Chemical Technology, Control and Management

Volume 2018
Issue 3 *SPECIAL ISSUE 4-5*

Article 5

10-19-2018

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Recommended Citation

Ovsiannikov, Michail V.; Podkopaev, Serguey A.; and Tarassov, Valery B. (2018) "Cloud system of pilot production management based on internet of things.," *Chemical Technology, Control and Management*: Vol. 2018 : Iss. 3 , Article 5.
DOI: https://doi.org/10.34920/2018.4-5.19-23
Available at: https://uzjournals.edu.uz/ijctcm/vol2018/iss3/5

ISSN 1815-4840
CHEMICAL TECHNOLOGY. CONTROL AND MANAGEMENT
2018, Special issue №4-5 (82-83) pp.19-23. https://doi.org/10.34920/2018.4-5.19-23
International scientific and technical journal
journal homepage: https://uzjournals.edu.uz/ijctcm
Since 2005

CLOUD SYSTEM OF PILOT PRODUCTION MANAGEMENT BASED ON INTERNET OF THINGS

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Abstract: *Some theoretical background of Industrial Internet and Cloud Computing opening new era in industrial automation is considered. A prototype of cloud system for IoT-enabled production management is presented. Its first version is based on Denford's equipment for manufacturing education and SAP HANA Cloud Platform. Main functions of cloud production management system are discussed. An architecture of «Denford-BMSTU» CIM system is shown. Basic components of SAP HCP are analyzed to clarify its implementation. Communication protocols between CIM devices and cloud platform are noticed. Examples of dispatching production rules are given.*

Keywords: *Industrial Automation, CIM, Industry 4.0 Strategy, Production Management, Internet of Things, Cloud Computing, Dispatching Algorithms Cloud Manufacturing*

Introduction

Nowadays the hard competition in world markets forces to solve such problems as shortening time of product development and sale, improving the quality of design and manufacturing processes, reducing costs (direct capital, wages both in production and logistics units),minimization of environmental damage, etc. A new European initiative called «Advanced Manufacturing Technologies for Clean Production» [1] is aimed at a significant increase in productivity (speed of production development, quality of work, reduction of material consumption, energy saving, etc.) with a substantial improvement in the ecology of production. To achieve this goal, the European Union launched its biggest ever research and innovation program, Horizon 2020 [2], with nearly €80 billion of funding available over seven years (2014–2020). Under Horizon 2020, the new contractual public-private partnerships on Factories of the Future will contribute to manufacturing innovations. Among them, the arrival of *Cloud Manufacturing* – a new manufacturing paradigm and model, based on Internet of Things (IoT), Cloud Computing, Virtual and Service-Oriented Technologies, is of special concern [3,4]. It transforms manufacturing resources into services that can be comprehensively shared and circulated.

The idea of connecting all kinds of technical objects and devices to the global network is called the Internet of Things [5,6]. According to Kevin Dallas, Microsoft Vice-President, responsible for AI, IoT and Intelligent Cloud Business Development, the idea of the IoT has existed for many years, but for its implementation there was not enough one link – the cloud.

The objective of the paper consists in presenting a prototype of cloud-based system for IoT-enabled production management. The pilot version of this production & research system based on flexible manufacturing equipment provided by Denford [7] and SAP HANA Cloud Platform (SAP HCP) [8] has been developed at CIM Department of Bauman Moscow State Technical University.

1. Some Theoretical Prerequisites

1.1. From Internet of Things to Industrial Internet

The Internet of Things refers to a network of networks in which various objects are embedded with electronic sensors, actuators, or other digital devices so that they can be networked and connected for the purpose of collecting and exchanging data (Figure 1).

In the manufacturing sector, the IoT changes processes and products: smart objects and machines have the opportunity to communicate with the participants of product's lifecycle (including people, robots and intelligent machines) at all stages that allows to track changes and correct processes in a real time.

In various industries, control and automation for lighting, heating, machining, robotics and remote monitoring can be achieved by IoT [9].

*Figure 1. **Internet of Things as Network of Networks***

This emerging industrial revolution requires a smart production management system to enable both manufacturing process modifications and new models of integrated logistics. Such processes blur the traditional boundaries between industries, creating many complex inter-relationships.

Generally, IoT offers connectivity of physical objects, systems, and services, enabling object-to-object communication and data sharing. Here any object or thing is equipped by a special device for accessing the network and has a dedicated IP-address. A key technology in IoT is the automatic identification (auto-ID) technology [5], which can be used to make smart objects.

In case of Industrial Internet, M2M connection provides a direct communication between machines or devices by using some channel together with wired or wireless networks. Such M2M communication can include industrial instrumentation enabling a sensor or meter to transmit the obtained data to application software that can use it.

The communication between various heterogeneous objects and devices having different operation principles and controlled parameters remains a rather difficult task even for a small number of such devices. It is evident that for a great number of these devices this task becomes much more complicated. The use of special cloud services providing necessary functionalities seems to be a suitable solution for IoT industrial promotion.

1.2. On Some Principles and Models of Cloud Computing

National Institute of Standards and Technology (NIST, USA) has suggested the following definition [10]: «Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, services, storages and applications) that can be rapidly provisioned and released with minimal management effort or service provider interaction». The cloud model includes five basic characteristics, three service models and four deployment models.

The following five cloud characteristics are considered in [10]: 1) broad network access; 2) on-demand self-service; 3) resource pooling; 4) rapid elasticity; 5) measured service.

Here broad network access means that various capabilities are available over the network and accessed through standard mechanisms promoting the usage by heterogeneous thin or thick client platforms (e.g. mobile phones, tablets, laptops, and workstations).

In the context of on-demand self-service, the consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

Moreover, the computing resources are pooled to serve multiple consumers by using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources (storage, processing, memory, network bandwidth).

Besides, computing capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

Finally, resource usage can be monitored and reported, providing transparency for both the provider and consumer of the utilized service.

Three service models are: a) Software as a Service; b) Platform as a Service; c) Infrastructure as a Service. Deployment models encompass private cloud, community cloud, public cloud and hybrid cloud.

Such technologies as grid-computing, virtualization, service-oriented architectures (SOA) can be viewed as predecessors of cloud computing. In particular, cloud computing extends SOA-applications.

2. Main Functions of Cloud-Based Production Management System

Denford CIM System [7] includes milling and lathe cell (CNC Machines, Manipulator Robot and Drive), Conveyor, Automated Storage and Retrieval System (ASRS) with stacker, *Coordinate Measuring* Machine (CMM) (Figure 2). The system has been designed as a three level hierarchy, from the machine tools on the shop floor at the bottom level, up to the system supervisor the Host computer at the top. This structure was chosen since it allows effective delegation of responsibilities from the top down and timely feedback of relevant information from the bottom up.

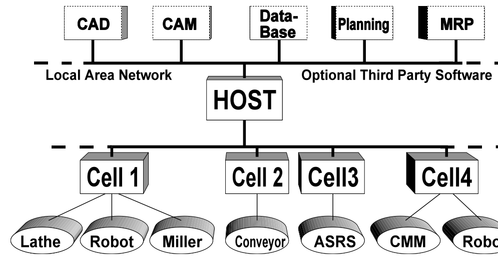

Figure 2. ***Architecture of Denford CIM System***

The basic functions of management system are the following ones: 1) remote control of production equipment, realization of SCADA-system functions in a cloud platform; 2) flexible equipment configuration to solve specific manufacturing problems; 3) real-time monitoring of manufacturing processes; 4) inspection of equipment state (including sensor data processing and geo-positioning; 5) big data processing in a cloud platform; 6) user-software interfaces; 7) interaction with MRP, CAD/CAM/CAE, MES.

3. Cloud-Based Management System for «Denford-BMSTU» FMS and Its Implementation

SAP Hana Cloud Platform (SAP HCP) [8] is a Platform viewed as a Service (PaaS) to create new applications or extend existing applications in a secure cloud computing environment managed by SAP. This platform contains the following basic components: a) Remote Devices Management Service (RDMS); b) Message Management Service (MMS); c) Runtime Software Modules (Servlets) implementing the business logic of managing processes or solving various kinds of computational problems; d) the Internet of Things Service Cockpit enabling an easy network access to various services. It offers API to register various devices and their data types.

A special SAP IoT Service is responsible for working with external devices in SAP HCP. Being a part of SAP HCP, it serves a link to work with external data sources and actuators.

A general scheme of interaction of the SAP HCP platform with external devices by using the SAP IoT Service is given in Figure 3.

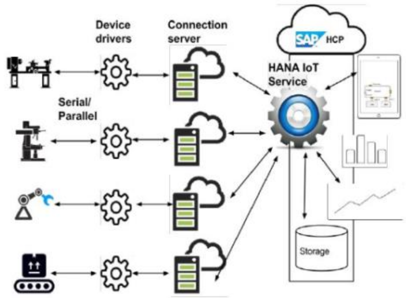

Figure 3. ***Communication of SAP HCP Platform* with external devices by using Hana IoT Service**

Devices may differ one from another by their architecture, hardware implementation, software languages, as well as variants of operating with SAP HCP. The most common hardware implementations of devices are microcontrollers, single board computers (like Raspberry Pi) and usual PC.

A database is presented in the cloud together with Java-applications that have access to it. Also HTML-applications with user interface are available in order to provide the opportunity of controlling the system through a normal web browser from anywhere [8,10].

Control computers (CC) communicating directly with the equipment are connected to the cloud. The purpose of the control computer is to perform two-way interaction of the cloud part with the equipment. On the one hand, the control computer must receive commands from the cloud, convert them into a sequence of control actions, and send control actions directly to the equipment by using standard protocols. On the other hand, the CC has to specify the state of the equipment, convert the information into special information structure and send it to the cloud part.

The control computer is linked to the SAP HCP via a secure connection using the WebSocket protocol. To differ from HTTP, this protocol eliminates the need for device to have a static IP address. In some cases, it removes significant limitations in the topology of the information network and may considerably speed up the process of system deployment.

The single boarded computer Raspberry Pi 3 is used as the control computer. It plays the role of a link between the cloud and production equipment. On the Raspberry Pi 3 boards a special Python script is launched that solves the problems of equipment control and obtaining feedback on equipment state.

The protocols used in the project are selected on the basis of the «Denford-BMSTU» FMS, the equipment is controlled through COM-port by employing RS-232 protocol. Software control of the port is performed with using the Pyserial Python library. Data on the current state of the equipment (is it busy or vacant) is obtained through the general-purpose input/output interface (GPIO) on the Raspberry Pi 3. Software control of the interface is carried out by using the RPi.GPIO library for Python.

4. Implementing Dispatching Algorithm for Denford-BMSTU FMS

First of all, we need to investigate FMS operational management. It is necessary to determine at what level (actuator, unit of equipment, production module or the whole system) we have to effectively implement management functions in a cloud platform

The use of decentralized dispatching concept means that most of the functions are implemented in the management system of the flexible production module. A main difference with respect to centralized system consists in the possibility to organize the communication between modules without any central dispatching system. All the dispatching functions are performed by the modules themselves. Here any module analyzes its proper state, makes the requests to other modules for the resources it needs, analyzes the messages from other modules. Thus, applications and messages circulate in a decentralized system [11].

Here the dispatching system is organized as a classical intelligent system that includes data and knowledge base, inference engine and explanation facilities. The dispatching algorithm based on production rules has been constructed. These production rules give the opportunity to form the device control command depending on the system state.

The following initial assumptions have been used: 1) the manufacturing process in FMS is viewed as both an ordered set of main operations and a set of auxiliary operations; 2) these operations are characterized by three sets of feasible parameter values for FMS devices (before, during and after operation); 3) if a resource parameter value does not meet the constraints above, then a branch of the graph is constructed to modify the resource state (from current to required).

Some examples of production rules are given below.

1. If <Key.value = 0 & Key.number = 0 & Stacker_2.value = 0 & Stacker _1.number = 0 & Robot.value = 0 & Robot.number = 5 & Machine.number=0 & Machine.value = 0>, Then < Execute command 10>

2. If < command 10 is executed>, Then <Key.value = 1, Key.number = N>

3. If < Key.value = 1 & Key.number = 0 & Stacker_2.value = 0 & Stacker _1.number =0 & Robot.value=0 & Robot.number=5 & Machine.number = 0 & Machine.value = 0 >, Then < Execute command 13>

Such a simple algorithm provides the operation of FMS in one shift both in the presence of shift job and in case of its dynamic correction.

Conclusion

Some concepts, basic functions and architecture of cloud-based production management system have been presented in the paper. Both algorithms and software for connecting devices to the SAP HANA Cloud Platform have been considered. As a result, the first version of cloud-based management system has been developed that demonstrates technical feasibility of the whole innovative cloud manufacturing project.

The investigation is supported by SAP University Alliance and SAP Labs in the CIS. It is also granted by Russian Foundation for Basic Research, projects №17-07-01374 and №18-07-01311. Authors are grateful to their students and colleagues for valuable contribution to joint research work.

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