A Cloud-Based Infrastructure to Support Manufacturing Resources Composition

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Abstract. Current development in emerging technologies, such as the Internet of Things (IoT), service-oriented and high-performance computing combined with the increasing advancement of manufacturing technologies and information systems, triggered a new manufacturing model. Modern industrial automation domain is characterized by heterogeneous equipment encompassing distinct functions, network interfaces and I/O specifications and controlled by distinct software/hardware platforms. To cope with such specificity, manufacturing enterprises are demanding for new service-oriented models that aimoc to abstract physical systems in terms of their functionalities/capabilities. In this scenario, Cloud Manufacturing (CMfg) arises as a new networked, service-oriented, customer centric and demand driven paradigm where manufacturing resources and capabilities are virtualized as services available in the cloud to users.

Keywords: Cloud Manufacturing, Service-oriented Architecture, Service Composition, Device Profile for Web Services

1 Introduction

Nowadays, manufacturing companies are more and more concerned with meeting the dynamic requirements imposed by the globalization [1]. Researchers and industry practitioners are striving for constant improvements and innovation in the business processes as a necessary condition for keeping the manufacturing companies competitive in market sharing [2]. In this scenario, the combination of new emerging technologies and paradigms such as IoT, Machine-to-machine (M2M), Cloud-computing/manufacturing, service-oriented architecture (SOA), service-oriented computing (SOC) together with the wider dissemination of information technology (IT) are driving powerful and, above all, new business opportunities for manufacturing enterprises. As deeply exposed in [3], for many years, business infrastructures has been mainly focused on connecting IT systems within the business environment. However, there are many businesses that are characterized by thousands of heterogeneous and geographically distributed devices deployed across the enterprise which are generating and consuming data and are isolated/separated from the enterprise IT backbone. This is particularly true in the manufacturing domain where the production processes are typically known for their plethora of heterogeneous equipment encompassing distinct functions, form factors, network interfaces and I/O specifications supported by different software and hardware platforms [4]. Today, mostly manufacturing enterprises have their operation technologies (OT) separated from the IT backbone infrastructure implying that the data generated by the field equipment is rarely used within business. As stated in [3], the business leaders of today are becoming more and more conscious about the possibilities and opportunities of gaining access to this data. In particular, data can be used for identifying important production events, predicting market fluctuations, savings costs and/or improving the overall quality of the products while optimizing their production processes. Furthermore, the rapid convergence of OT and IT – triggered by the proliferation of plant-floor Ethernet, smart devices, sensors networks, local computing solutions and network technologies – is rapidly changing the way the data can be used by enabling from one side the transformation of information into insight and from the other side extending the reach of the business [3][5]. In this context, cloud-based systems enable manufacturing enterprises to improve data management even further and move performance and profitability to a level once thought impossible while accommodating operational spikes more easily, procuring manufacturing resources when needed – and only when needed, on demand and as shared resource [6].

Finally, the introduction of cloud-based system in the world of manufacturing production systems can bring into the game the necessary degree of dynamicity and capability to change to enable enterprises to survive in current dynamic environment, i.e. to be able to respond to competitive challenges and to sustain their competitive advantage in order to reach the success [7].

2 Contribution to Cloud-based Engineering Systems

The embedded technology progresses are promoting the transfer of more complex functionalities – currently hosted on powerful back end systems – in the world of manufacturing resources at shop floor level [2]. This technological revolution is radically changing the way production systems are designed and deployed, as well as, monitored and controlled. The dissemination of smart devices inside production processes confers new visibility on the production system while enabling for a more efficient and effective management of the operations. Taking advantage of the current technological trends, CMfg aims to integrate manufacturing resources into the cloud manufacturing services in order to expose them as a service to the users [8]. The binomial manufacturing resource/service will push the entire manufacturing enterprise visibility to another level while enabling the global optimization of the operation and processes of a production system and – at the same time – supporting its accommodation to the operational spike easily and with reduced impact on production. The present work implements a cloud-based infrastructure for achieving the resource/service value-added i.e. to facilitate the creation of services that are composition of currently available atomic services. In this context, manufacturing resource virtualization (i.e. formalization of resources capabilities into services accessible inside and outside the enterprise) and semantic representation/description are the pillars for achieving resource service composition (RSC). In conclusion, the present work aims to act at the manufacturing resource layer where physical resources and shop floor capabilities are going to be provided to the user as SaaS (Software as a Service) and/or IaaS (Infrastructure as a Service).

3 Supporting Concepts

3.1 Cloud Manufacturing

CMfg is a new paradigm where manufacturing resources and capabilities are virtualized as services available in the cloud to users. This concept was firstly proposed by [9] with the intent to transform the manufacturing business into a new paradigm where manufacturing resources (i.e. physical devices, machines, products, processes, etc.) are transformed into cloud entities. This transformation is also called virtualization and enables for full sharing and circulation of virtualized resources that are capable of providing fundamental information about their own status. This information can potentially be used for local and global optimisation of the whole lifecycle of manufacturing. The current work addresses this theme by presenting a cloud-based infrastructure that enables manufacturing devices virtualization, deployment and selection by users for dynamically assembling them into a virtual manufacturing solution.

3.2 Service-Oriented Architecture (SOA)

SOA paradigm has emerged and rapidly grown as a standard solution for publishing and accessing information in an increasingly Internet-ubiquitous world. SOA defines an architectural model aiming to enhance efficiency, interoperability, agility and productivity of an enterprise by positioning services as the building blocks through which solution logic is represented in support of realization of strategic goals [10]. The existence of Web Services technology has enabled and stimulated the implementation and development of SOAs. The application of SOA and Web Services in the context of manufacturing layer is still scarce, since a set of persisting technical challenges exists as pointed in [11]. SOA and Web Service are considered promising techniques for integrating all the existing layers within a manufacturing enterprise spacing from business to the physical process. The capability of encapsulating functions and tools as services through standard interfaces and protocols, enables their access and usage by clients without the need to know and control their specific implementations. All these aspects promote the SOA paradigm and its most used implementing technology (Web Services) as the *de-facto* standards for fast, secure and, above all, easy integration of any new functionality within existing software solutions while electing them as one of the pillars for implementing the CMfg paradigm.

3.3 Service Composition

Services are the building block of a SOA, they provide simple interactions between client and server provider. However, sometimes atomic services need to be straightforwardly combined and/or assembled in order to generate more complex ones rising the service abstraction as referred by [12]. In this scenario as argued in [13], the term service composition is referred to the process of developing a composite service. Moreover, a composite service can be defined as the service that is obtained by the composition of the functionalities of several simplest services.
Currently in the domain of SOA-based systems, two main approaches can be used for the service composition, namely [14]: orchestration and choreography.

3.4 Devices Profile for Web Services

The Device Profile for Web Services (DPWS) is a standard by the OASIS Web Services Discovery[1] and Web Services Devices Profile Technical Committee[2]. It defines two main elements: the device and the hosted services. The device element gathers all the meta-information about the attached physical device that is provided during the discovery activity. The hosted services gathers the main functionalities of the device. As explained in [15], the application of Web Services at device level implies significant improvements in both operational and development aspects while unifying the ICT protocols of a manufacturing enterprise by providing a single stack to communicate from device-level to MES or ERP level over Web Service technology.

4 Cloud-based Infrastructure

The proposed infrastructure (see Fig. 1) is composed by three main components/resources, namely: the *deployer*, the *cloud server manager* and the *client UI*.

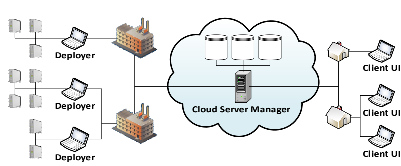

Fig. 1. Infrastructure Architecture

[1] http://docs.oasis-open.org/ws-dd/ns/discovery/2009/01
[2] https://www.oasis-open.org/committees/ws-dd/

These three components/resources are together responsible for:

1. virtualizing the manufacturing resources available in the physical system in terms of capabilities and functionalities and deploying such virtualized resources in the cloud (cloud entities);
2. Exposing the capabilities/functionalities of the cloud entities for enabling their invocation by external users that are accessing the cloud in order to execute certain tasks on the physical system.

In the next sections, a detailed description of the developed components/resources is given.

4.1 Deployer

The *deployer* is the component/resource responsible to scan the network (i.e. the local network in which it is connected) searching for *DPWS*-enabled devices. Whenever a new device is encountered then the following tasks are executed:

- **Virtualization**: an abstract description will be associated to each device in order to transform the physical device into a cloud entity.
- **Deployment**: make the virtualized devices available on the cloud for allowing the users to invoke the functionalities/services hosted by the device according to their needs.

Taking into account these tasks, the architecture of Fig. 2 has been designed and implemented for the *deployer*. The proposed architecture is constituted by the following core task-oriented components:

- **Device Explorer**: it allows to search the network for available DPWS-enabled device.
- **Device Virtualization**: once a device is discovered this component extracts all the information from the device with the objective of creating a virtual entity with all the capabilities of the physical device.
- **Device Repository**: it is responsible to store all the information about the devices in the network and push it into the cloud. This information will be internally used by the Device Handler (whenever a new request comes from the cloud) and externally by the *server* component/resource.
- **Device Handler**: it is responsible to handle requests asking for the execution of some functionality that come from the cloud.

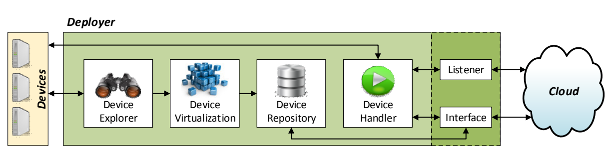

Fig. 2. Detail of the *deployer* architecture

4.2 Cloud Server Manager

The *cloud server manager* component/resource (see Fig. 3) is actually hosted into the Amazon Web Services[3] (AWS) free tier. This cloud provide a virtualized resources that enables the accessibility of the *cloud server manager* component/resource from everywhere while allowing the configuration of the storage and processing power according to the user needs. The *cloud server manager* component/resource provide two Web Service endpoint to permit from one side the communication with the *deployer* and from the other side the communication the *client*. Moreover, it includes a local database that is used to store all the information about the devices connected to the *deployer* and their related functionalities. Furthermore, the database also stores all the requests performed by the client using the *client UI* and all the responses to these requests performed by the *deployer*. Thereby, the *cloud server manager* is also responsible to guarantee the communication between *deployers* and *client UIs*.

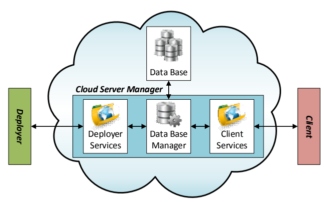

Fig. 3. Detail of the *cloud server manager* component/resource

4.3 Client UI

The *client UI* (User Interface) is a simple graphical form that allows the users connected to the cloud to both select the capabilities/functionalities that they need and to graphically compose them to create complex tasks to execute on the physical process. Therefore, the *client UI* is logically composed by two main components, namely: a graphical control that allows the creation of the composition of capabilities/functionalities and an internal engine that translates the graphical representation of the composite tasks into requests to be sent to the *cloud server manager*.

5 Experimental Setup

As proof of concept, the MOFA kit by Staudinger GmbH has been used. This educational kit simulates a flexible manufacturing system and is composed by four machines, a buffer area, a crane robot, local transporters (conveyors or tables) and sensors to detect product positions. The original control equipment was replaced by Inico[4] S1000 components. The S1000 is a smart remote terminal unit (RTU) capable

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[3] http://aws.amazon.com/free/
[4] http://www.inicotech.com/index.html

of real-time control, field data processing and web-based monitoring, programming and configuration tool. Moreover, it offers an embedded web server and implements a XML/SOAP interface based on DPWS standard. More details about the system used and its related monitoring and control solution can be found in [4].

The developed cloud-based infrastructure has been instantiated on the presented kit. The system configuration is presented in **Fig. 4**. The *deployer* is a local entity that will gather all the information about the physical devices (Inico S1000) connected and the capabilities/functionalities hosted. This information is passed to the *cloud server manager* that will expose it in order to be accessed and eventually requested by cloud users. Moreover, the *cloud server manager* also keep the information about the *deployer* localization. Finally, the *cloud UI* will provide a user interface where the user can pick the capabilities/functionalities he required and compose them to create a process plan.

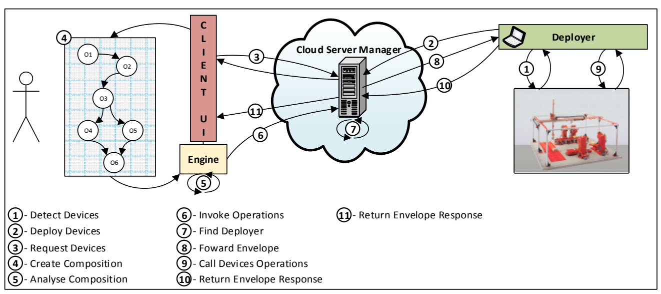

Fig. 4. Generic System configuration and workflow

For the time being, the focus of the present work was to provide an infrastructure capable from one side to transform manufacturing resources into virtualized cloud entities deployed into the cloud and, from the other side, to expose the resources capabilities in order to enable external users to create simple processes by combining the available capabilities (using the provided graphical tool).

6 Conclusions and Future Works

The present infrastructure provides a cloud-based manufacturing system where available manufacturing resources are virtualized as cloud entities and which capabilities/functionalities are exposed for enabling the creation of processes by composition of such capabilities/functionalities. During this work some fundamental pillars of the CMfg paradigm have been approached, namely: virtualization access, deployment into cloud and service encapsulation of physical manufacturing resources. The present work proves the feasibility of the CMfg paradigm if it is supported by smart/intelligent devices. Moreover, the implemented infrastructure provides a normalized layer where the typical heterogeneity of the automation domain is hidden into a generic semantic representation. Furthermore, since the solution is supported by open web standards it leaves the doors open for the integration of more internet-based solution such as Self-Learning solutions [16]. However, some improvements opportunities can also be found. First of all the integration of a more sophisticated graphical tool for service composition is required (BPMN, BPEL, etc.). Secondly, the semantic representation can be significantly improved by introducing ontologies (OWL, OWL-S, etc.).

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References

1. D. Wu, J. L. Thames, D. W. Rosen, and D. Schaefer, "Enhancing the Product Realization Process With Cloud-Based Design and Manufacturing Systems," *J. Comput. Inf. Sci. Eng.*, vol. 13, no. 4, p. 041004, 2013.
2. L. M. S. De Souza, P. Spiess, D. Guinard, M. Köhler, S. Karnouskos, and D. Savio, "SOCRADES: a web service based shop floor integration infrastructure," in *Proceedings of the 1st int. conference on The internet of things*, Berlin, Heidelberg, 2008, pp. 50–67.
3. L. Davidsen, "IBM MQ: Integrated messaging to connect your enterprise." IBM Corporation, 2014.
4. G. Candido, C. Sousa, G. Di Orio, J. Barata, and A. W. Colombo, "Enhancing device exchange agility in Service-oriented industrial automation," in *2013 IEEE International Symposium on Industrial Electronics (ISIE)*, 2013, pp. 1–6.
5. Rockwell Automation, "The Connected Enterprise Maturity Model." CIE-WP002-EN-P, 2014.
6. J. Katzel, "Power of the Cloud," *Control Engineering*, vol. 58, no. 12, pp. 16 – 21, 2011.
7. J. Jassbi, G. Di Orio, D. Barata, and J. Barata, "The Impact of Cloud Manufacturing on Supply Chain Agility," presented at the 12th IEEE International Conference on Industrial Informatics (INDIN'14), Brazil, 2014.
8. L. Zhang, H. Guo, F. Tao, Y. L. Luo, and N. Si, "Flexible management of resource service composition in cloud manufacturing," in *2010 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2010, pp. 2278–2282.
9. B.-H. Li, L. Zhang, S.-L. Wang, F. Tao, J. Cao, X. Jiang, X. Song, and X. Chai, "Cloud manufacturing: a new service-oriented networked manufacturing model," *Comput. Integr. Manuf. Syst.*, vol. 16, no. 1, pp. 1–7, 2010.
10. T. Erl, *Service-Oriented Architecture: Concepts, Technology, and Design*. Upper Saddle River, NJ, USA: Prentice Hall PTR, 2005.
11. L. Ribeiro, G. Candido, J. Barata, S. Schuetz, and A. Hofmann, "IT support of mechatronic networks: A brief survey," in *Industrial Electronics (ISIE), 2011 IEEE International Symposium on*, 2011, pp. 1791 –1796.
12. N. Kavantzas, D. Burdett, G. Ritzinger, T. Fletcher, Y. Lafon, and C. Barreto, "Web services choreography description language version 1.0," *W3C Candidate Recomm.*, vol. 9, 2005.
13. Hazenberg, *Meta Products. Building the Internet of Things*. Uitgeverij Bis, 2011.
14. K. Ashton, "That 'internet of things' thing," *RFiD J.*, vol. 22, pp. 97–114, 2009.
15. G. Candido, F. Jammes, J. B. de Oliveira, and A. W. Colombo, "SOA at device level in the industrial domain: Assessment of OPC UA and DPWS specifications," in *2010 8th IEEE International Conference on Industrial Informatics (INDIN)*, 2010, pp. 598–603.
16. G. Di Orio, "Adapter module for self-learning production systems," FCT-UNL, 2013.