Towards Increased Flexibility and Interoperability in Distributed Process Control Applications

Ahsan Zia, David Hästbacka
Computing Sciences
Tampere University
Tampere, Finland
{ahsan.zia, david.hastbacka}@tuni.fi

***Abstract*—The modern process automation plants are changing into flexible designs, which raises the requirements for distributively controlled logic, a high degree of interoperability, dynamic reconfiguration and software reusability. Thus, creating an opportunity to integrate the distributed control system standards and platform independent communication protocols. In this paper, we propose the use of OPC UA to increase interoperability of communication and the utilization of Arrowhead Framework to enhance interoperable service compositions of control applications implemented in IEC 61499. The concept is outlined for the integration and modeling of a distributed control system for a FESTO laboratory batch process system. A control application example is provided to create distributed control of Cyber-Physical Systems using services that are connected using IEC 61499 in accordance to Industry 4.0 for improved interoperability and flexibility.**

***Index Terms*—Cyber-Physical Systems, Industry 4.0, IEC 61499, 4Diac, OPC UA, Arrowhead Framework**

I. Introduction

The world of technological developments of industrial production systems are changing on a rapid pace. Industry 4.0 is a concept that explains how industrial production systems are enhancing over time [1]. Industry 4.0 is based on Industrial Internet of Things (IIoT) and Cyber-Physical Production Systems (CPPS), an amalgamation of the real world and the virtual world [2] [3].

The implementation, development and use of the IEC 61499 standard supports a model-based development of distributed control systems [4]. The key entity in the IEC 61499 standard is the Function Block (FB), which envelops the control and communication algorithms in different programming languages [5].

OPC Unified Architecture [6], simply referred to as OPC UA, is a standard that ensures interoperability, open connectivity, security and reliability of industrial automation system and devices. It is vendor independent and works with different software platforms, offering OPC UA an edge over the traditional industrial communication protocols [7].

Arrowhead is an open source framework for industrial Service Oriented Architectue (SOA) based applications [8]. It has been designed to not interfere with the basic control operation of industrial systems. The great challenges of the Arrowhead Framework (AHF) are to enable interoperability and integrability of services produced and consumed by the devices [9]. The AHF is addressing IoT based automation and it provides interoperability between services, in a SOA [10].

This paper serves as a base study for dynamic orchestration of process control functions exposed in OPC UA to be utilized in IEC 61499 applications and using Arrowhead to manage the connections.

The rest of the paper is organized as follows. Section II describes the related work, background and technologies used. In Section III the objectives and the motivation behind the approach is explained. Section IV details the case process and gives a brief description about the laboratory process. Section V presents the proposed concept of connecting the Arrowhead services and OPC UA services to IEC 61499 applications. Section VI contains results and discussion. Finally, the conclusion and future work is presented in Section VII.

II. Related Work and Background

A few key arguments in support of Industry 4.0 include modular structure, CPPS, remotely monitoring physical processes, digital twins and decentralized decision making. These requirements lead to the investigation and introduction of new concepts and standards [11]. The standards and concepts explained in Section I support distributed controlled logic, interoperability, portability, reconfiguration, software reusability and platform independent communication protocols as explained by [2].

The integration of the IEC 61499 standard and Arrowhead IoT services for flexible manufacturing applications present SOA where services are located at the device level as well as in local and global clouds orchestrated by the AHF as proposed by [9].

A study [12] addresses a similar methodology of combining batch process design and control applications with IEC 61499 for improving flexibility of the system. Regarding interoperability of CPPS, this has been previously discussed by [13] for harmonizing the interfaces using Semantic Web technologies. Similarly, in [14] Semantic Web technologies have further been combined with OPC UA. The information model of OPC UA can also be seen to provide the required semantics but without the Semantic Web reasoning aspects.

The following subsections briefly explain the implementation technologies for the development concept.

A. OPC UA

OPC UA is a communication protocol [6], that is platform independent SOA, which integrates all the functionality of the individual OPC Classic specifications into one extensible framework. It is deployed over TCP/IP but more recently also supports UDP. OPC UA has its own binary protocol but can also make use of Web Service communication. Different control systems can provide its own OPC UA servers, and clients can access it directly.

Typical application areas for OPC UA is communication between Process Control Systems (PCS) and Manufacturing Execution Systems (MES) as well as between the individual components of production systems [15].

B. Arrowhead Framework

AHF is addressing IoT based automation. It is an open source framework for industrial SOA based applications [8]. It has been designed to not interfere in the basic control operation of industrial systems. AHF are to enable integrability and interoperability of services produced and consumed by any system or device. AHF defines systems as the participant entities of the SOA. The systems then communicate via service contracts. The core functionalities of the framework include orchestration, service registry and authorization [10].

C. IEC 61499 standard

IEC 61499 standard for the distributed systems, which is able to handle the complexity of inter-connected automation systems. It also significantly decrease the development time by overcoming driver programming and signal mapping for communication between different systems and devices [4]. IEC 61499 also allows platform-independent PLC code development [16].

III. Objectives of the Approach

The diagram in Figure 1 shows the approach behind the the idea of this implementation. The control is bound to logical data points and functions of the devices. The communication takes place through a number of OPC UA services represented as corresponding interface FBs.

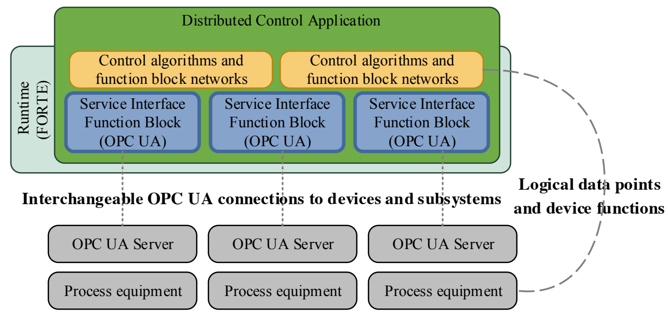

Fig. 1. Block Diagram for the implementation of the System

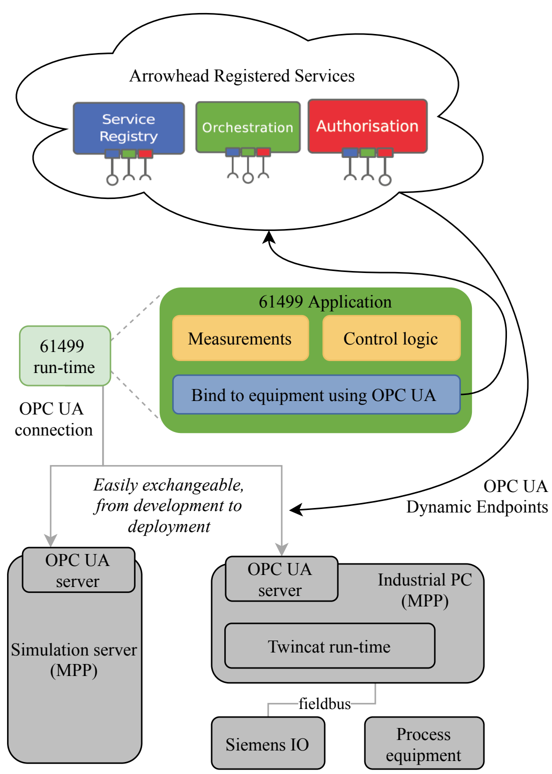

Fig. 2. Exchangeable OPC UA connections with agreed, interoperable interface definitions facilitate development.

A benefit of the approach is that the control system components have the capability of being interchangeable given that same interface semantics are adhered to. This is also the case in our example between a simulation process and corresponding actual hardware as shown in Figure 2. In our example, a simulation server is used to ease development as well as testing and it is easily replaceable with the real hardware due to an exactly identical OPC UA interface of the physical setup.

Figure 2 also shows the integration of AHF to the system where the idea is to acquire these service end-points dynamically at run-time for the application to use. In comparison, OPC UA discovery is typically used in a local network whereas AHF provides discoverability and composability across the internet, if required.

IV. Case Process Laboratory Setup

This section explains the hardware of the Mini Pulp Process (MPP) system. Figure 3 presents the physical setup of the laboratory process.

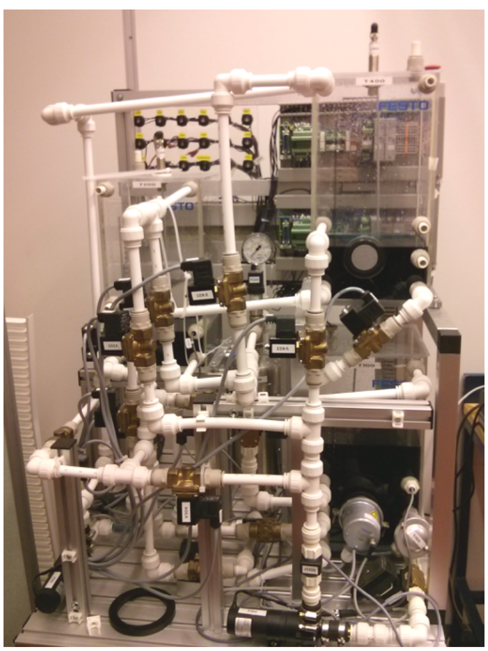

Fig. 3. Image of the actual physical process with its equipment

The MPP system processes are divided into five unit procedures. These unit procedures are controlled by the functional elements such as valves and pumps along with temperature sensors and analogue gauges. The equipment consists of four large tanks, of different capacities. One of the tanks is a pressure-controlling vessel, which is used to control pressure inside the system environment. The equipment includes two pumps, a heater and two control valves and a series of open shut valves.

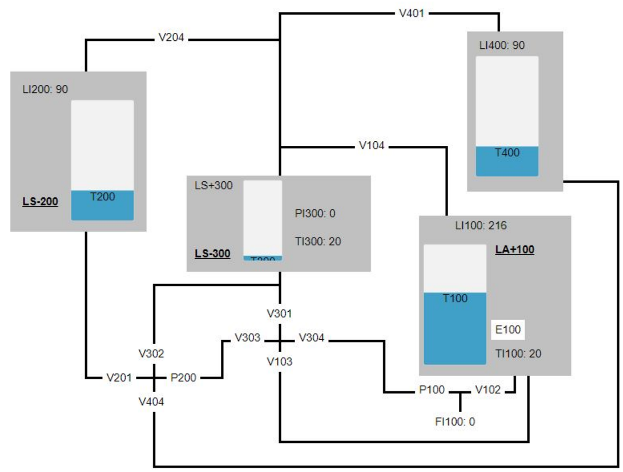

Fig. 4. The mini pulp process simulator user interface

In addition to that, there is a manual valve; PVC pipes used for the connection between the tanks. The tanks are connected either directly or through a connection of second tank. Liquid can be pumped into any of the alternative tanks using the pipe system.

Apart from a few alterations and a few additions, the process Simulator contains all the functionalities. Figure 4 presents the MPP simulator user interface.

V. Increased Interoperability and flexibility

A. Connecting OPC UA services

The control application created in 4Diac framework is composed of different FBs and data connection among the FBs. The OPC UA servers expose all the services of the process equipment (simulator or hardware). From the OPC UA address space each node representing a device that offers input or output is translated into a FB. Figure 5 presents a snapshot of a distributed control application.

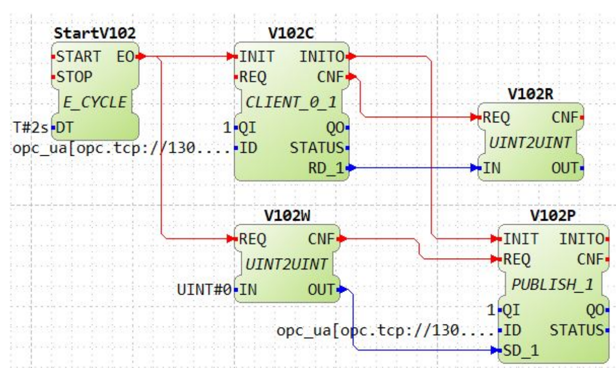

Fig. 5. 4Diac application SIFBs

The Service Interface Function Block (SIFB) PUBLISH FB is to write to an OPC UA variable to a remote server, and uses the SIFB CLIENT FB to read the incremented value from the remote server, which reads the variable's value as soon as the request is triggered.

B. Envisioned Usage of Arrowhead Framework

The envisioned usage of AHF is that the OPC UA endpoint services can be registered at the service registry from where they can be discovered to be combined into applications. AHF provides the endpoints to the applications dynamically at run-time. For example, a controller requests the orchestrator and the service registry for which devices and sensors it should use. The orchestrator has the configuration and the setup is maintained centrally, instead of declaring it locally in the 4Diac control applications. 4Diac FB library have been defined for AHF version 4.1.2 [17] but they are not yet available for the newer AHF versions. Figure 6 present the application in the Arrowhead Function Blocks in the 4Diac application.

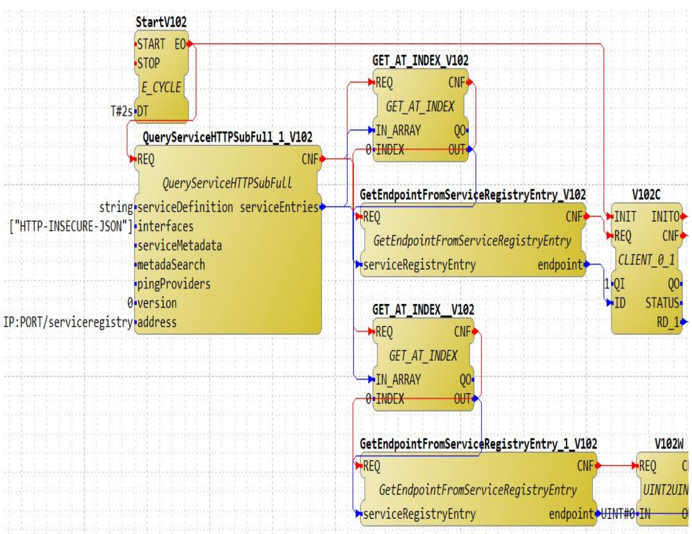

Fig. 6. Arrowhead FBs developed for 4Diac ease integration of Arrowhead orchestrated services into IEC 61499 applications.

VI. RESULTS AND DISCUSSION

The ambition behind the work is the integration of OPC UA endpoint services as interoperable and exchangeable building blocks of devices and their functionality in IEC 61499 control applications.

These services contain OPC UA endpoints which are provided to the SIFB. SIFBs avail OPC UA as an information model to exchange data between the IEC 61499 (4Diac) control applications and the industrial systems and externally triggers the different application's services.

To summarize, OPC UA is a more open, secure and dependable mechanism for transferring information between clients and servers. It provides added open transport, greater security and a complete information model over the traditionally used controller interfaces, as well as is able to connect to databases and enterprise management systems with real world data from actuators, controllers, sensors and monitoring devices that are able to interact with real processes [6]. In addition, the advantage of IEC 61499 over other programming languages is that, it utilizes eXtensible Markup Language (XML) as a storage and exchange format, which enables the migration among other IEC 61499 software tools and permits platform independent PLC code development. This facilitates the reusable nature of FBs on other platforms, and therefore offering increased flexibility compared to IEC 61131 [16].

The interoperability and flexibility is expected to be increased with the use of AHF providing an interoperable and common model for discovering and composing services dynamically, including also a model for authenticating and authorizing application systems for secure compositions. In its simplest form AHF can be used to directly retrieve service endpoints from the registry for the applications to compose their interaction. This model, however, leaves the burden on the application to decide and know what specific services to use. By using the AHF orchestration some of this logic can be shifted to be centrally managed. The OPC UA discovery is currently limited to use in a local network environment. In comparison AHF provides discoverability and composability across the internet.

VII. CONCLUSION AND FUTURE WORK

There is an increase in demand for the distributed control systems, with the requirement of integrating devices and systems from different vendors. By utilizing IEC 61499, we can now model and implement the control logic to control processes without dependencies of the device specific features or vendor specific communications.

This paper demonstrates how OPC UA can improve the interoperability of communication and provide means to interchangeably switch target devices to support development. The concept is extended by envisioning the use of AHF to provide the OPC UA endpoints to IEC 61499 distributed control application dynamically at run-time. This is to further increase flexible use of interoperable services using the AHF model for service composition and management. For example, a controller requests the service registry or orchestrator for which devices and sensors it requires. The orchestrator has the configuration and the setup is maintained centrally instead of declaring it locally in various application instances.

This improves flexibility of the system as well as eases the engineering effort through improved interoperability once standards based information models are being used. In our small example the control system is fully capable to be interchangeable between the simulator and the actual hardware which proves the point of interoperable semantics as well as facilitates further development.

ACKNOWLEDGMENT

This work is related to the Productive4.0 project and has received funding from the EU ECSEL Joint Undertaking under grant agreement no. 737459 and from the national funding authority Business Finland. The authors are also grateful to the Academy of Finland for their funding supporting this work (grant no. 310098).

REFERENCES

[1] D. Vuksanović, J. Vešić, and D. Korčok, "Industry 4.0: the future concepts and new visions of factory of the future development," in *Sinteza 2016 - International Scientific Conference on ICT and E-Business Related Research*, 01 2016, pp. 293–298.

[2] M. Garcia, E. Irisarri, F. Pérez González, E. Estevez, and M. Marcos, "Automation architecture based on cyber physical systems for flexible manufacturing within oilgas industry," *RIAI - Revista Iberoamericana de Automatica e Informatica Industrial*, vol. 15, pp. 156–166, 01 2018.

[3] M. V. García, F. Pérez, I. Calvo, and G. Moran, "Developing cpps within iec-61499 based on low cost devices," in *2015 IEEE World Conference on Factory Communication Systems (WFCS)*, May 2015, pp. 1–4.

[4] A. Zoitl and R. Lewis, *Modelling control systems using IEC 61499. 2nd Edition*, 01 2014.

[5] T. Bezak, "Iec standards and distributed control systems modelling," in *2012 IEEE Symposium on Industrial Electronics and Applications*, Sep. 2012, pp. 242–245.

[6] *OPC Unified Architecture Specification Part 1: Overview and Concepts v.1.01*, OPC Foundation, 2008.

[7] S. Kožár and P. Kadera, "Integration of iec 61499 with opc ua," in *2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA)*, Sep. 2016, pp. 1–7.

[8] Arrowhead. Project github-repository and documentation. Accessed: 2020-02-10. [Online]. Available: https://github.com/arrowhead-f

[9] H. Derhamy, D. Drozdov, S. Patil, J. van Deventer, J. Eliasson, and V. Vyatkin, "Orchestration of arrowhead services using iec 61499: Distributed automation case study," in *2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA)*, Sep. 2016, pp. 1–5.

[10] J. Delsing, P. Varga, L. Ferreira, M. Albano, P. Puñal Pereira, J. Eliasson, O. Carlsson, and H. Derhamy, *3 The Arrowhead Framework architecture: Arrowhead Framework*, 02 2017, pp. 43–88.

[11] A. Bicaku, S. Maksuti, S. Palkovits-Rauter, M. Tauber, R. Matischek, C. Schmittner, G. Mantas, M. Thron, and J. Delsing, "Towards trustworthy end-to-end communication in industry 4.0," in *2017 IEEE 15th International Conference on Industrial Informatics (INDIN)*, July 2017, pp. 889–896.

[12] D. Ivanova, S. Panjaitan, I. Batchkova, and G. Frey, "Iec 61499 component based approach for batch control systems," *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 17, 01 2008.

[13] D. Hästbacka and A. Zoitl, "Towards semantic self-description of industrial devices and control system interfaces," in *2016 IEEE International Conference on Industrial Technology (ICIT)*, 2016, pp. 879–884.

[14] V. Jirkovský, M. Obitko, P. Kadera, and V. Mařík, "Toward plug play cyber-physical system components," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 6, pp. 2803–2811, 2018.

[15] J. Virta, I. Seilonen, A. Tuomi, and K. Koskinen, "Soa-based integration for batch process management with opc ua and isa-88/95," in *2010 IEEE 15th Conference on Emerging Technologies Factory Automation (ETFA 2010)*, Sep. 2010, pp. 1–8.

[16] M. Kazmierkowski and F. A. Silva, "Distributed control applications: Guidelines, design patterns, and application examples with the iec 61499 [book news]," *IEEE Industrial Electronics Magazine*, vol. 10, no. 4, pp. 81–82, Dec 2016.

[17] 4Diac. Documentation. Accessed: 2020-02-10. [Online]. Available: https://www.eclipse.org/4diac/en$_{h}elp.php?helppage = html/communication/arrowhead.html$