A framework for planning and scheduling shop floor logistics via cloud-edge collaboration

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Abstract. Under the autonomous production mode, the production and operation process of smart shop-floor is operated by manufacturing units themselves. This paper describes a new framework for the order-driven products processing based on cloud-edge collaboration, in which the production-logistics tasks are planned and scheduled by the manufacturing resources at the bottom of smart shop-floor. The key enabled technologies and roadmap are further pointed out. The core idea of autonomous production mode is the autonomous communication and collaboration through an industrial network between all physical resources during production in a shop-floor. It is intended to serve as a reference for the managers while handling the flexible production organization and management based on the dynamic customer requirements.

1. Introduction

Today's manufacturing industry is in an era of rapid social changes, economic waves and technological changes [1]. With the globalization and increasingly fierce market competition, there are increasingly high for users' demands in customized, personalized and diversified products. The new generation of information technologies, characterized by mobile and ubiquitous network interconnection, the Big Data, information processing supported by Cloud Computing and intelligent and personalized information services, are being widely and deeply penetrated and integrated into manufacturing technology [2]. The whole manufacturing industry has been changing its form and appearance, and then it is inevitable to realize the transformation from tradition manufacturing to smart manufacturing. Many countries have introduced corresponding policies or strategies to adapt to the trend, such as Industry 4.0, Industrial Internet, Future Factory, and Made in China 2025, etc [3].

In 2016, Ministry of Industry and Information Technology of China proposed in the smart manufacturing development plan that "Smart manufacturing is a new production mode with functions of self-perception, self-learning, self-decision-making, self-execution and self-adaptation". Many scholars have made a more detailed interpretation of the connotation of smart manufacturing. Tao’s team at Beijing University of Aeronautics and Astronautics focuses on the research of digital twin. They pointed out that one of specific challenges to achieve smart manufacturing with these strategies is how to converge the manufacturing physical world and the virtual world, so as to realize a series of smart operations in the manufacturing process, including smart interconnection, smart interaction, smart control and management, etc [4]. Ding built the interconnection and interoperability of a
physical shop floor and corresponding cybershop floor, and he further established a Digital Twin-based Cyber-Physical Production System (DT-CPPS), and then discussed configuring mechanism, operating mechanism and real-time data-driven operations control of DT-CPPS [5]. Mourtzis proposed a cloud based cyber-physical system for adaptive shop-floor scheduling and condition-based maintenance, and realized to deploy a cost-effective and reliable real-time data collection, processing, and analysis from the shop floor [6]. Alexopoulos presented an industrial Internet of things (IIoT) context-aware information system that provides decision support for mobile or static operators and supervisors [7]. From what has been discussed above, as the minimum implementation unit of smart manufacturing [8], shop floor manufacturing units are emphasized to improve their learning and cognitive ability due to the characteristics of autonomy and self-optimization for smart manufacturing. For manufacturing enterprises, depending on the application of emerging technologies such as sensor network, Internet of Things and Cyber-Physical System, the production process in the manufacturing workshops of enterprises becomes transparent, real-time, flexible and intelligent [9]. Facing the individualized and flexible product orders, smart manufacturing emphasizes the end-to-end digital integration of engineering and the horizontal integration of networked manufacturing systems through value networks [10]. It is necessary for the manufacturing shop floor to obtain the ability to realize the rapid response and communication interaction of a large number of real-time heterogeneous data by the requirement of large-scale personalized product manufacturing [11]. Shop floor resources should be able to independently and accurately make group production decisions by establishing a complete knowledge system. Based on cloud manufacturing equipment and big data analysis to meet the needs of customers' individual demands to the greatest extent.

However, the centralized production mode can no longer to meet the new requirements of the smart shop floor [12]. An autonomous production mode, in which manufacturing tasks are accomplished through autonomous communication and cooperation between wip and equipment, has become an inevitable trend. Specifically, in the manufacturing phase, all physical resources of the workshop (including equipment, work-in-process, auxiliary resources, etc.) are interconnected through the industrial network, and these resources are endowed with self-X intelligence by means of the IoT devices of the shop floor (such as self-perception, autonomous learning, self-organization, autonomous decision-making, autonomous control, etc) [13]. Workshop production planning and scheduling have transformed from centralized control to distributed and autonomous control. Therefore, autonomous manufacturing task orchestration of smart shop floors becomes an urgent problem to be solved in the field of smart manufacturing.

The rest of the paper is as follows: Section 2 constructs a framework of products processing based on cloud-edge collaboration. In Section 3, the key enabled technologies for autonomous production and operation control are discussed. Section 4 and Section 5 present the discussions and conclusions, respectively.

2. The framework

2.1. Autonomous production

The traditional shop floor production control and management is centralized and unified. When the orders arrive, the central control unit starts calculating instantly and assign production tasks to alternative machines. Faced with highly personalized product orders, smart shop floors are required to quickly respond to the transmission and communication interaction of a huge number of real-time heterogeneous data. Centralized production control and management mode can inevitably lead to slow transmission speed, crowded transmission channels, and inaccurate task assignment results. While autonomous production is a new mode, which realizes the production control and management through independent negotiation of all the manufacturing resources (e.g., machines, automated guided vehicle (AGV), work-in-progress(WIP), humans) in a shop floor. These manufacturing resources configured with RFID readers, sensors, and embedded devices so that they are connected with Industrial Internet of Things (IIoT) and are endowed with human-like self-X intelligence, as shown in
Figure 1. In this situation, production-logistics tasks integrated planning and dynamic scheduling becomes autonomous and distributed. After the production tasks are released in a shop floor, the alternatives machines and AGVs assess their current job capability and compete with each other for tasks to realize the production control and management in a shop floor.

![Image 1](image1.png)

**Figure 1.** Physical resources interconnection.

2.2. The framework of products processing based on cloud-edge collaboration

Figure 2 shows a framework for planning and scheduling shop floor logistics via cloud-edge collaboration, which integrates construction of IIoT, production-logistics task planning and dynamic scheduling. In the construction of IIoT, by configuring IoT hardware to shop floor physical resources, the edge nodes are set. And these nodes collaborate with each other and with the cloud node, then the core network is established. In the production-logistics task planning, the synergistic mechanism of production and logistics is first studied, and then the game theory is used to describe the bidding process of physical resources, so static process-level manufacturing tasks are planned. In the production-logistics dynamic scheduling, physical resources actively recognize the disturbance in the
production, on this basis, dynamic scheduling trigger mechanism is established. Then production-logistics real-time tasks are scheduling through autonomous decision making. Based on the above framework, a smart shop floor production and control system can be developed in order to realize the management of the production preparation phase and operation phase in an autonomous shop floor.

3. Key enable technologies

3.1. Cloud-edge collaboration-based shop floor IIoT configuration

In autonomous production mode, it is required to realize ubiquitous interconnection and intelligence of physical resources for an enterprise manufacturing shop floor, which is the basis of research on production-logistics task integration planning and dynamic scheduling. In the construction of IIoT, the cloud server and edge servers are set in different physical resources respectively. Specifically, RFID readers, inductors, sensors, and parameter measuring instrument are configured in machines, humans, WIP and AGVs to forms edge nodes, which can communicate and interact with each other. At the same time, these edge nodes communicate with cloud center through the core network, as shown in Figure 3. So the study begins with identifying the location attributes of machines, WIP, humans, AGVs, and other physical resources in the shop floor. And the heterogeneous resource distribution structure will be established. Embedded equipment and heterogeneous sensors are configured for these resources to realize the interconnection of the edge nodes of IIoT distributed network. Then, a scalable IIoT core network model is built based on Software-Defined Network (SDN), and the ubiquitous interconnection of edge nodes and the vertical interconnection between cloud serves and the edge nodes will be realized. On this basis, the operation mechanism of smart shop floor collaboration manufacturing network under autonomous production mode can be studied. And the autonomous communication and collaborative interaction mechanism of multi-nodes in the process of autonomous production operation can be established to support the data communication and interaction in product manufacturing.

3.2. Order-driven production-logistics integrated planning

In autonomous manufacturing, physical resources are bidding to achieve the integrated production-logistics planning, among them, both machines and AGVs are endowed with intelligence, so logistics factors must to be considered when studying task planning issues. Then, the implementation of manufacturing task planning becomes complex and uncertain. So the analysis of the factors affecting the steady-state operation of the smart shop floor is began in the first step. On this basis, the production operation mechanism in which the underlying heterogeneous resources compete with each
other can be established. Then the establishment method of production-logistics autonomous integrated bi-level programming model based on game theory can be studied, and the manufacturing resources self-decision production planning is realized.

3.3. Autonomous production-logistics process real-time monitoring and dynamic scheduling

During the production operation, i.e., in the manufacturing process of products, real-time information is required to sharing between different resources. Due to the fact that machines in shop floors are configured with RFID readers, sensors, and embedded devices, and they can interact with each other and with smart WIP, share real-time gathered data and commands with each other, and make collaborative decisions when the manufacturing system is disturbed. Therefore, we can establish the multi-source heterogeneous data association strategy by analysing the factors that produces the disturbance/anomaly. According to the historical manufacturing data, the equipment disturbance/anomaly in the manufacturing process is mined, the dynamic schedule prediction model of equipment disturbance/anomaly can be built, and the production-logistics process evaluation strategy oriented to the autonomous workshop can be generated. Then, the self-decision dynamic scheduling of manufacturing resources can be obtained.

4. Discussions

This paper positions the order-driven production based on cloud-edge collaboration under the autonomous production mode. The research contents of production-logistics integrated planning and dynamic scheduling of smart shop floors are listed emphatically. It has proposed the framework and key enabled technologies, but there are still some problems that need to be noticed and discussed:

(1) All the physical resources are configured with RFID readers, sensors, and other equipment to achieve the construction of the IIoT in shop floors. This approach has realized the transformation from traditional shop floor to smart shop floor. However, the cost will be much higher than that of traditional shop floor production. How to improve the efficiency of production under the novel architecture so as to ignore the high cost of input still remains to be studied.

(2) Many scholars have proposed the benefits of digital twin technologies to improve reliable and accuracy of products manufacturing. Through introducing digital twin technologies into the research contents of this paper to immediately acquire and process the real-time manufacturing data by the smart physical resources in the smart shop floor, which is worth deep study in future work.

5. Conclusions

Production planning and scheduling in shop floors is a traditional subject in machinery manufacturing. Many scholars have done a lot of research in this research and most of them hold the view of centralized control and management. However, the traditional approach is no longer applicable to highly personalized product orders, which may lead to slow transmission speed, crowded transmission channels, and inaccurate task assignment results.

To solve the above problems, this paper proposed a novel autonomous production mode. First of all, the framework for the order-driven production based on cloud-edge collaboration is proposed. Through analyzing the connotation of autonomous production, its operating mechanism is obtained. Then, the key enabled technologies of production and control of autonomous shop floors are discussed from construction of IIoT, production-logistics task planning and dynamic scheduling, respectively. Finally, some problems still need to be noticed are further discussed. It is respected that this paper will contribute to the promotion of smart manufacturing.

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