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Model similarity evidence and interoperability affinity in cloud-ready Industry 4.0 technologies

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ABSTRACT

Cloud computing is revolutionizing IT environments in most fields of economy. Its service-based approach enables collaboration and data exchange on higher level, with better efficiency and parallel decreasing costs. Also manufacturing environments can benefit from cloud technology and better fulfill fast changes in market demands, by applying diverse cloud deployment models and by virtualizing manufacturing processes and assets into services. As cloud becomes the basis of most innovative manufacturing IT systems, its future role in Cyber-physical Production Systems has to be properly investigated, as their interoperability will play a role of vital importance. In this paper, after a brief introduction to cloud criticality and cloud-based manufacturing, the mutual conceptual similarities in modelling distributed industrial services of two of the major standardization frameworks for industrial Internet architectures are presented: the Industrial Internet Reference Architecture (IIRA) and the Reference Architectural Model Industrie (RAMI 4.0). It is also introduced how their integration feasibility finds a strong affinity in specifications of the Open Connectivity Unified Architecture, a service-oriented architecture candidate to the standardization of Industrial Internet of Things based manufacturing platforms. Finally, the preliminary architecture of a prototype Smart Factory is presented as a case study.

1. Introduction

Based on the evolution of the information and communications technologies, a new "digital" economy has reached a point where it can be called the *forth revolution*, and where Cyber Physical Systems (CPSs) are interlinked through real and virtual objects and processes. This phase is featured as a deep interdisciplinary integration of technologies in digital, physical and biological world [22]. Manufacturing industry also belongs to those sectors which are basically changing in all of their component systems as new paradigms are consolidating (e.g. additive manufacturing, nanotechnology, cloud based manufacturing) and the integration of subsystems is becoming crucial for interoperability. The European Commission has launched an initiative named "Digitising European Industry" which focuses on speeding up the standardization on five priority areas: 5G, cloud computing, internet of things – IoT, data technologies and cyber-security [4]. In USA the National Science Foundation released a call on "Cyber physical Systems" in December 2016 that covers, among others, the research areas of IoT, CPS Security and Privacy, Real-time Control and Adaptation and Manufacturing [18]. The high-tech ICT-based strategic program of the German government, called "Industrie 4.0", primarily focuses on manufacturing and describes the up-to-date automation and data exchange in manufacturing technologies, including Cyber-Physical Systems (CPS), Internet of Things (IoT) and Cloud Computing (CC). According to a statistics from Weins [26], the 95% of US firms use CC technology, while the applications of Cloud-based Manufacturing (CM) are trying to make use of CC technology by mirroring its service orientation and deployment approach. The Industrial Internet Reference Architecture (IIRA) and the Reference Architectural Model Industrie (RAMI 4.0) are two of the major standardization frameworks for industrial Internet architectures, which aim at extending industry interoperability through a high level of abstraction and common use case characteristics (in the case of RAMI 4.0 also by providing features and patterns derived from the manufacturing domain). The aim of this paper is to show how both technologies share conceptual similarities in modelling distributed industrial services, and also how their integration feasibility finds relevant affinity in the specification of OPC Unified Architecture (OPC UA), as one of the possible candidate architectures for IIoT-based service standardization [7]. The paper finally presents a case study containing the preliminary architectural of a prototype smart factory.

2. Motivations and related work

Based on opinions of industrial experts in cloud environments, the

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greatest challenge facing longer-term adoption of CC might not be security, but rather interoperability and data portability [27], due to the exponential growth of Internet-connected devices involved in new business models [5]. Industrial Internet Consortium and "Plattform Industrie 4.0" in March 2016 announced common efforts to align RAMI 4.0 and IIRA but they did not agree on an ultimate solution. Today CM interoperability is in the focus of current research topics and this paper aims at showing that Industry 4.0 (I4.0) service standardization is not a mere problem of communication and protocols but taking into consideration interoperability already starts at design level: this permits to realize a significantly higher flexibility and adaptability of production systems. I4.0 is all about information and data exchange: between people, machines, materials and systems. But while standardization is indispensable in communication, machines and systems should be helped in interpreting the meaning of the communication and that is where interoperability comes in: interoperability is about the meaning of the contents of exchanged data.

Several papers can be found in literature in this field but their argumentations are not fully in scope with the ones presented in this paper. In Gøtze [6], for example, a major attention is given to RAMI 4.0, recalling that possible generalization of reference architectures is not an I4.0 specific topic as it has always seen important attempts in industry starting from the early 1990s. In Uslnder and Epple [23] authors essentially focus on RAMI 4.0 and its nature of service oriented architecture (SOA). In Pai [20] author provides an interesting comparison of both architectures but this description is customized to specific application of the industrial assets.

On the other hand, this paper's specific contributions aim at:

- presenting general indications of functional mapping between IIRA and RAMI 4.0;
- highlighting a modelling link for interoperability between the concepts of digital twin in IIRA and the Administration Shell in RAMI 4.0 (RAMI 4.0 AS);
- providing evidence of the affinity between RAMI4.0 AS and OPC UA (as a possible candidate to bridge I4.0 service infrastructure) in modelling the underlying physical environment;
- establishing a development pattern for interconnected physical components and services in I4.0 manufacturing architectures.

3. Cloud, cloud manufacturing and factories of the future

The future of manufacturing will probably depend on the conceptualization of new architectures, which cannot be handled in a traditional manner as smart devices, or in general smart-X-objects (including humans), smart connected assets intend to communicate directly with each other. The development of new interaction models will be the crucial aspect of future production strategies.

3.1. Cloud characteristics and deployment models

CC is in general an IT architectural model where computing services (both hardware and software) are abstracted and delivered to customers over the Internet, on-demand, in a self-service fashion, independent of device and location [15]. Cloud model embodies unique characteristics and can have various service and deployment models: while service models are typically an end-user's perspective in CC industry, different delivery models refer to different layers of the CC architecture. The most common form of CC is Software as a Service (SaaS), in which the application runs on the vendors infrastructure and is recognized as a service. The consumer is unaware of the application providers infrastructure and complexity. A Platform as a Service (PaaS) facilitates the development of applications without the cost and complexity of buying and managing the underlying hardware and software layers, like operating system, network, and servers, and development tools. Infrastructure as a Service (**IaaS**) offers also storage, network and computational capabilities as a service.

Container as a Service (CaaS) is a form of cloud-based virtualization in which so-called container engines, orchestration and the underlying computing resources (application, operating system dependencies, libraries, and so forth) are delivered to users as a service from a cloud provider. Serverless computing (or Function as a Service – FaaS) is the highest technology level today, where the whole application, with all of its business logic, is implemented as functions and events at cloud level. Manufacturing specific Hardware as a Service (HaaS) is a technique for consistently describing and serving equipment and its functionality, behaviour, structure, etc., and represents one of the major challenges in service implementation description of core physical equipment in the context of Manufacturing as a Service (MaaS). Cloud in manufacturing is expected to provide a solid support for service-oriented environments, simulations and global services. For a comprehensive list of key players in the CC industry can be found in Marston et al. [15].

Essential properties of cloud-based systems can be classified according to Xu [29], Zissis and Lekkas [33], and Wang and Xu [25] into core, business, enterprise and manufacturing clouds. Resource abstraction, self-service-centricity, rapid elasticity, multi-tenacity, load-balancing and virtualization are basic characteristics of CC. Business-relevant properties comprise quality-of-service, service level agreement, user experience, fault-tolerance, auditability and certifiability. At an enterprise level, interoperability, deployment models, security and business process management increase the complexity of CC requirements.

Cloud hosting deployment models are mainly distinguished by the proprietorship, size and access and are classified in *public* cloud (the cloud owner provides Internet-based public services on predefined rules, policies, and a pricing model); *private* cloud (benefits of a public cloud but decreased security concerns as used "in-house" by the company); *community* cloud (organizations having similar requirements and concerns share the CC and a third-party service provider is responsible for providing the required infrastructure of the CC); and *hybrid* cloud (a combination of two or more different public, private, or community clouds). In hybrid clouds business- and mission-critical services and sensitive data are kept unpublished, while non-critical services are published for others to share and use. Illustration in Fig. 1 depicts common cloud deployment models with service-critical instantiation orientations.

Besides obvious benefits of CC there are still significant barriers for its adoption; e.g. according to Zissis and Lekkas [33] and Lee [12]: mission-critical services in enterprises need to be locally reinforced, in order to ensure continuity in the execution of business processes. Consulting companies reported how current cloud services may not be cost-effective for larger enterprises which have achieved best efficiencies from their own computing infrastructure [1].

3.2. Cloud standardization

Cloud service providers usually have own approach on interactions and cloud-APIs required to users but complex applications on the cloud require adequate standards, in order for organizations to consolidate their IT systems in the cloud and realize productivity increase. To-day more than 15 different groups, committees and organizations have established a Wiki site for Cloud Standards Coordination [3], whose goal is to document activities from various Standards Development Organizations (SDOs) and leading technology. In general, there are different major approaches to solve interoperability challenges in networked enterprises: *integrated* - a common format for all models; *unified* - common format at meta-level and mapping between models; and *federated*. Our scope addresses the federated one, in which no common format exists and partners have to share ontology to map concepts at semantic level. The detailed description of the above methods can be found e.g. in Chen et al. [2]. Trend and issues for enterprise integration and interoperability in manufacturing systems are presented in detail in

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