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Software-Defined Cloud Manufacturing for Industry 4.0

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Abstract

Many of the world's leading industrial nations have invested in national initiatives to foster advanced manufacturing, innovation, and design for the globalized world. Much of this investment has been driven by visions such as Industry 4.0, striving to achieve a future where intelligent factories and smart manufacturing are the norm. Within this realm, innovations such as the Industrial Internet of Things, Cloud-based Design and Manufacturing (CBDM), and Social Product Development (SPD) have emerged with a focus on capitalizing on the benefits and economies of scale provided by Internet Protocol (IP) communication technologies. Another emerging idea is the notion of software-defined systems such as software-defined networks, which exploit abstraction and inexpensive hardware advancements in an effort to build more flexible systems. Recently, the authors have begun considering how the notion of software-defined systems might be harnessed to achieve flexible cloud manufacturing systems. As a result, this paper introduces the notion of Software-Defined Cloud Manufacturing (SDCM). We describe a basic SDCM architecture based on leveraging abstraction between manufacturing hardware and cloud-based applications, services, and platforms. The goal of SDCM is to advance Cloud-Based Manufacturing and other Industry 4.0 pillars by providing agility, flexibility, and adaptability while also reducing various complexity challenges.

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Keywords: Industry 4.0; Software-Defined Manufacturing; Cloud Manufacturing, Operationan Technology, Industrial Internet, Internet of Things

1. Introduction

Many of the world's leading industrial nations have invested in national initiatives to foster advanced manufacturing, innovation, and design for the globalized world. Much of this investment has been driven by visions such as Industry 4.0, striving to achieve a future where intelligent factories and smart manufacturing are the norm. Within this realm, innovations such as the Industrial Internet of Things, Cloud-based Design, Cloud-based Design & Manufacturing, and Social Product Development have emerged with a focus on capitalizing on the benefits and economies of scale provided by Internet Protocol (IP) communication technologies.

Over the past five years, we have investigated ways of integrating cloud-based systems and social networking into the design and manufacturing space [1-5]. Recently, we have been investigating the idea of Software-Defined Cloud Manufacturing (SDCM). SDCM seeks to advance cloud-based manufacturing by introducing a hardware-software abstraction layer between manufacturing hardware and cloud-based applications, services, and platforms. The ideas underlying SDCM are inspired by other software-defined systems such as software-defined networks [6]. The overarching objective is to provide more generic and reconfigurable hardware systems that are open and easily modified at the software level.

In this paper, we set the stage by providing a very brief overview of the Industry 4.0 vision and some of its associated pillars. The paper then introduces the ideas underlying software-defined systems along with a basic architecture of software-defined cloud manufacturing. The paper concludes

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with a discussion of future work and long-term research objectives along with an outline of potential opportunities and challenges associated with software-defined manufacturing.

2. Industry 4.0 and Smart Manufacturing

Industry 4.0 is sometimes referred to as the 4th industrial revolution, and it is a vision of smart factories built with intelligent cyber-physical systems. It will enable manufacturing ecosystems driven by smart systems that have autonomic self-properties, for examples self-configuration, self-monitoring, and self-healing. Industry 4.0 will allow us to achieve unprecedented levels of operational efficiencies and accelerated growth in productivity. New types of advanced manufacturing and industrial processes revolving around machine-to-human collaboration and symbiotic product realization will emerge.

Industry 4.0 will encompass numerous technologies and associated paradigms. A few of these emerging paradigms include the Industrial Internet of Things, cloud-based manufacturing, and social product development. A brief overview of these paradigms is provided in the following sections.

2.1. Industrial Internet of Things

One of the most significant collections of technology that will contribute to Industry 4.0 and smart manufacturing is the Industrial Internet of Things (IIoT). The IIoT is a new revolution resulting from the convergence of industrial systems with advanced computing, sensors, and ubiquitous communication systems. It is a transformative event where countless industrial devices, both old and new, are beginning to use Internet Protocol (IP) communication technologies.

The Industrial Internet of Things is a subset of what we have come to know as the Internet of Things (IoT). The IoT is an abstract idea that captures a movement that started when we began integrating computing and communication technology into many of the “things” that we use at home and work. It started with the idea of tagging and tracking “things” with low cost sensor technologies such as radio frequency identification (RFID) devices. However, the paradigm shifted as the market began delivering low-cost computing and Internet-based communication technologies, simultaneously with the rise of the ubiquitous smartphone. This perfect storm of low cost computing and pervasive broadband networking has allowed the IoT to evolve. Now, the IoT includes all types of devices ranging from home appliances, light bulbs, automation systems, watches, to even our cars and trucks. Technically speaking, the IoT is a collection of physical artifacts that contain embedded systems of electrical, mechanical, computing, and communication mechanisms that enable Internet-based communication and data exchange.

The Industrial IoT follows the same core definition of the IoT, but the things and goals of the Industrial IoT are usually different. Fig. 1 illustrates the Industrial IoT at a simplified level. Some examples of the ‘things’ of the Industrial IoT include devices such as sensors, actuators, robots, manufacturing devices such as milling machines, 3D-printers, and assembly line components, chemical mixing tanks, engines, healthcare devices such as insulin and infusion pumps, and even planes, trains, and automobiles. Indeed, it is a vast spectrum of devices.

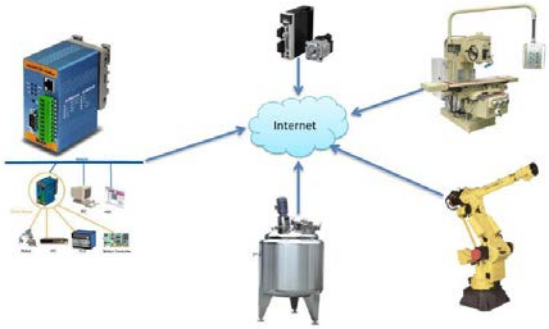

Fig. 1. Abstract idea of the Industrial Internet of Things.

Another term commonly used when discussing the Industrial IoT is operational technology. Operational technology (OT) refers to the traditional hardware and software systems found within industrial environments. Some examples include programmable logic controllers (PLC), distributed control systems (DCS), and human-machine interfaces (HMI). These systems are also known as Industrial Control Systems (ICS) because they “control” the various processes that occur within an industrial environment. These traditional control systems are rapidly beginning to use Internet-based communication technologies so that they can be integrated into manufacturing organizations’ information technology (IT) systems and infrastructures. This OT/IT integration movement is currently happening in large scale across numerous industries, and it provides a technological alignment with the needs of future smart manufacturing systems and Industry 4.0 [12,13].

2.2. Cloud-based Manufacturing

Cloud-based manufacturing (CBM) is another rising paradigm that will contribute significantly to the success of Industry 4.0. CBM can be described as a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable cyber-physical production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource allocation in response to variable-demand customer generated tasking [7-9]. Characteristics of CBM include networked manufacturing, scalability, agility, ubiquitous access, multi-tenancy and virtualization, big data and the IoT, everything-as-a-service (e.g., infrastructure-as-a-service, platform-as-a-service, hardware-as-a-service, and software-as-a-service), scalability, and resource pooling.

A similar paradigm to CBM has become known as cloud-based design and manufacture (CBDM) [4]. CBDM refers to a more comprehensive view of the product realization process