Results, Insights and Best Practices from IIC Testbeds: Smart Manufacturing Connectivity for Brown-field Sensors Testbed

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This article gathers information from the Industrial Internet Consortium's (IIC) Smart Manufacturing Connectivity for Brown-field Sensors Testbed. The information and insights described in the following article were captured in an interview conducted by Joseph Fontaine, Vice President, Testbed Programs at IIC with Dr. Michael Hilgner, Manager Consortia & Standards at TE Connectivity.

The Testbed is carried out in two phases: on an initial demonstration case (phase I) and a real industry deployment (phase II). The interview was carried out after the completion of phase I and thus refers to the results and learnings from there.

TESTBED PROFILE

The Smart Manufacturing Connectivity for Brown-field Sensors Testbed is a joint effort of the IIC members, TE Connectivity (TE), a world leader in connectivity and sensors, and SAP, a world leader in enterprise applications in terms of software and software-related service revenue. Further collaboration partners are ifm, a worldwide leader in sensors, controllers and systems for automation, and the OPC Foundation, the organization defining the industrial interoperability standard OPC Unified Architecture (OPC UA). The Testbed was approved in April 2016 by the IIC Steering Committee. Public information is available from the Testbeds section of the IIC's website.

Objectives

The main objective of the Testbed is to provide a high volume of sensor data from brown-field manufacturing installations to enterprise IT systems in near real-time. In the discrete manufacturing domain, which is characterized by a strictly hierarchical structure, also referred to as the "Automation Pyramid," sensors are typically connected by input/output (IO) modules to programmable logic controllers (PLCs) which govern the real-time control (sub-)systems. There are generally three options for retrieving data from these systems for the use in enterprise IT systems:

1. To incorporate communication technology into the sensors themselves
2. To extract the data from the first aggregation level, i.e., the IO modules
3. To provide the data through the governing PLC which normally requires some re-programming

In brown-field installations, option 3 is not favorable or even not possible as the PLCs, which were once selected and programmed to process the automation sequence only, are typically far from modern and hence not capable of processing the volume of data required by advanced (cloud-based) analytics. Furthermore, the original programmer is often not available anymore and thus, re-programming a PLC which has been running an optimized code for years implies a considerable risk.

Option 1, to extract data from the sensor and communicate it, has its cost limitations. At least from today's perspective, the incorporation of communication capabilities in every sensor is too expensive. Furthermore, in terms of size, many sensors need to be very small to be incorporated into the appropriate locations at the machines and thus cannot be equipped with a receiver.

This testbed suggests using option 2 to extract data from the first aggregation level and to transfer that data through an additional communication path to the enterprise IT system without impacting the real-time operations.

The architecture proposed by this testbed can also be applied if there is a modern PLC and if it is beneficial to extract data close to the sensors, e.g., to reduce the traffic on the Industrial Ethernet system. However, modern PLCs are definitely suitable to process the required amount of data and many PLC suppliers offer modules with integrated OPC UA servers. So, with a modern PLC available, users would likely select option 3 above.

Another objective of the Testbed was to provide a retrofit solution for the factory floor. Many older machines are delivered without sensors integrated for diagnosis purposes. Thus, there is a distinct potential of increasing the Overall Equipment Effectiveness (OEE) by adding sensors and running machine learning algorithms.

Machine learning and advanced analytics are currently not used in the Testbed. Simple monitoring and analytics applications were used within the validation usage scenario, but it was not the focus of the Testbed. Nonetheless, this could be a point of connection with additional IIC members to perform advanced analytics on the Testbed.

Elements of the Technical Solution

This testbed introduced a special IO module which connects up to 8 IO-Link sensors and which provides interfaces to the real-time control system (Industrial Ethernet) and the enterprise IT system (TCP/IP) at the same time and that is why the name "Y-Gateway" is used for it. The Y-Gateway is a retrofit-able hardware solution intended to substitute classical IO modules where data with relevance for higher-level processes are passing through. This approach creates a new proponent suitable for brown-field installations; namely, extracting data from where it is actually generated while the original system architecture is preserved. Existing cabling can be re-used.

The Y-Gateway implements computational and storage capabilities and is thus able to perform some pre-processing of data from the eight IO-Link sensors and to buffer data for later bulk retrieval if required by the application.

There are some estimations that only about 5% of the sensor data are actually used by the governing PLC for running the automation task. As explained above, elder PLC are typically not suitable to process more than that, so the Testbed's sensor-to-the-cloud approach enhances the data availability for brown-field installations by up to a factor of 20. This higher quantity of data is especially interesting when considering to implement machine learning algorithms at enterprise IT level that require a higher volume of training data prior to actually running real-time analysis tasks.

The additional path established by the Y-Gateway uses OPC UA, meaning that the Y-Gateway accommodates an OPC UA server to provide the sensor data to an OPC UA client integrated within an enterprise IT system. In the Testbed, a consistent mapping of IO-Link data to OPC UA was defined and implemented which allows for the easy integration with the IT system. This mapping is currently being standardized in a joint effort of the IO-Link Community and the OPC Foundation. The Testbed provides essential input here and delivers a reference implementation at the same time.

The enterprise IT systems used in the Testbed are:

1. SAP Manufacturing Integration & Intelligence (MII) which is an SAP application for synchronizing manufacturing operations with back-office business processes. In many use cases it is configured as a data hub between SAP ERP and operational applications, such as a manufacturing execution system (MES), and provides analytics and workflow tools for identifying problems in the production process and improving its performance.
2. SAP Cloud Platform which is a platform as a service developed by SAP for creating new applications or extending existing applications in a secure cloud computing environment managed by SAP. The SAP Cloud Platform integrates data and business processes.

Both systems use the OPC UA server integrated within SAP Plant Connectivity (SAP PCo) that is a kind of hub capable of connecting to either of the two systems.

TECHNICAL CHALLENGES

Performance

The additional data processing required for the IO-Link/OPC UA conversion on the Y-Gateway shall have minimum impact on the real-time operations, meaning that the latency of the cyclic exchange of sensor data with the PLC shall not significantly increase. Testbed deliverables include a specification on how to measure the additional delay that occurs between a sensor and the governing PLC. The specification considers all latency contributions within the real-time control system and determines how to measure the effect of the additional data processing. Measurements were carried out according to this specification. Software and hardware optimizations were performed to minimize the impact.

Security

The additional communication path is established underneath the governing PLC which normally implements security mechanisms to protect the attached devices from unauthorized access. So, a door is opened to attacks through this additional connection with the enterprise IT system, which is normally blocked by the PLC. That is why sufficient levels of endpoint protection for the Y-Gateway and protection of the communication via the additional path are essential; similar to those implemented within the PLC at the control level. Endpoint security is achieved, for example, through the implementation of a Trusted Platform

Module (TPM) as a hardware-based root of trust (RoT). An endpoint without a correctly implemented RoT will lack the ability to establish confidence that it will behave as intended.

Communication security is mainly based on OPC UA's own security mechanisms. The German Federal Office for Information Security (BSI) has recently carried out an in-depth security analysis of OPC UA; the results of which confirm that "OPC UA was designed with a focus on security and does not contain systematic security vulnerabilities." However, security always comes at some costs and thus reduces the performance of the additional connection. The Testbed determined the appropriate OPC UA security level and provided a performance benchmark. One of the findings was that TCP/IP communication using OPC UA performs in the same range as other protocols with similar security mechanisms implemented on top of them.

TESTBED RESULTS

Retrofit Solution for the Factory Floor

The Smart Manufacturing Connectivity for Brown-field Sensors Testbed introduces a general architectural approach with the goal to make a high volume of sensor data available in enterprise IT systems. This approach can be applied to realize various usage scenarios that are based on combining the information from a sensor system with historical data and that aim at performing advanced analytics, monitoring the results and deriving actions.

The Testbed makes the factory floor more retrofit-able through architectural adaptations. The preferential scheme implements a small change to an architecture with a preexisting IO module with sensors attached to it. The IO module is simply replaced by the Y-Gateway which delivers preprocessed sensor data to the enterprise IT system in addition to the IO module's original task of feeding the real-time control system with the sensor data. As an alternative, an additional Y-Gateway could be incorporated underneath an existing PLC, where new sensors would be attached to retrieve data not previously available.

Deployment

Phase I's outcome is a demonstrator, which resides in a box with all the components described above and in accompanying documents. IO-Link sensors are connected to the Y-Gateway, which communicates to SAP PCo via OPC UA and with the PLC using the Industrial Ethernet connection at the same time. TE is currently determining how to deploy it in its factories and TE and SAP will then offer it to its customers and partners. This will result in multiple real industry implementations as planned for phase II.

There is a complete range of IO-Link sensors available from many vendors nowadays. In fact, the IO-Link community currently stands at 200 members. With the wireless IO-Link being recently introduced, there will soon be even more opportunities with the technology.

Application Use Case

The Testbed is applied to a manufacturing use case with the objectives to monitor and optimize the amount of consumed compressed air per produced part. This usage scenario is implemented primarily for validation purposes, however it addresses a common manufacturing challenge at the same time. The setup includes two sensors: An IO-Link compressed air meter to precisely measure the air flow, the consumption and the current temperature, and an IO-Link laser distance sensor to count the produced pieces and thus, to determine the produced volumes. Diagrams with consumed compressed air per produced part and over time give indications on potential problems with the supply of compressed air or on potential process improvements, e.g., in terms of process speed vs. pressure.

There will be additional usage scenarios specified by sensor and machine manufacturers with expertise to define applications that bring benefits to their customers and the data needed to be made available for their implementation.

Deliverables

Phase I's scope addresses the development of the Y-Gateway and the OT/IT communication, ensuring insignificant latencies from the additional data processing on the device, a consistent conversion from IO-Link to OPC UA and appropriate security mechanisms being in place. After Phase I is completed, the Testbed team has decided to author a conclusory white paper. Other detailed technical reports internal to the IIC ecosystem have been delivered, e.g., a detailed explanation of IO-Link/OPC UA conversion technologies and how they are internally structured. The conclusory intends to recount these aspects at a higher level, and factor the remaining Phase I information yet to be reported. Real industry deployments will generate additional technical reports.

IIC Interactions

Between the Individual Members

At the inception of the Testbed, the companies seeking to collaborate put a testbed proposal together and presented it to the IIC. Interaction with IIC members commenced immediately after the introduction of the Testbed. It was interesting to witness the amount of contacts that were established during the first two or three quarters of the Testbed's existence. Individuals from all over the world scheduled meetings just to understand the Testbed and offer how they might contribute. People offered to assist with the analytics and connectivity side of the Testbed so they could provide additional connectors other than OPC UA towards common cloud systems. On the security side, companies were interested in increasing the Testbed's communication and endpoint security features. There was a multitude of opportunities that were presented to the team following the introduction of the Testbed.

The cooperation of companies from different areas (such as OT and IT) and the discussions on the Testbed with people with various backgrounds also deliver a better picture of the overall business environment, including the demand of "the customers of the customers." For instance, TE primarily provides its components to the original equipment manufacturers (OEMs) in the automation domain (e.g., Siemens, Rockwell) and is very well connected with them (also through engagements in user groups such as PROFIBUS & PROFINET International and ODVA). Working within the greater IIC ecosystem fosters understanding of the demands of the value chain beyond those well established relationships, e.g., machine builders.

With IIC Working Groups

The Testbed team has held valuable discussions about structuring Testbeds and using the IIC's [Industrial Internet Reference Architecture] (IIRA), which has facilitated work. The Three-Tier architecture pattern of the IIRA was very helpful in defining testbed roles and in understanding how to establish individual interfaces and where potential testbed partners would extend the current setup.

Similarly, the IIC's [Industrial Internet Security Framework] (IISF) was instrumental in the Testbed's work. The structure regarding endpoint and communication security serves as a good distinction of how there are really two challenges that need to be separately considered. Given the structure of the IISF, there is a checklist of sorts that one could go through. For example, the IISF was used as a reference for the Testbed's threat analysis.

The IIC's [Industrial Internet Connectivity Framework] (IICF) is very relevant to the Testbed as the Industrial Internet of Things (IIoT) connectivity stack defined in the IICF provides an appropriate structure to explain the properties and interoperability requirements of the communication protocols used in the Testbed. For instance, OPC UA's high-level allocation in the stack indicates that it operates with lower-level transport and networking protocols (e.g., TCP/IP), clarifying that OPC UA provides for semantic interoperability.

The Testbed results have been shared with the IIC Standards Task Group (a group within the IIC Liaison Working Group) who had previously expressed interest. The Testbed team is working with the Standards Task Group to discuss how to proceed regarding a common scheme tying testbeds and investigatory standards together. The Testbed is also one of the testbeds contributing to the IIC Networking Task Group (a group within the IIC Technology Working Group) in their development of an Industrial Internet Networking Framework by adding specific details on network requirements and implementations of the Testbed's usage scenarios. The Testbed results are also being used in a section of a smart factory white paper by the IIC Smart Factory Task Group under the IIC Marketing Working Group elaborating on sensor-to-cloud connectivity.

STANDARDS

TE is currently working on an OPC UA Companion Standard for IO-Link which will complement the already existing range of OPC UA Companion Standards that map existing device profiles or semantics to OPC UA information model extensions of the basic OPC information model as defined in

IEC 62451-5. To be more precise, this standardization activity, which is jointly carried out by the IO-Link Community and the OPC Foundation and which is led by TE, uses the derivative IEC 62541-100 for device integration as the base class for the IO-Link/OPC UA Companion Standard. The final draft of this new standard is currently under review and the team hopes to publish it before the SPS IPC Drives 2018 event being held in November in Nuremburg. The Testbed provides input to this standardization activity, and delivers a reference implementation for the future OPC UA for IO-Link Companion Standard.

The IO-Link Device Description (IODD) defines the IO-Link semantics which is converted by the Testbed to an OPC UA information model. IEC 61131-9 is a reference to the fundamental standard for IO-Link, which does not include the IODD specification. The Testbed may be influencing the IODD specification to some extent because the team also discovered inconsistencies between the IODD from different vendors, which actually made the conversion fail.

THE EXPERIENCE

Within the Greater IIC Ecosystem

The Testbed team received a lot of feedback from other IIC members. As a result, many contacts were established and individual Testbed team members/partners were increasingly recognized over the course of many presentations for the IIC. The Testbed has been a valuable experience for everyone involved. The Testbed participants are also engaged in many user groups and consortia, however most of them are maintained by companies that form neighbors in the value creation chain. At the IIC, Testbed members have the opportunity to form relationships with other companies (e.g., the customers of TE's customers) that could provide value via the deployment of testbed technologies.

Within the Testbed Project

The Testbed got its start with TE's hardware project on the Y-Gateway where its base features had to be available prior to the implementation of the Testbed. So, the actual cooperation project started two or three quarters after the Testbed's approval. This setup was challenging because project teams need to be nurtured during the project phase and it is important for every team member to be involved from the very beginning. That is why the Testbed team recommends using available hardware for a testbed and focusing on the interoperability and security aspects rather than on the development of hardware components. From a technical point of view, there was one provider for every component along the Three-Tier architecture so the roles were well-defined. Every company executed its role well and virtually everything proceeded as planned. Naturally, there were minor challenges along the way.

The special resources that were needed both inside and outside the Testbed perimeter were the contributing experts in IO-Link and OPC UA. Their intense cooperation under the Testbed's umbrella definitely led to some increase in competencies of the respective participant companies during the project and to a further extension of their knowledge bases.

Another finding by the Testbed team was the discovery that the amount of work put into developing a testbed is similar to that required when setting up an application for a governmentally funded research project. That is why it could make sense for IIC members to combine future research projects with testbeds. The practical aspect of a research endeavor could be implemented through a testbed, but it would largely depend from case-to-case whether such an approach would be practical or not.

To reduce the amount of work, proper planning in the testbed preparation phase is required. The schedule must be near exact and each testbed team member must understand each partner company's technologies. IT and OT people have different mindsets, terminologies and expectations towards other parties that are involved in a testbed. Good team preparation helps overcome typical struggles in the initial phase of a testbed to optimize collaboration.

By nature, the Testbed focuses on technical aspects. A usage scenario was defined and implemented for demonstration and validation purposes only. However, the Testbed's objectives and message could have been delivered even better through the inclusion of multiple business-relevant usage scenarios.

The intention is to roll the Testbed solution out to TE factories as an operations development project involving the Y-Gateway. This device is ready to be industrialized and prepared to sell. However, a demand for a considerable number of devices by TE's customers is required to define the final portfolio, variants, etc.

CONCLUSION

The Testbed provides a high volume of sensor data from brown-field manufacturing installations to enterprise IT systems in near real-time. The Testbed team attributes its remarkable success to good and early team preparation, respect across the OT/IT divide, valuable industry-leading participants, input from many IIC experts and IIC industry resources such as the IIRA, IICF and IISF. Their successes are influencing industry standards and Testbed participants are exploring paths to deployment and consumer demand in multiple real industry implementations. The significant impact this testbed is having and will continue to have on the manufacturing industry will be further detailed in an upcoming white paper summarizing the Testbed's findings and results, while future industry deployments will generate additional technical reports.

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