Conceptual Model of Digital Platform for Enterprises of Industry 5.0

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Abstract. The paper proposes conceptual model of advanced digital platform for adaptive management of enterprises within the next generation of digital economy in the upcoming era of Industry 5.0. It analyzes existing digital platforms and their limitations due to their centralized and hierarchical management style supported. The paper considers the concept of digital ecosystem as an open, distributed, self-organizing "system of systems" of smart services capable of coordinating decisions and automatically resolving conflicts through multi-party negotiations. It proposes classification of services to be provided by the introduced advanced digital platform and describes their functions. It substantiates the leading role of multi-agent systems as the basic software architecture and technology for developing applications managed by the introduced digital platform. The paper results are applicable to many modern industrial enterprises.

Keywords: Complex adaptive systems · Self-organization · Digital platform · Digital ecosystem · Multi-agent technology · Smart services · Resource management

1 Introduction

About decade ago, Industry 4.0 has manifested transition to the new era in manufacturing through integration and combining of innovations and advancements of modern digital technologies like artificial intelligence, big data and analytics, robotics, smart sensors, cloud computing, Internet of Things, cyber-physical systems and some others. Since that time, Industry 4.0 remains to be a flagship determining the main global trends in development of manufacturing systems. However, the landscape of modern IT-models, paradigms and control technologies accelerated by novel emergent applications has been changed rapidly, thus motivating researchers and practitioners to update some basic principles of Industry 4.0.

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The recently introduced concept of the "system of systems" is aimed to manage distributed processes of the subsystems in a coordinated way according to p2p principles. This actually means transition to network-centric production control model borrowed from military area, where lack of coordination and any delays can critically change the outcome of a military operation [1].

According to Industry 4.0 view, coordinated operation of digital networking enterprise is achieved via use of a software and communication infrastructure called also digital platform (DP). The main objective of this platform is to constitute, for the network components, common information and communication space as well as runtime environment. However, such view of DP looks too limited for the next generation of enterprises comprising of autonomous subsystems, which should be capable to proactive behavior, adaptive planning and on-line re-planning, communicating the enterprise units to employees. In fact, the enterprise should operate according to the well-known Deming cycle *"Plan-Do-Check-Act"* [2] in all the aspects concerning the enterprise activities.

Creating DP with such extended capabilities is the key issue of the next step of digital economy formulated as Industry 5.0. More specifically, the intended capabilities of digital enterprise DP are to unite enterprise subsystems into a common semantic information space and provide for them access to the rich set of reusable applied services intended to support for distributed resource planning and control in real time. DP of Industry 5.0 should also provide the networked enterprise units with the standard access to the cloud resources and services and to data perceived by external smart sensor networks.

The paper objective is to introduce and outline the architecture, basic functions and services of DP of enterprise that fits the requirements of Industry 5.0. Accordingly, Sect. 2 outlines the current R&D regarding to the enterprise DP issues. Section 3 explains the recently introduced concept of digital ecosystem as a conceptual framework for enterprise of Industry 5.0. Section 4 presents high-level view of architecture of DP in question and outlines the services that should transform production ecosystem to adaptive real-time resource management networked system of system fitting the requirements of Industry 5.0. Conclusion summarizes the results of the paper.

2 Related Research and Developments

Quite an extensive amount of information on models, architecture and software and hardware implementations of enterprise DP can be found in literature. However, most of them refer to Industry 4.0 and do not go outside the classical ERP- and BI-systems. For example, in current EU Horizon 2020 program, about dozen of projects deals with R&D concerning various aspects of enterprise DP of Industry 4.0 level. Short overview of these projects and their outcomes can be found in [3]. These projects focus on the role of DP as an integrator of knowledge and data of different enterprises composing B2B-manufacturing network to ensure their information and software compatibilities.

An architecture and basic functions of the advanced DP for a B2B production network compatible with the Industry 4.0 concept are proposed in [4]. In it, DP supplies the following basic services:

- communication service providing, for network nodes, communication channels for message exchange and routing supplies services of White and Yellow pages;
- support for network openness letting;
- support for ontology-based information compatibility of production network nodes;
- support for network node interaction protocols, in various use cases.

Among agent platforms, one should mention JADE (Java-Agent Development Framework). Due to the use of open source concept, many reusable software have been developed for it [5]. Moreover, there are exists real experience of use the JADE to implement DP for self-organizing agent networks [3,4]. However, the JADE plat-form, despite it is a product of industrial level, has several significant limitations preventing its use as a prototype of digital enterprise DP.

Our experience of developing industrial multi-agent systems [6] shows that existing platforms are lacking key components for providing enterprise-ready solutions.

But the main topic now is how to provide interaction and communication be-tween these systems of systems and what kind of services are required.

3 The Concept of Digital Ecosystem

The concept of digital ecosystem was introduced in [7]. According to Wikipedia, a digit role of transformer ecosystem is a distributed, adaptive, open socio-technical system with properties of self-organization, scalability and sustainability inspired from natural ecosystems. Digital ecosystem models are informed by knowledge of natural ecosystems, especially for aspects related to competition and collaboration among diverse entities [8]. It is worth to note that exactly the same necessary features were claimed in Sect. 1 for an enterprise of Industry 5.0 and therefore the latter can be viewed as a particular case of digital ecosystem, and enterprise DP – as a particular case of ecosystem DP. To be more precise, the enterprise DP should play the role transformer of a digital enterprise to the digital ecosystem of smart services. The ecosystem of smart services should hold the following basic new features:

- *Openness* - ability to introduce new services into ecosystem “on the fly”, with no stop or restart of it;
- *Distributed architecture* - ability of all services to operate autonomously, continuously, in parallel and asynchronously. The service calls can be initiated by either users, or by other services, or the calls can be initiated proactively by internal events generated depending on the system state, criteria values, and decision-making policy;

- *Adaptability* - the ecosystem ability to change its structure or functions in dynamic fashion in order to increase own efficiency, or, in a narrower sense, – the ability of ecosystem to adaptively respond to events via change of previous decision or adaptively revisit the existing plan due to change of situation;
- *Self-organization* - the ability of ecosystem of services to pro-actively create local connections and review them when the situation changes;
- *Service competition and cooperation* - the capability of the ecosystem service requester to choose among the services provided by different service suppliers.

In contrast to traditional closed hierarchical centralized and sequential systems for enterprise management, the considered enterprise ecosystem is built from autonomous intelligent component capable for proactive situation analysis and resource management, to interact on joint actions, to respond to incoming real-time events through on-line revisiting the current plans to achieve ultimate goals. Implementing of enterprise ecosystem with such features requires development of a fundamentally new DP.

4 Architecture and Services of Digital Platform

As a rule, ecosystem of smart services is composed of a large or even huge number of autonomous but relatively simple entities solving their tasks based on intensive interactions. It is common opinion that, for such class of systems, the multi-agent technology relying on distributed autonomous software agents situated within shared software, information and communication environments is the best framework, architecture and implementation technology. Accordingly, in the paper, this approach is accepted as the basic one for ecosystem of smart services. Additional argument in favor of such decision is that multi-agent community developed many standard architectural and software solutions that can be productively exploited for implementation of digital platform of ecosystem of smart services. For example, the FIPA abstract architecture proposes practically ready solution for implementation of some system services constituting the software and communication environment (infrastructure) of DP in question. It proposes a number of standard protocols supporting for virtual market self-organization techniques for resource planning and scheduling, e.g. Contract Net Protocol.

The developed architecture is illustrated in Fig. 1. In it, the services of the platform are divided into two groups. The first of them called "system services" implements the standard functionalities of FIPA-compliant agent platform constituting what is usually called software and communication agent infrastructure. The second group of services comprises application services. They play the roles of interfaces connecting the software and users with ecosystem smart services. Let us outline both sorts of services.

The FIPA abstract architecture [9] includes system services that can be exploited practically without change in the DP of the ecosystem of smart services (see Fig. 1). Let us motivate and outline the application services.

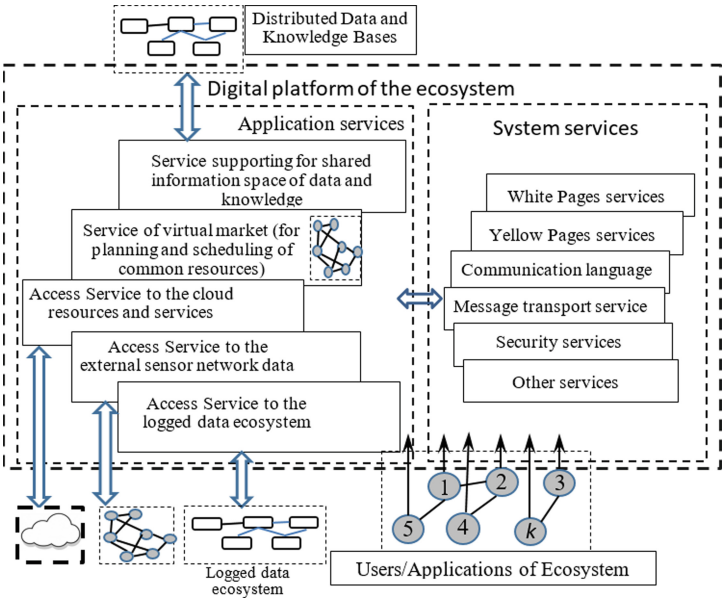

Fig. 1. Digital Platform of the ecosystem of smart services

1. *Service intended for integration of knowledge and data* into a shared semantic space ensuring unambiguous understanding of all terminology used in it with support for multi-aspect issue and integrity of data and knowledge. This service should monitor all the processes of data and knowledge creation, modification and usage to guarantee the unique and unambiguous understanding and use by all the software entities. Graph databases are considered as a primary candidate interacting with the data and knowledge consumers through this service.
2. *Virtual market service* of DP is the main resource planning and scheduling and deconfliction service. Specific feature of ecosystem DP, compared to MAS platform, is that DP usually runs in parallel a number of tasks that, at the same times, need the same resources and services, data from same sensor network, etc. Naturally, there will always be conflicts in competition for limited resources. However, a distinctive feature of digital production is the fact that all resources are of public availability. These services do not have particular owners, and therefore one of the key tasks of DP of production ecosystem of smart services is online planning of the resource allocation over a multitude of potential consumers.
3. *Service supporting for access to the logged data ecosystem.* Smart environment like ecosystem of smart services is the source of large quantity of valuable data, and one of the modern trends is creating a special data ecosystem containing data on every aspects of the environment performance [10]. Data ecosystem is a new challenge for DP of data-intensive ecosystem of smart

services, on the one hand, and a new opportunity to take advantage of the data to increase its intelligence. The main functionality of this service of DP is to enable data sharing between the systems of ecosystem in order to support semantic interconnections of them.

Other application services indicated in Fig. 1 are self-explaining and, thus, do not need additional description.

5 Conclusion

The paper presents the concept of digital ecosystem of smart services for digital enterprise and DP transforming the ecosystem into single whole. The latter should constitute a basis for managing the enterprise ecosystem in the upcoming era of Industry 5.0. The paper contribution concerns development of the DP architecture and services it has to provide. The efforts of the future research and development will be intended to the implementation of a proof of concept prototype of DP corresponding to the Industry 5.0 concept of digital production systems.

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