A case study of intelligent manufacturing for key components of vehicles

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Abstract. Currently, most research on intelligent manufacturing stays at the theoretical stage, which can enhance the understanding of smart factory concepts, but it is still difficult to establish a clear strategy for the industry. In this research, cyber-physical system (CPS) is applied to connect the manufacturing equipment of the production system, so as to develop the internet of things (IoT) object layer. Furthermore, a smart factory framework consisting of IoT object layer, CPS network layer, and CPS service layer is developed, connecting the smart shop-floor and the cloud service platform through the industrial network so as to implement the integration of physical manufacturing and virtual manufacturing. This framework is applied in the production of vehicle components, and the results show that the application of this framework in an actual automobile chassis smart factory can greatly improve production efficiency and energy efficiency, reduce enterprise costs, and shorten product development cycles, accelerating the process of enterprise transformation to informatization, digitalization, and intelligence. Since this framework for intelligent manufacturing has been verified under actual conditions, it can be taken as a reference for further development of the framework for intelligent manufacturing.

1. Introduction

Currently, traditional mass production cannot meet the requirements of users for small batches of highly customized products. Smart factory for smart manufacturing shows the characteristics of self-organizing, self-disciplined, self-learning, self-adapting, being reconfigurable, and can produce customized products efficiently.

The most commonly used methods for constructing manufacturing platforms and system frameworks are modular methods and multi-layer architectures [1]. A smart factory framework composed of four layers including physical resource layer, industrial network layer, cloud layer, and supervisory control terminal layer was proposed [2], and the personalized candy packing application was used as a demonstration to illustrate this smart factory design [3]. In comparison, a fog layer was used to bridge the gap between the IoT devices and the cloud [4]; while a six-level functional architecture of smart factory was proposed for the interconnection [5]. On another hand, a platform of the automobile assembly line which integrated the automobile assembly, logistics warehouse, and cyber-physical system (CPS) was simulated [6]. As CPS interacts with machines, device, and actuators, and is highly relevant in the manufacturing process, which is widely used in industrial environments such as intelligent manufacturing [7]. These researches mentioned above, however, are still at the stage of concept or laboratory.
Although some integrated frameworks for smart factories have been presented in the literature, the research depth and systematisms of CPS smart factory system architecture are insufficient, and it still lacks industrial applications [5]. In addition to this, most firms lack insight into these key challenges, or into the activities and capabilities required to support a successful smart factory implementation [8]. So it is still difficult for industrial companies to establish a concrete strategic roadmap through these frameworks [9].

Based on an actual smart factory of automobile chassis, this research proposes a three-layers smart factory framework, consisting of IoT object layer, CPS network layer, and CPS service layer. Furthermore, the effectiveness of intelligent manufacturing is illustrated in this research, providing a reference for further implementation of intelligent manufacturing.

2. Research methodology

2.1. Methodology

This research proposes a smart factory framework consisting of an IoT object layer, a CPS network layer, and a CPS service layer, as presented in Figure 1.

![Figure 1. General framework for this smart factory.](image)

2.2. Scope

The smart factory framework proposed in this research is applied in Guangxi Automobile Group Liudong passenger vehicle smart factory demonstrated in Figure 2.
Figure 2. The smart factory of Guangxi Automobile Group Liudong passenger vehicle chassis.

Based on the industrial internet, cloud platform, intelligent software, and equipment, the smart factory has completed the construction of multiple digital production lines such as the main reducer assembly line and the rear independent suspension assembly line for the products shown in Figure 3. This smart factory can achieve the digitization and informatization of the entire process of design, manufacturing, quality inspection for the key components of the chassis.

(a) (b)

Figure 3. Main reducer and independent suspension produced by this smart factory.

2.3. Implementation

This part introduces the three levels of the framework and as well as how the smart factory for key components of vehicles is implemented.

2.3.1. IoT object layer. The IoT object layer is the basic structure of the smart factory, including physical space and cyber space, which are also quite critical for the intelligent manufacturing.

1) Physical space

In this smart factory, the physical space mainly includes main reducer assembly lines, smart assembly equipment and smart logistics system.

The main reducer assembly line is based on computer numerical control (CNC) equipment and robots, which integrated electrified assembly, error-proofing, and real-time online quality inspection. It is also equipped with a large number of displacement and torque sensors to monitor the assembly process in real time.

Smart assembly equipment in this smart factory includes intelligent gasket selection equipment, digital bearing mounting machine, digital nut tightening machine and digital torque detection equipment. The accuracy and efficiency of assembly can be improved significantly through smart assembly equipment.

Smart logistics equipment mainly includes automatic guided vehicle (AGV) and automatic warehouse. Through the laser navigation and scheduling management system, AGV can complete the automatic material circulation distribution. On the other hand, automatic warehouse can achieve unmanned sorting and warehousing through information control system, thus improving the efficiency of logistics.
2) Cyber space

The cyber space includes services, applications, and decision-making unit, which can be implemented via radio frequency identification devices (RFID) technology and manufacturing execution system (MES).

In this smart factory, RFID technology is applied to workshop logistics management, digital manufacturing, digital testing, and product quality monitoring.

MES can interact with robots, machine equipment, detection equipment, scanning gun, and other equipment, and the production information of parts and the operation information of equipment can be collected to achieve parts production traceability and equipment condition monitoring. Therefore, the MES of assembly line can perform process management, production operation management, quality management, and statistical analysis.

2.3.2. CPS network layer. The industrial network uses fieldbus technology to construct the communication network of the workshop, connecting IoT object layer and CPS service layer. At the same time, a distributed data collection system is used to upload equipment data, product data, and quality data of production process to the cloud service platform through various sensors deployed on the equipment.

The factory industrial network includes various communication and network facilities. This smart factory is deployed with 2 core switches, 2 distributed switches, 10 access switches, 2 firewalls, 2 wireless controllers, and 25 wireless access point (AP); 4 intermediate distribution frame (IDF) and logistics three-dimensional library cabinets are connected to the main distribution frame (MDF); assembly line, machining line, and logistics office point using network access, office building and workshop using wireless AP wiring.

2.3.3. CPS service layer. The core of CPS service layer is industrial cloud and intelligent service platform, integrating the equipment data, production data, quality data and energy consumption data of smart factory, which can provide equipment status detection, quality detection and intelligent decision-making services through the analysis of data.

1) Architecture of cloud platform

The architecture of the cloud platform mainly includes three parts: IaaS (infrastructure as a service) layer for equipment access platform, PaaS (platform as a service) layer for application development, and SaaS (software as a service) layer for application, as presented in Figure 4.

As the core basic component of the industrial cloud platform, the IaaS layer for equipment access platform in Figure 4 is responsible for the collection and analysis of device data. The access platform includes two parts. One is the marginal layer, which communicates with the device through the hardware gateway or the software gateway, collecting original data to the cloud according to the appropriate cloud communication protocol. The second is the unified data acquisition adaptation layer, which takes the connection management of the gateway and the scheduling of acquisition tasks as the core. This is mainly to implement protocol adaptation and data analysis for the massive data reported by the marginal layer.

As part of the PaaS platform, the development tools including configuration design, view design, process design, and index design are provided by the application development service. Developers or enterprise system administrators can build IoT applications based on these tools.

The SaaS layer for application includes equipment management and operation and maintenance platform. The equipment management part provides the basic management functions of the access equipment in the cloud platform, including equipment template, equipment account, failure analysis, and maintenance management. Mechanisms such as secure access and equipment authorization are provided by the operation and maintenance platform part to achieve multi-layer protection of data and build a safe and reliable environment for data.
2) Intelligent decision system based on cloud platform

As a data-driven platform, the intelligent decision system can perform the optimization of assembly process parameters, fault prediction, product quality evaluation, and energy optimization scheduling.
As presented in Figure 5, the data foundation platform transmits product data and equipment operating data to the data application platform through the industrial network. On the one hand, the data model including the evaluation model, diagnosis model, and prediction model is established in the data application platform; on the other hand, perform data management on the collected data, including data presentation, data delivery, data integration and data analysis. Then the final results are visualized. Professionals use visualized data to perform failure early warning prediction, quality analysis, operation optimization analysis and impact analysis, completing intelligent decision-making throughout the production process.

3) Data integration platform
As illustrated in Figure 6, the data integration platform includes 5 hierarchical structures, i.e., data integration layer, data processing layer, data storage layer, data analysis layer, and data presentation layer. In particular, each of these 5 levels has adopted distributed technology to achieve high processing performance.

![Figure 6. Technical architecture diagram of data integration platform.](image)

3. Results
This smart factory framework is applied to the actual automobile parts factory, namely the Guangxi Automobile Group Liudong passenger vehicle chassis factory which was launched in 2015 and formally put into production in 2018. The effect of this framework can be verified through the production data from the factory actual feedback as listed in Table 1.

| Year | Sale volume | Production cost (M) | Average cost (K) | Annual electricity consumption (kW·h) | Average unit energy consumption (kW·h) |
|------|-------------|---------------------|-----------------|--------------------------------------|--------------------------------------|
| 2015 | 1734389     | 177775.198          | 1.02500         | 9382752                              | 5.409831                             |
| 2018 | 1585847     | 97763.39            | 0.61647         | 5363603                              | 3.382169                             |

In Table 1, the average cost of factories dropped from 1025 RMB in 2015 to 616.47 RMB in 2018, which has been reduced by 39.98%, as presented in Figure 7(a); the average unit energy consumption of the enterprise dropped from 5.4 kW·h in 2015 to 3.38 kW·h in 2018, which has been decreased by 37.48%, as presented in Figure 7(b). In addition, the product development cycle is reduced from the original average of 18 months to an average of 4 months, which has been shortened by 77.78%. Therefore, it is reasonable to say that significant improvements have been achieved via the implementation of intelligent manufacturing based on the framework proposed in this research.
4. Conclusions

This research proposes a smart factory framework composed of the IoT object layer, CPS network layer and CPS service layer, which is applied to an actual lightweight automobile chassis key components smart factory. The smart factory based on this framework developed production lines of rear axle main reducer and independent suspension assembly, and integrated virtual manufacturing and physical manufacturing based on a cyber-physical system, forming a unified data platform for the whole product life cycle. As a result, most production indicators have been improved significantly, indicating the effectiveness of this framework for intelligent manufacturing. Therefore, it can be concluded that the framework for intelligent manufacturing presented in this research is practical and can provide guidance for the implementation of smart factories in the future.

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