A software design of the equipment management business in Digital Workshop

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Abstract. Firstly, the present situation and business requirements of the digital workshop equipment management business are designed, and a hierarchical functional architecture based on cloud platform is proposed, combined with the top-level function allocation and information integration model of the workshop equipment management business software. Then, combined with the discussion of the key points of software design, the technical approaches of vertical service support and horizontal interconnection integration, such as building a stable, reliable and low delay distributed system framework, real-time equipment state monitoring based on OPC UA, etc. Finally, the feasibility and effectiveness of the software design approach is further verified through the application practice of the equipment management business in an electronics product manufacturing workshop, which helps to improve the automation degree and real-time deterministic effect of the workshop equipment management business, and provides a reference for business planning and condition construction of similar enterprises’ digital workshop.

1. Introduction

The digital workshop is based on the process and equipment required by the production object, and by means of information technology, automation, measurement and control technology. It connects different units of the workshop with data to plan, manage, diagnose and optimize the production process[1]. The construction of enterprise digital workshop usually aims at reducing cost, improving quality and efficiency, and quickly responding to the market. On the basis of optimizing the management of process design, production organization and process control, the production resources and production process such as human, machine, material, method, environment and measurement are simulated, designed, managed, optimized, controlled and visualized[2]. At present, digital workshop has become the main battlefield for manufacturing enterprises to implement intelligent manufacturing. As the core unit of intelligent manufacturing, digital workshop involves information technology, automation technology, mechanical manufacturing, logistics management and other technical fields. The digitization degree of the workshop directly affects the production efficiency and product quality of the enterprise.
2. Current situation and business requirements of workshop equipment management

Workshop equipment management is one of the core functions of digital workshop manufacturing operation management, and its management objects are various processing equipment, logistics equipment, testing equipment, auxiliary equipment and other manufacturing equipment[1]. With the continuous construction of enterprise digital workshop, the workshop must be equipped with various manufacturing equipment and production resources.

According to the analysis from "Alliance of Industrial Internet" in February 2019, the industrial internet platform has begun to play a core supporting and driving role in the process of enterprise digital transformation, and its application mainly focuses on three major scenarios: equipment management service, production process control and enterprise operation management[3]. Among them, the digital level of foreign manufacturing enterprises is relatively high, and equipment management services such as equipment health management and remote operation and maintenance relying on big data have become hot applications, accounting for nearly 50% of all applications. Although domestic manufacturing enterprises pay attention to equipment management services and have strong demand, the penetration rate is relatively low, accounting for 27%. Different from foreign enterprises, domestic enterprises pay more attention to production process control and resource allocation optimization, accounting for 32% and 21% respectively[3]. This incomplete statistics not only reflects the common trend of digital application scenarios gradually focusing on equipment IOT, equipment management and data value mining, but also implies that the underlying foundation of digital workshop of Chinese enterprises is relatively weak, and professional service capabilities such as equipment access, equipment management and remote operation and maintenance need to be improved.

Workshop equipment management needs to focus on the use of equipment, maintenance, repair and troubleshooting and other on-site business application requirements. Compared with the previous workshop level business, relying on the industrial internet platform (hereinafter referred to as cloud platform) for comprehensive integration has become the only way for workshop digital transformation construction. At this stage, the digital workshop of manufacturing enterprises urgently needs to provide equipment management function services such as equipment file management, equipment status monitoring, equipment maintenance and equipment operation analysis based on cloud platform, so as to further improve the fine equipment control ability and intelligent data service ability[1].

3. Hierarchical functional architecture based on cloud platform

In order to meet the application requirements of digital workshop equipment management business and the development trend of workshop information service architecture, the hierarchical functional architecture should be built based on "cloud platform". By defining the functional services and key elements required for business implementation, flat integration optimization and function allocation are carried out to ensure the stability and reliability of the basic framework, the flexibility and scalability of functional services, and the standardization and unification of interactive interfaces. At the same time, considering that service-oriented architecture (SOA) is not only suitable for network application development with loose coupling and distributed structure, but also has the advantages of generality, extensibility, interface standard and strong openness, it should be selected in architecture design. As shown in Figure 1, the whole SOA architecture can be divided into edge layer, platform layer and application layer from bottom to top. The modular elements and collaboration relationship of each level are designed as follows:

(1) Edge layer: the edge layer is the foundation. Relying on the equipment access of edge physical resources such as series of sensors/collectors, instruments, test facilities, logistics equipment, CNC machine tools, industrial robots and other edge physical resources, data collection and data upload are carried out for equipment status data, equipment processing and operation parameters, equipment operation and idle time, environmental location information and other original data information.

(2) Platform layer: the platform layer is the core platform. Based on the open system architecture and standardized interface, the integrated platform service system is designed. A series of platform service resources such as IaaS infrastructure, general PaaS platform, big data storage platform, big data
processing and analysis platform and application development platform are provided for the application layer.

(3) Application layer: the application layer is the key. It focuses on the field business links such as equipment status monitoring, equipment maintenance, equipment fault management and equipment operation analysis, makes full use of the service capabilities provided by the platform layer, integrates the field operation process and application scenario requirements, and customizes a series of application apps or functional components for field users.

Figure 1 The schematic diagram of hierarchical functional architecture

4. Top level function allocation and information integration model

Combined with the business requirements analysis of digital workshop and following the design principle of "generalization, modularization and componentization", the equipment management business software should provide sub function modules such as equipment file management, equipment status monitoring, maintenance management and equipment operation analysis. As shown in Figure 2, these sub function modules should be based on the unified user operation platform interface, and guide and assist in the way of user operation guide or post operation assistant, so as to effectively improve the control efficiency and human-computer interaction experience of users. The function allocation of sub function modules is as follows:

Figure 2 The top level function allocation diagram

[Equipment file management]: carry out equipment category management, equipment manufacturer management, equipment account management, file data management and equipment status management. It can establish and maintain workshop level equipment basic information according to the actual situation of workshop equipment, and provide basic information for equipment daily management, equipment status monitoring, equipment maintenance and other business management.

[Equipment status monitoring]: collect equipment operation data, visualize equipment status and warn abnormal state. Among them, the operation data collection should be able to automatically collect the key data needed to reflect the equipment status on-line. The equipment status visualization should adopt the graphical way to display the equipment operation status and historical operation data information. The equipment status abnormal warning should be based on the equipment operation standards and requirements, and the monitoring results of the status parameters should be analyzed and judged, and the abnormal change trend could be detected to give early warning and give an alarm in case of abnormal or fault.
[Maintenance management]: carry out periodic maintenance, predictive maintenance, equipment fault management and spare parts management. The equipment maintenance function should establish a standardized maintenance system with the process of equipment maintenance plan formulation, work order allocation, issuance, implementation and feedback. Take the planned work order as the main management form to complete the implementation and feedback of the equipment maintenance.

[Equipment operation analysis]: based on the process data collected during equipment real-time status collection and maintenance, the equipment related indicators are automatic statistical analyzed, mainly including equipment intact rate, equipment utilization rate, equipment failure rate, shutdown (or shutdown) time, shutdown (or shutdown) times, equipment mean time between failures (MTBF), etc[1]. At the same time, it provides statistical analysis report generation and export function.

In accordance with the requirements of workshop digitization, the functions of data collect, upload storage, extract transform load (ETL) and data interaction of field equipment are the basis of information integration ability of digital workshop. The information integration model is shown in Figure 3. The integrated monitoring data shall include equipment status data, equipment processing and operation parameters, equipment operation and idle time, equipment alarm information and equipment fault information. The integrated maintenance data shall include fault tree information mainly including equipment, fault type, fault location and fault name, and the fault solution and fault treatment records obtained from the cause analysis of the fault phenomenon.

![Figure 3 The schematic diagram of workshop equipment management information integration model](image)

5. Key points and technical approaches of software design
Considering that there are many kinds, large quantities and regional dispersion of equipment in digital workshop, and the time range of perception, operation and control action of field equipment layer is usually seconds, millisecond, or even faster[4], the application scenarios of workshop equipment management business must meet the requirements of efficiency and time indicators and pay attention to the automation degree and the real-time response of the business activities. In this way, how to build a stable, reliable and low delay distributed system framework, real-time equipment status monitoring based on OPC UA, naturally become the design points of workshop equipment management business software, and should be combined with the actual needs of the workshop to verify the availability of technical approaches.
5.1. Stable, reliable and low delay distributed system framework

Digital workshop is located in the distributed network production environment. There are a large number of field equipment access and data interaction, a variety of equipment types, interaction protocols and data multi-source heterogeneous. Therefore, a stable, reliable and low delay distributed system framework becomes the underlying foundation and necessary guarantee of real-time business interaction and process collaboration in application layer. Considering that middleware technology is not only the best development practice of client/server application in distributed heterogeneous network environment, but also the service resources provided by middleware products can be integrated into SOA system architecture seamlessly. When building a distributed system framework, a drawer type hierarchical function model with the characteristics of easy reconfiguration, loose coupling and dynamic replacement can be selected, as shown in Figure 4.

The hierarchy of the whole system framework is divided into server layer, middleware layer and application layer from bottom to top. The same layer is a loose coupling structure. The bottom layer is "transparent" to the upper layer. The lower level functional components provide services to the upper level functional components, and the changes of the upper level have no effect on the calling services of the bottom layer. The application layer software of management control node, operation and maintenance management node and monitoring node can not only directly call the database access and data exchange services provided by local middleware, but also call web services, FTP services, database services, device driven services and publishing/subscription services with the help of distributed middleware services. However, the data publish/subscribe middleware, which has the greatest impact on the real-time of data exchange in distributed applications, needs to be optimized according to the constraints of the distributed network environment and the data content transmitted.

In view of this, the time delay of network transmission will directly affect the technical implementation of time sensitive links such as operation data collection and abnormal state alarm. Using LabWindows/CVI built-in network variable function library "Network Variable Library" is used to create data publisher and data subscriber. The "end-to-end" data transmission time statistics between data publishers and data subscribers can directly reflect the real-time experience of distributed application interaction and collaboration. As shown in Table 1, the "end-to-end" longest time consumption statistics under different statistical durations between one data publisher application and multiple subscriber concurrent applications. Among them, the internal network environment of the workshop where the application is running is Gigabit Ethernet. The network connection speed is 1.0
Gbps, and the system clock synchronization is carried out in advance to ensure that the synchronization accuracy reaches the order of milliseconds. Statistical data show that although the longest time will be increased with the increase of concurrent applications, it can be kept within 0.05 seconds, which can meet the real-time demand of second level response in the field network environment.

Table 1 Statistics of the longest time consumption of "end to end" interconnection (unit: s)

| Total statistical time (minute) | Number of concurrent applications | 1   | 2   | 3   | 5   | 10  |
|---------------------------------|-----------------------------------|-----|-----|-----|-----|-----|
| 1                              |                                   | 0.016 | 0.017 | 0.020 | 0.021 | 0.022 |
| 5                              |                                   | 0.019 | 0.018 | 0.023 | 0.022 | 0.023 |
| 10                             |                                   | 0.021 | 0.021 | 0.023 | 0.023 | 0.025 |
| 60                             |                                   | 0.031 | 0.033 | 0.034 | 0.034 | 0.036 |

5.2. Real time state monitoring of equipment based on OPC UA

The field equipment of digital workshop has the characteristics of large number, multiple interface types, nonstandard protocol and diverse data formats, and some old equipment even do not have the ability of networking. Due to the heterogeneous and diversified status of this kind of equipment, the mode of state data collection often depends on the specific situation of the device object, such as manual auxiliary mode, RFID (Radio Frequency Identification) electronic tag mode, PLC (Programmable Logic Controller) control interface, device interface (such as LAN, RS232/RS485, WiFi), etc. With the equipping of various intelligent equipment and the installation and layout of a large number of sensors/collectors, the equipment control and data collection methods are gradually standardized and consistent. Based on OPC UA (OLE for Process Control Unified Architecture) unified architecture, the interconnection of field equipment has become the common choice of intelligent equipment and industrial control system manufacturers. OPC UA not only provides a set of standard and unified interface for data exchange in process control, but also has many characteristics such as platform independence, high security, high reliability, high availability, extensibility and comprehensive information modeling[5-8]. It can easily obtain the data information on each distributed node, and make the service-oriented (SOA) business application realize.

Considering the current engineering practice, the application based on OPC UA still adopts C/S communication mode[8]. The publish/subscribe mechanism is used to handle the request and response process. As shown in Figure 5, the whole communication link is mainly composed of UA server application, UA server API, UA client API, UA client application and UA communication stack.

Figure 5 The integrated block diagram of equipment condition monitoring based on OPC UA

The UA server application is deployed on the edge equipment side to connect the workshop field equipment or PLC, providing address space configuration, node management, monitoring items and subscription management and other functions[8]. The UA server API is a bridge between the communication stack and the server application, providing interface and function services in the form of SDK to assist developers to implement the server application customization development. UA client API is a bridge between communication stack and client application, providing interface and function
services in the form of SDK to assist developers to realize customized development of client applications. UA client applications are generally integrated in workshop business terminals in the upper computer, the OPC UA client API is used to find and connect to the UA server. Through the unified standardized interface, the device real-time status data mapped by the nodes in the specified address space can be obtained by reading and writing variables or subscribing to events. UA communication stack is mainly responsible for the implementation of interaction and protocol specification, receiving requests and subscriptions and returning processing results. In addition, in the publisher/subscriber communication mode, the publisher module can publish data to any number of subscriber modules. In this way, the coupling between the UA client application and the UA server application can be decoupled, and the real-time access control of multiple workshop equipment can be realized through asynchronous cooperative connection with multiple UA servers. The server-side application based on OPC UA is particularly critical. Through the direct docking with the workshop equipment or PLC, it can timely process the control instructions from the UA client application in the role of "Intermediary Agent". Obviously, this OPC UA based workshop equipment interconnection and data transmission way can meet the functional requirements of equipment status monitoring in the distributed network environment.

6. Application practice
The upgrading and transformation of the electronic product manufacturing workshop of an enterprise, there are many types of field equipment, with a quantity of nearly 60 sets/set. These equipment can be divided into four categories: testing equipment (such as semiconductor device tester, analog circuit test equipment, RF component test system, etc.), environmental equipment (such as electromagnetic compatibility system, temperature and humidity box, salt spray test box, mold test box, etc.), vibration equipment (such as vibration table, electric vibration test bench), aging equipment (such as aging equipment, aging system, aging screening table) and so on.

Its equipment management business functions mainly include equipment account management, equipment status monitoring, test record tracing and equipment maintenance. The software running environment of supporting client computer is windows7 operating system, the server database system is MySQL server 5.1, and LabWindows/CVI is used for C/S communication mode application programming of edge layer data collection program and application layer business function components. The user operation platform interface of workshop equipment management business is shown in Figure 6. Based on the user operation guide, the user can be guided to perform functions such as equipment file management, equipment maintenance, equipment status monitoring, equipment operation analysis and equipment information query. The equipment management in the workshop is easier. The equipment monitoring personnel can observe the operation status and working parameters of all field equipment only in the monitoring center. If the operation status of the concerned field equipment is abnormal, it can timely notify by various notification methods, and then timely inform the relevant personnel for quick solution. With the help of the equipment information query function, users can trace all kinds of historical records of the specified equipment, such as operation status records, maintenance records and other relevant data information, so that the relevant data information of field equipment can be available.
7. Conclusion

In a word, the workshop equipment management business software described in this paper can effectively improve the user's control efficiency and human-computer interaction experience, aiming at the field business functional requirements such as equipment file management, equipment status monitoring, equipment maintenance and equipment operation analysis. The hierarchical functional architecture, top-level function allocation and related technical approaches based on cloud platform, especially the design of stable, reliable and low delay distributed system framework, real-time equipment status monitoring based on OPC UA and other key points are discussed and expected to fundamentally improve the automation degree and real-time deterministic effect of equipment management business. It is hoped that this paper can provide a valuable reference for the digital workshop planning and construction of manufacturing enterprises.

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References

[1] DING Lu, WANG Chengcheng, WANG Chunxi, et al. GB/T 37393-2019 Digital factory-General technical requirements [S].State Administration of Market Supervision and Administration, Standardization Administration of China,2019,5

[2] ZHU Duoxian, ZHAO Min. Machine Intelligence: From digital workshop to intelligent manufacturing [M]. China Machine Press,2018,10
[3] Alliance of Industrial Internet. White paper on industrial internet platform [R].2019,2
[4] LIU Dan, ZHAO Yanling, XIE Sufen. OPC UA-based Interconnected Network Architecture in Digital Plant and Implementation of OPC UA [J]. CHINA INSTRUMENTATION, 2017(10):39-44
[5] China Academy of Information Communication Technology, Alliance of Industrial Internet. White paper on industrial internet interconnection [R].2018,9
[6] Alliance of Industrial Internet. Industrial internet architecture(V2.0) [R].2020,4
[7] XU Bingbing. Design and Implementation of Key Modules of SCADA System Based on OPC UA [D]. Xi’an XIDIAN UNIVERSITY,2017,6
[8] LIU Yang, LIU Mingzhe, XU Aidong, et al. Research and implementation of OPC UA Publish/Subscribe mode based on message broker [J]. High Technology Letters,2018,28(6):553~559