data models, and application specifications. Traditional field devices such as PLCs, process instruments, actuators and intelligent I/Os are connected using industrial, field-bus standards such as IEC 61158 [5], CAN [6] and Modbus [7]. Collectively, these standards enabled computer integrated manufacturing. Since these standards are not interchangeable, they can create communication challenges when using IIoT devices. Today, MTConnect [8] and OPC UA [9] are two emerging standards at the forefront of harmonizing data exchange across shop floors.

3.0 A New Landscape for SM

SM is characterized by ubiquitous, digital connectivity, which enables multiple types of stakeholders, systems, services, machines, devices, and factories to talk to one another. The current manufacturing integration standards landscape shown in Figure 2 is no longer adequate. New standards are needed to integrate IIoT data with 1) existing manufacturing control and management functions, 2) AI-enabled smart manufacturing services, and 3) smart logistics and connected enterprise.

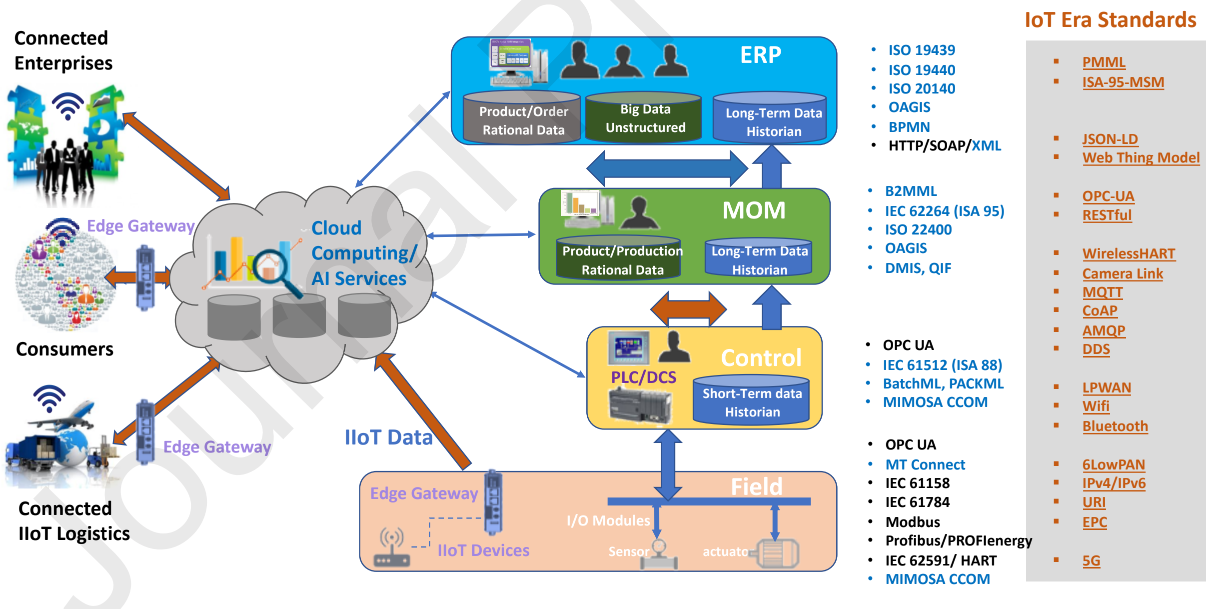

Figure 3. IIoT empowered manufacturing integration standards landscape

Figure 3 illustrates a new standards landscape for IIoT empowered manufacturing paradigm shift . The figure shows three, emerging IT technologies: Industrial Internet of Things (IIoT), cloud computing and AI, interconnecting with the existing manufacturing pyramid.

Importantly, the rigid, hierarchical architecture is gone. Data flows are no longer restricted - in both time and space - to adjacent, functional layers only. Consequently, the hierarchical architecture is being replaced by a multi-layered, software-based, and service-oriented architecture where the data flows have no temporal or spatial restrictions.

For example, the data from manufacturing shops, products-in-use, and goods transportation can be incorporated into MOM (Manufacturing Operations Management) and enterprise level information systems using a cloud computing platform [10]. This data then becomes available to be analyzed and used for real-time decision making. Together with the archived data, proactive actions can be taken to optimize enterprise performance and improve the manufacturing strategies.

In general, the numerous IIoT devices in use are driving the rapid evolution and development of new standards which have proliferated in the last 20 years, creating a vast library of connectivity. Speed and volume are the two required qualities considered for IIoT protocol development, by the Internet Engineering Task Force (IETF), the Institute of Electrical and Electronics Engineers (IEEE), and the International Telecommunication Union (ITU). One current portrayal of IIoT often relates to 5G technology, which can currently be defined by multiple standards, including the ITU IMT-2020 standard[1] and the 3rd Generation Partnership Project (3GPP) standard[2]. These new standards significantly increase currently available communication bandwidths, supporting much faster speeds and a significantly increased number of possible connections, up to 100 billion, which will enable seamless, real-time connectivity amongst the factory floor.

Besides 5G standards, the box at the right in Figure 3 summarizes the most used IIoT connectivity standards grouped based on the Open Systems Interconnection (OSI) model[3]. Among the data layer standards, WirelessHART is a datalink protocol purposed specifically for manufacturing fields. At the network layer, IETF is developing a set of standards to encapsulate IPv6 datagrams in different datalink layer frames for use in IoT applications, such as 6LoWPAN. IoT has many standardized session layer protocols, like Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), and Data Distribution Service (DDS).

This wide variety of connection options can be applied to meet various requirements of smart manufacturing applications. For instance, MQTT is a publish/subscribe protocol with minimal overhead and reliable communications, good for supervisory control and data acquisition (SCADA) and remote networks. CoAP provides the interoperability of HTTP but with minimal overhead, an appropriate substitution for edge-based devices where HTTP would be too resource intensive. DDS is an open publish/subscribe protocol for fast and decentralized communication, best for machine-to-machine (M2M) communications.

Given the complexity of the architecture in Figure 3, and its new technology components, existing standards must be re-evaluated and improved. Moreover, new standards for manufacturing must be developed to enable the new IIoT integration scenarios and business models. Communication protocols and connectivity standards are vital for the seamless exchange of information. Information exchange standards are vital to share the information in commonly understood syntax and semantics.

4.0 Discussion

Recent innovations in digital technologies, including IoT, Cloud computing and AI as well as advanced manufacturing technologies such as additive manufacturing and robotics, are serving as catalysts for new manufacturing paradigms. While connectivity and underlying technologies such as 5G are central to this paradigm, it cannot succeed without structuring the data and information

[1] https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx

[2] https://www.3gpp.org/dynareport/SpecList.htm?release=Rel-15&tech=4

[3] https://www.iso.org/ics/35.100/x/

being shared. To ultimately realize smart manufacturing, maturations of these manufacturing technologies must be accompanied by maturations of the information technologies that monitor and control them. A successful, interoperable production platform must be able to understand and communicate the information generated by both technologies.

In addition, to take advantage of the great utility of IIoT, the technologies that drive this connectivity must be secured, to enforce the privacy, reliability, and quality of services. Existing industry control system security standards, e.g., IEC 62443 and emerging IoT security standards and regulations, e.g., (EU) 2016/679 (GDPR) only address the tip of the iceberg. More efforts have to be put in developing IIoT security standards and integrating them with the existing safety standards.

5.0 Summary

Manufacturing is always a major beneficiary of what are generally called Industrial Revolutions. Currently, we are in the 4th such revolution, which is based on major, new information technologies that include IIoT sensors, cloud services, data analytics, and AI tools. Examples of potential manufacturing benefactors of these technologies include additive manufacturing and collaborative robotics. The concept, Smart Manufacturing, requires the ability to connect all these technologies together. This ubiquitous connectivity is the promise of the 4th Industrial Revolution.

Similar, but smaller-scaled, connectivity problems arose toward the end of the 3rd Industrial Revolution. This paper describes some of the solutions to those connectivity problems: standards. And it argues that standards will be needed before ubiquitous connectivity will become a reality. Finally, the paper provides an initial list of the standards needed to support that reality.

References

1. Lu, Y., Morris, K. C., Frechette, S., Current Standards Landscape for Smart Manufacturing Systems, NISTIR 8107, 2016
2. IEC TC 65, Industrial-process measurement, control and automation, https://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1250, Accessed on May 20, 2020
3. ISA95, Enterprise-Control System Integration, https://www.isa.org/isa95/, Accessed on May 20, 2020
4. ISO TC 184 Automation systems and integration, https://www.iso.org/committee/54110.html, Accessed on May 20, 2020
5. IEC 61158-1:2019 Industrial communication networks - Fieldbus specifications - Part 1: Overview and guidance for the IEC 61158 and IEC 61784 series, https://webstore.iec.ch/publication/59890; Accessed on May 20, 2020
6. ISO 11898, “Road vehicles – Controller area network (CAN) — Part 1: Data link layer and physical signalling”, https://www.iso.org/standard/63648.html, Accessed on May 20, 2020
7. Modbus Specifications and Implementation Guides, http://www.modbus.org/specs.php, Accessed on May 20, 2020
8. MTConnect Standard, Version 1.6.0, https://www.mtconnect.org/standard20181, Accessed on May 20, 2020
9. OPC Unified Architecture Specification, https://opcfoundation.org/developer-tools/specifications-unified-architecture, Accessed on May 20, 2020

10. Hattingh, H., “PLM-ERP-MOM: The ‘Holy Trinity’ of Manufacturing and Digitalization”, https://ingenuity.siemens.com/2019/02/plm-erp-mom-the-holy-trinity-of-manufacturing-and-digitalization/, Accessed on May 20, 2020
11. GSMA, “IOT Security Guidelines – Overview Document”, https://www.gsma.com/iot/iot-security-guidelines-overview-document/