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Service-based Architecture with Product-centric Control in a Production Island-based Agile Factory

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***Abstract*—This paper presents the Aalto Factory of the Future, an ongoing initiative in establishing an agile, net-centric production-island based factory utilizing service oriented architecture concepts. Recent progress towards realizing the software architecture with product-centric control in the facility is reported in this paper, which features communication between different production islands, and actors in the space between the production islands and humans.**

***Index Terms*—Agile manufacturing, industrial internet of things, production islands, mobile robots, automated guided vehicle, service oriented architecture, Industry 4.0**

I. Introduction

This paper reports the current progress in setting up our Aalto Factory of the Future (AFoF), a facility for demonstrating and investigating various concepts and enabling technologies in agile manufacturing, including: Industrial Internet of Things (IIoT), digital twins, augmented and virtual reality, reconfiguration and remote operation and maintenance techniques. These are embedded into a facility that shall integrate with Enterprise Resource Planning (ERP) and outside facilities such as other factories, suppliers and logistics operators.

AFoF physical space comprises several stationary and mobile "production islands", each specializing in a distinct task, where the space can be shared with humans. The production islands' controllers are interconnected using wired or wireless networks, enabling communication with each other or to cloud-based services. The facility adopts a service oriented architecture (SOA) approach [6], where factory equipment offers services to other equipment and external stakeholders. Services are logically connected to a service bus and can be discovered using service discovery mechanisms. Services can be composed and invoked to carry out certain production tasks.

The Reference Architecture Model for Industry 4.0 (RAMI 4.0) [12] is a promising starting point for implementing our SOA with technologies that have a strong chance for broad industrial adoption [1]. In particular we are utilizing OPC UA [11], which already has industrial grade implementations and applications, and also the Industry 4.0 component and asset administration shell, which exposes the data of the software and physical aspects of the component in a standard, machine readable way [2].

At this point, we are targeting the following research questions with our facility: 1) Testing and evaluation of new software architectures and approaches for industrial automation. We are particularly interested in questions on where to deploy software that performs certain functionality such as control, analysis (see [3]), automated dynamic composition of manufacturing services, and monitoring. Latency and throughput of data are important questions in our evaluation. 2) Product centric manufacturing. Here, a digital twin controls the assembly of its physical counterpart by utilizing available manufacturing services at certain given times, dynamically composing, and triggering their operations. The information flow and the dynamicity of this approach are among our interests to investigate.

II. Concept and Current Progress

Fig. 1 (left) gives an illustration on the service oriented architecture we envisage for our facility. Based on information associated with a digital twin of a product, product-centric manufacturing means that the digital twin is augmented by the capability to orchestrate services available at the facility as needed to assemble the product. Services can potentially invoke other services, for example, a transport service can decide on concrete transport robots and call the appropriate services.

Currently, two different service-based architectures are tested separately in the facility. The first is a service-based architecture with an IEC 61499-based product-centric control (see [10]). This work attempts to decouple and encapsulate a product-centric control implementation deployed in our AFoF production islands shown Fig. 2 (left and center) (see [7] for the original implementation), where software control of each production resource is abstracted as service by associated OPC UA servers. The OPC UA Discovery specification is used to realize service discovery, where each manufacturing service becomes discoverable and composable dynamically to achieve production. This attempt results in an architecture shown in Fig. 1 (center) (see [10] for more details), where each resource is more modular and decoupled compared to the one in [7]. The second architecture utilizes a novel service-oriented programming approach with a formal globally asynchronous locally synchronous (GALS) model of computation called SOSJ-OPC UA [8]. This approach is based on the synergy of formal GALS programming approach SystemJ [14] [15] / Service Oriented SystemJ [9] and OPC UA, allowing the creation of functionally correct, formally verifiable software control with vast interoperability, dynamic reconfiguration, and service discovery and composition based on OPC UA. In SOSJ-OPC UA, software control of each production resource

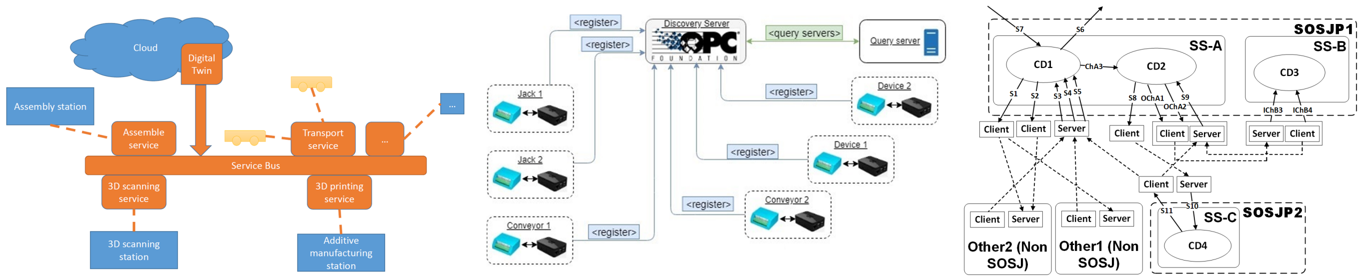

Fig. 1. Abstract concept of SOA in our AFoF (left) and two different SOA realizations currently being investigated (center and right)

is modular, in the form of asynchronous software components called clock domains (CDs), which are distributable over multiple control devices. Each CD has associated OPC UA clients and servers which abstract it as service and allow communication with other software control in different languages via OPC UA. Initial deployment of this approach has been done in AFoF using distributed Raspberry Pi based control devices to demonstrate the approach.

Another realization of product-centric manufacturing in AFoF is implemented in a 3D simulation and demonstrated in [4]. A partial implementation exists with an assembly station based on ABB YuMi robot [5] (Fig. 2 (right)). The assembly station can assemble a large subset of all possible designs built from square and rectangle lego blocks automatically, by consulting the digital product description. The current setup of the AFoF is shown in Fig. 2. A stationary production island is shown (left), which comprises a conveyor belt ring, sensors and actuators. Two mobile production islands are depicted in Fig. 2 (center and right), which are capable of moving around and assisting production at different locations. Some real demonstrations of work related to our AFoF can also be viewed on the AFoF Youtube channel [13].

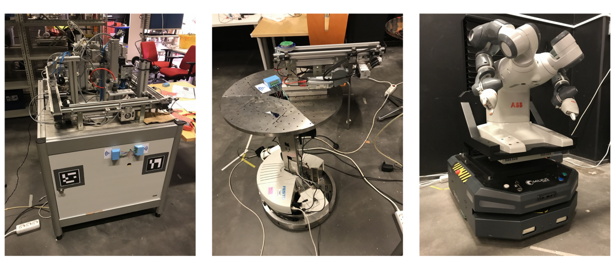

Fig. 2. Examples of a production island and mobile robots in our setup

III. Conclusions & Future Works

This paper presented our ideas towards realizing a service based architecture in our agile factory called Aalto Factory of the Future (AFoF), which consists of stationary and mobile production islands and space shared with humans. Two different OPC UA-compliant service-based architectures are currently being deployed and investigated in a product-centric control context. Additional stationary and mobile production islands are currently planned. Also, the experiments on various software architectures, digital twins and ontologies are planned in this context, as well as work towards more standardized services, service hierarchies and service composition based on OPC UA.

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