Current and future of software services in smart manufacturing

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Published online: 12 May 2020
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1 Introduction

Smart manufacturing, which is fundamental of industries, is to realize information-based manufacturing under the condition of ubiquitous perception for the whole lifecycle of products. Generally, the service-oriented smart manufacturing software not only includes industrial service based on CPS technology [TII, 1], which aims to realize the timely perception, flexible networking, intelligent processing, dynamic operation and other processing based on IoT equipment, but also involves enterprise dataspace [TKDE, 2], which acts as the carrier of obtainment, construction, analysis and application of information, so as to realize the integrated value-added logistics, information flow and value flow among enterprises, and better meet the multi-dimension needs of end-users.

2 Current supporting technologies of smart manufacturing services

Smart manufacturing system can be divided into two types of discrete manufacturing and process manufacturing. The objectives of smart manufacturing can be described as different indicators like time T (R & D time, manufacturing time, service response time, etc.), quality Q (product quality, installation quality, etc.), cost C (material cost, manufacturing cost, service cost, maintenance cost, etc.) and service S (procurement service, manufacturing service, after-sales service, operation and maintenance service, etc.). The implementation process of smart manufacturing covers small batch trial production, large-scale production, mass customization and other modes, which are often organized according to dif-

ferent processes centered on design, production, service and so on.

At present, there are three ways to implement smart manufacturing system: (1) existed automation systems expansion to realize a smart manufacturing system in a bottom-to-top pattern, which is represented by CPS technology; (2) Extern user demand-driven information transferring to construct a smart manufacturing system in a bottom-to-top pattern, which is represented by 3D printing technology; (3) comprehensive integration based on user demand and existing equipment automation systems in a pattern of top and bottom combination, which is represented by dynamic and flexible integration of industrial services.

Considering that comprehensive service integration is the main way to realize smart manufacturing at present, it can be divided into inner enterprise integration based on enterprise business systems, inter-enterprise integration based on industrial chain collaboration and wide area integration based on industrial services ecosystem. Here, the current main technologies and services are described from the aspects of architecture, data, function and interaction.

• The IoT information perception service based on edge computing

Edge computing [FGCS, 3] is the current manufacturing mode adopting distributed structure for distributed environment, which can flexibly expand the storage, computing and network capabilities on the edge side to achieve the business goal of real-time intelligent control. Edge computing nodes (ECNs) include intelligent devices, intelligent systems and intelligent gateways, which are used as services to complete the function matching of application scenario from operating system, functional modules and integrated development environment and other functional components, to construct an integrated enterprise operation environment. Furthermore, through the integration of different platforms and tool chain, the edge computing model library and vertical industry model library can provide the whole lifecycle manufacturing services that

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support development, integration, simulation, verification and release of products.

- **Data analysis service based on knowledge graph**

Constructing domain knowledge graph [FGCS, 4] can realize efficient and intelligent data analysis. Generally, when sensor data are collected by physical entity to form a dataflow, semantic annotation is thus added to transform data from different sources into general data format to construct virtual entity; then sensor data and domain data in dataflow are fused according to virtual entity fusion. Furthermore, through the machine learning framework, data analysis operation based on knowledge graph such as clustering, classification, association and regression can be realized according to diagnosis, prediction, decision-making and other manufacturing needs [SOCA, 5].

- **Function encapsulation service based on micro-services**

Encapsulating business functions as services is an important way to realize a web-based easy access and execution model in the network environment [EIS, 6]. Microservice architecture provides loosely coupled, bounded context service architecture to meet the independent deployment and update requirements of manufacturing functional systems. Through the encapsulation of manufacturing functions, each service has its own processing and lightweight communication mechanism, which can be deployed on a single or multiple server, providing a container and other carriers for the autonomy and independent operation of the manufacturing system, as well as a way to realize remote deployment and dynamic collaboration in the distributed environment. Furthermore, the process mining technology based on event log analysis [SOCA, 7] also provides support for the continuous governance of microservice applications.

- **Collaborative service based on semantic interoperability**

Semantic interoperability involves the combination of ontology theory, semantic technology, context awareness services and other technologies to support the integration and collaboration of manufacturing systems in dimensions such as information, function and resource. Collaborative manufacturing involves the semantic extension of services, the semantic fusion of multi-source heterogeneous services, and the semantic operation of services based on ontology and other domain knowledge driven by data, process or model, so as to support the manufacturing collaboration in the distributed network environment.

3 Future trends of smart manufacturing services

With the rise in industrial Internet and big data technology, Internet-based manufacturing has been strongly promoted. At present, smart manufacturing has made a lot of development in some certain areas or some functional applications, but there are often some deficiencies. In a general sense, there are problems such as lots of data but not intelligent, strong single module but a weak whole system, demonstration good but difficult to promote and so on. The fundamental problems come from the lack of domain model and related intelligent processing mechanism, which result in the difficulty of construction, implementation and migration of smart manufacturing system. The development trend of smart manufacturing services in the future is described from the aspects of computing architecture, processing mode, function combination and collaborative interaction.

- **Computing architecture combined cloud and edge service based on digital twin**

Digital twin [TII, 8] covers four dimensions of physical fusion, model fusion, data fusion and service fusion. It is the basic theory and key technology to realize the information physical fusion of digital workshop. In the environment of industrial Internet combined with cloud sides and edge nodes, the computing architecture of manufacturing services will be built based on the concept of digital twin, and the service architecture that embodies the interaction of multiple digital twin systems will become a research focus soon.

- **Knowledge reasoning service based on event evolutionary graph**

The event evolutionary graph describes the evolution rules and patterns between events, which is the knowledge base of dynamic activity-oriented reasoning developed from the knowledge graph. The diagnosis, analysis, prediction and decision making of manufacturing system based on the event evolutionary graph are an important way to construct intelligent processing mechanism of smart manufacturing in the future. It is important to establish the mechanism of information completion and likelihood reasoning on the basis of incomplete data and imprecise model.

- **Flexible services union based on community discovery**

With the popularization of manufacturing microservices in the industrial Internet environment, in order to adapt to the flexible manufacturing mode such as mass customization, the future manufacturing services will be based on the industrial Internet to carry out flexible self-organization, using group intelligent methods such as community discovery technology to realize the association matching and dynamic organization of functional equipment and related

services, so as to realize optimal resources allocation to achieve efficient manufacturing organization.

• **Dynamic cooperative service based on pragmatic interoperability**

Pragmatic interoperability is the extension and deepening of semantic interoperability, which not only involves the understanding and sharing of format and semantics, but also considers the specific content and runtime environment, and can better realize the service interaction and intelligent linkage in the Internet environment. It will become the main foothold of dynamic collaborative service in the future.

In general, the platform, data, function, interoperation and other aspects of smart manufacturing need to be serviced, which will be a booming research direction.

Acknowledgements This work was supported by the National Natural Science Foundation of China under Grant No. 61972243.

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