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Research on Cloud-side Collaborative Computing MES System based on Revolving Door Algorithm

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Abstract

Aiming at the problem of slow processing speed and large delay of MES system caused by massive data and service requests generated in the operation of intelligent terminal equipment in industrial field, a cloud-edge collaborative MES system based on revolving door algorithm is proposed. The system uses a combination of cloud computing and edge computing. The edge side focuses on real-time, locality and low-computation. The edge side transmits data and service request processing to the cloud according to actual needs. The cloud side is responsible for global, non-real-time, high-computational business processing and analysis. The adaptive frequency conversion data acquisition is carried out by using the revolving door algorithm, and the calculation resources and the occupied transmission bandwidth are allocated according to the change of the acquisition frequency. After the system is deployed to the production workshop through microservices, it can adapt to the characteristics of diverse and heterogeneous network protocols in the industrial field, break the original data island, give full play to the value of data elements, and improve the processing speed and real-time performance of the system.

Keywords

Cloud-edge Collaboration; MES; Data Acquisition; Revolving Door Algorithm; Microservice Architecture.

1. Introduction

With the support of relevant national and government policies and the rapid progress of information technology, the domestic industry is developing towards digitization, networking and flexibility. The industrial production process and industrial equipment are becoming more and more intelligent. The communication protocols of industrial field equipment are complex and diverse, which leads to the difficulty of interconnection[1]. The phenomenon of " information island " is widespread, and the utilization rate of data resources is low. At the same time, the amount of industrial equipment and production data and service requests that need to be perceived, transmitted and calculated is becoming larger and more complex, and the difficulty of data acquisition, analysis, processing and storage is increasing, resulting in slow processing speed and large delay of MES system[2].

Liu Wei[3] proposed a MES production scheduling model based on master-slave chain and edge computing. The MES service is split into multiple services and integrated into the edge node. Data processing is completed on the data source side and the lightweight data is uploaded to the blockchain network. Yin[4] proposed an intelligent CNC workshop self-regulation system based on cloud-edge collaboration. The edge sensing nodes are deployed on the equipment side of the intelligent CNC

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workshop to realize the real-time processing of sensitive manufacturing data and the self-regulation of CNC equipment manufacturing and production, which alleviates the transmission, calculation and storage pressure of the cloud data processing center. Zhao[5] proposed a collaborative framework based on the edge computing of the Internet of Things to reduce the computational pressure and achieve distributed decision-making.

The above literature adopts the method of edge computing, and puts the calculation of some modules to the edge end, which reduces the pressure of cloud computing. However, most of the requests with real-time requirements are still carried out in the cloud, and the massive data will occupy the network bandwidth and lead to delay. This paper proposes a cloud-edge collaborative MES system based on the revolving door algorithm. According to the amount of data and service requests, the device is abstracted into multiple edge nodes. Each edge node is equipped with an edge computing gateway to collect and preprocess data using an adaptive frequency conversion data acquisition method, and allocate computing resources and transmission bandwidth according to the acquisition frequency. In the system development and deployment, the micro-service architecture is used to speed up the processing speed of the MES system and improve the real-time performance through intelligent collaboration between the cloud and the edge.

2. Design Scheme of Intelligent Management System based on Cloud Edge Collaborative Manufacturing

2.1 Cloud-edge Collaborative Architecture

The architecture of cloud-edge collaborative MES system includes two layers : edge end and cloud end. The edge end is in the production workshop, and all kinds of intelligent equipment in the production workshop are abstracted as edge nodes. The edge computing gateway and edge computing server are deployed in the production workshop, and an edge node corresponds to an edge gateway. The microservice ME system is deployed on the cloud and the edge respectively, and The specific architecture is shown in Fig. 1.

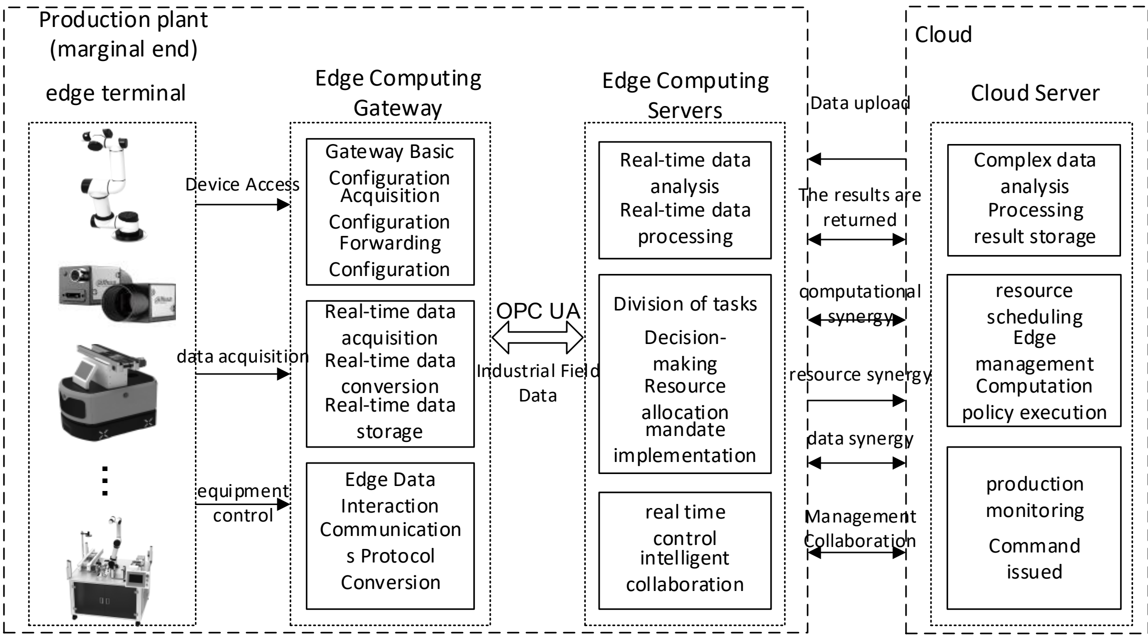

Fig. 1 The architecture diagram of intelligent management system based on cloud edge collaborative manufacturing

Through resource collaboration, management collaboration, and application service collaboration, the cloud and edge terminals meet the needs of high computing performance, low network latency,

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multi-device communication, and real-time response in industrial production scenarios. At the same time, the system realizes microservices, standardization, and generalization.

2.2 Function Modules of System

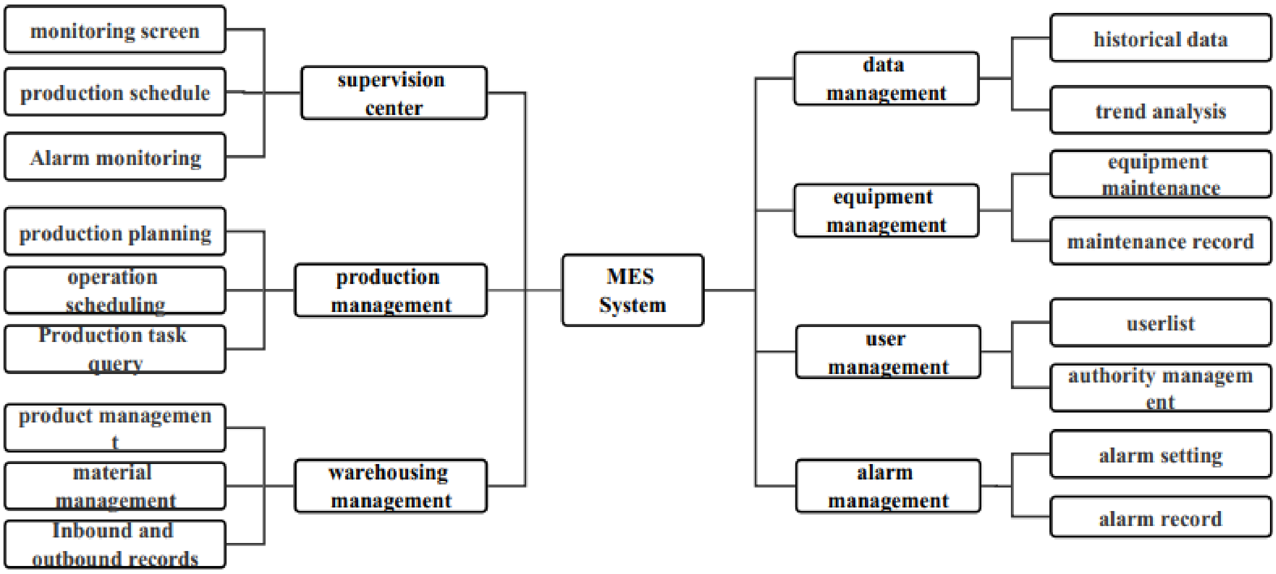

Fig. 2 System function module diagram

According to the analysis of a variety of intelligent manufacturing production processes, the MES system based on cloud-side collaboration is designed with 7 functional modules. The monitoring center module : data visualization large screen can display the data, production progress and alarm information generated in the production process in real time. Production management module : According to the production demand, the production plan is formulated and the production value is set. The production instructions are sent to the equipment side, and all production tasks can be viewed at any time. Warehouse management module : real-time monitoring and management of raw materials, semi-finished products and finished products inventory quantity, location and status, management and record out / storage information, regular inventory, timely warning of low inventory or excess inventory Data management module : statistics and analysis of production data to generate relevant data statistical reports and visual display, to provide analysis and decision support for production business. Equipment management module : Record and manage the basic information of the equipment, make the maintenance plan of the equipment, including regular maintenance, overhaul and calibration, ensure the normal operation and life of the equipment, record the equipment fault maintenance information, track the maintenance progress and results. Alarm management : Set the alarm rules and conditions. When the alarm is triggered, the detailed information of the alarm will be displayed on the alarm monitoring billboard and pop-up reminder, so that the operator can timely discover and deal with the alarm event, and record and store the alarm information, which is convenient for the management personnel to analyze the cause of the alarm. User management : record user information and set user permissions.

3. System Microservice Architecture based on Cloud Edge Collaboration

In order to alleviate the pressure of cloud computing, this system adopts micro-service architecture, classifies according to the main business and real-time requirements of the system, and follows the principle of high cohesion and low coupling. The functional modules of the system are deployed in the cloud and the edge to realize the computing collaboration and service collaboration of the cloud and the edge. Table 1 is the classification of the functional modules of the system.

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Table 1. Classification of microservice function modules

Cloud	Edge
monitoring screen	data acquisition
warehousing management	real-time data processing
equipment management	real-time data analysis
user management	Alarm data information
production planning	Alarm monitoring billboards
operation scheduling	Equipment instructions issued
Production task query	production schedule monitor
Historical data and trend analysis	

This system adopts the micro-service architecture for development and deployment, and has the following advantages :

(1)Each module is responsible for specific functions, and can be independently deployed and expanded to meet the growing business needs.

(2) Through horizontal and vertical expansion, make full use of computing and storage resources to ensure the stability and performance of the system, to cope with large-scale production environment and high concurrent data processing requirements[6].

(3) The system provides standardized interfaces and protocols to facilitate integration and docking with external systems, such as SCADA, WMS, PLM, etc.

(4)The cloud is responsible for service-oriented and management-oriented processing, which improves the operation speed and response time. It can monitor the production process in real time, collect and analyze equipment data, product data and production data in real time, so as to accurately grasp the dynamic situation of the production site.

4. Data Acquisition

The edge computing gateway accesses the terminal device and collects the industrial field data in real time, and uploads the data to the edge server. However, the data acquisition is now based on the equal time interval method. This method is simple to operate, but it is not analyzed according to the change law of the data points. When the high-frequency acquisition method is adopted, the integrity of production data can be guaranteed, but when the numerical fluctuation is not large, a large amount of redundant data will be collected, which will occupy the network bandwidth and affect the real-time performance. When using low-frequency acquisition method, if the value fluctuates greatly, it will lead to the omission of key data and affect the accuracy of real-time data.

Fig. 3 is the fitting curve generated by two data points using equal time interval method for data acquisition. The acquisition frequency is 1000 milliseconds. The left image is the joint pose data of the cooperative robot manipulator. It can be seen that the pose data fluctuates greatly in actual operation, and the fitted curve is quite different from the actual situation. The right diagram is the AGV running speed data. It can be seen that the data point fluctuates very little during actual operation. The fitted curve is basically consistent with the real reaction, which basically reflects the real change law. Therefore, it can be concluded that when the data fluctuates greatly, the equal time interval method is used to collect, and there is a big difference between the fitting and the reality, resulting in a large amount of redundant data, and the integrity of the data and the authenticity of the real-time data are difficult to guarantee.

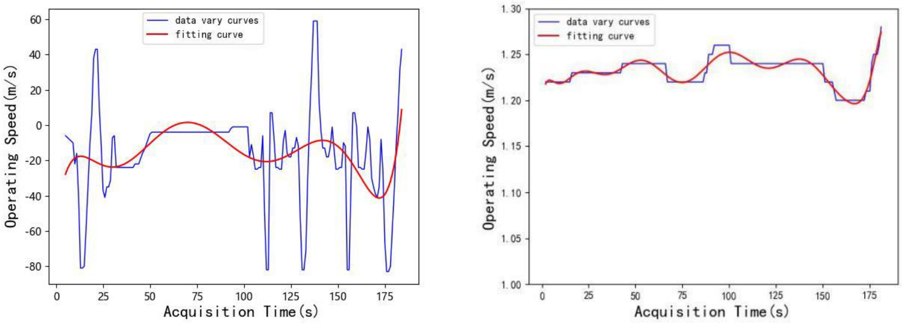

Fig. 3 Data change curve

Therefore, in the actual production and manufacturing process, the method of adaptive frequency conversion data acquisition should be used, that is, the time interval of acquisition should be dynamically adjusted according to the frequency and amplitude of data change. In the study of this method, the idea of rotating door algorithm is used. Two virtual doors are established by taking the upper and lower points with the value of △E from the first point as the fulcrum. With the increase of data points, the door will rotate and open. As long as the sum of the angles of the two doors is less than 180°, it will rotate all the time. When the sum of the angles of the two doors is greater than or equal to 180°, it stops rotating and stores the data of the point, and then starts a new rotation operation with the point as the starting point.

With the help of the revolving door algorithm, when the increasing data points can be included in the constructed virtual revolving door, the fluctuation range of the data is small, and the time interval of data acquisition can be gradually increased until the time interval reaches the set maximum, as shown in Equation (1). When there are data points that cannot be included, it shows that the amplitude of data fluctuation is increasing, and the time interval of data acquisition can be gradually reduced from the point that cannot be included until the time interval reaches the set minimum value, such as formula (2).

$$T_{new} = \{ \begin{matrix} T_{now} + T_{increase} & T_{new} \le T_{\max} \\ T_{\max} & T_{new} > T_{\max} \end{matrix} \quad (1)$$

$$T_{new} = \{ \begin{matrix} T_{now} \times \frac{1}{2} & T_{new} \ge T_{\min} \\ T_{\min} & T_{new} > T_{\min} \end{matrix} \quad (2)$$

This method is different from the traditional revolving door algorithm in practical application. The traditional revolving door algorithm has a new starting point when the angle between the two revolving doors is greater than or equal to 180° .This method takes the point that is not within the scope of the revolving door as a new starting point. Compared with the traditional revolving door method, it will increase the collected data, but it can improve the accuracy of the data.

The following figure is the adaptive frequency conversion acquisition process, T_{now} is the current acquisition time interval, T_{max} is the maximum time interval, T_{min} is the minimum time interval, K_{upmax} is the maximum slope of the upper revolving door, $K_{downmin}$ is the minimum slope of the down revolving door, K_{upnow} is the slope of the current upper revolving door, $K_{downnow}$ is the slope of the current lower revolving door.

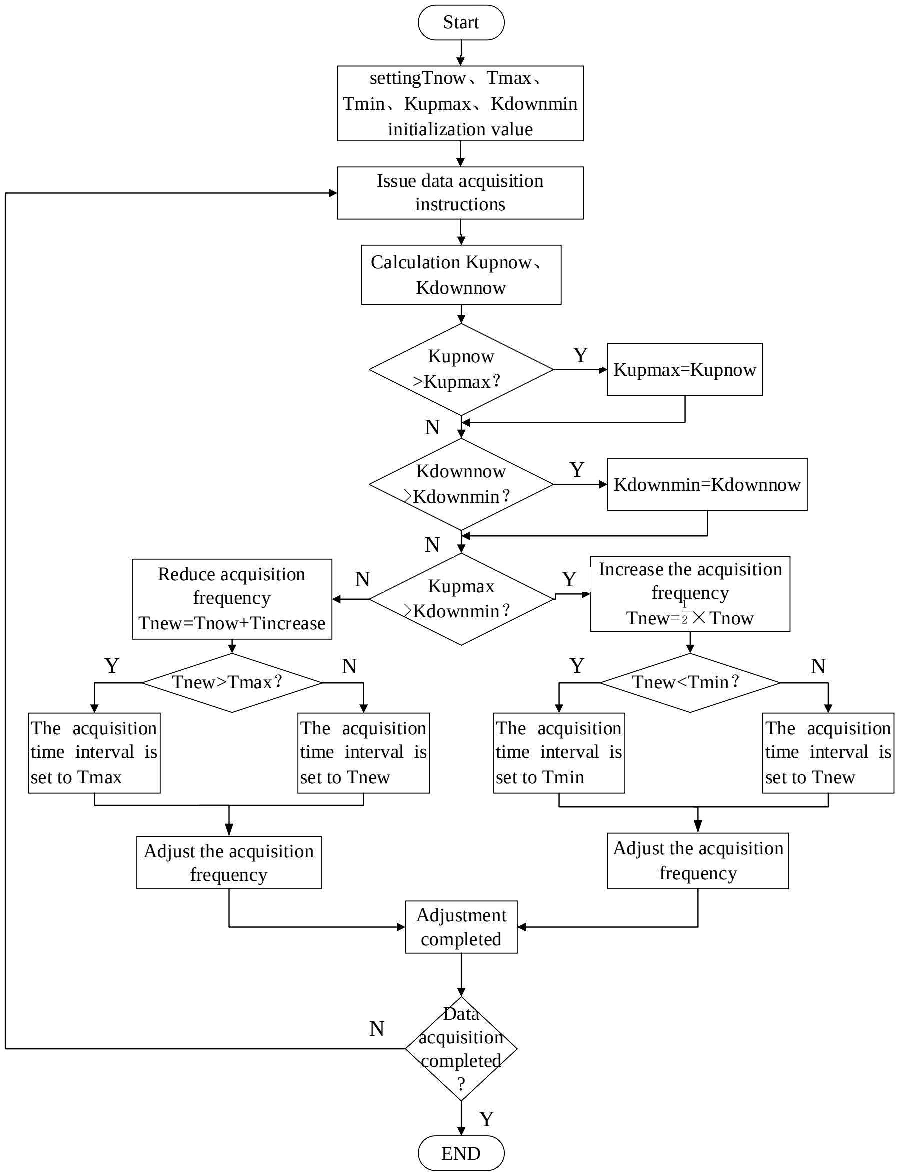

Fig. 4 Flow chart of adaptive frequency conversion data acquisition

When the acquisition frequency of a data point increases, the system will perform automated scripts to allocate more computing resources to the data point, while increasing the priority of transmission, allocating more network bandwidth, and improving the system 's processing speed for business requests.

5. Field Measurements

5.1 Testing Environment

In order to verify the feasibility of the MES system proposed in this paper, the intelligent assembly production line is selected as the experimental equipment, which includes intelligent storage unit, intelligent robot assembly unit, detection unit and autonomous mobile robot. The edge server is deployed in the production workshop, and the system is deployed to the cloud server and the edge server for normal use.

5.2 Operational Testing

In each unit of the device, data points are selected for response time comparison. It can be seen from Table 2 that when using the cloud-edge collaborative manufacturing intelligent management system for production monitoring, the data transmission takes less time, the real-time performance is stronger, and the response to alarm information is faster. In the data processing of the traditional manufacturing intelligent management system, the data first needs to be sent to the cloud server for processing and analysis, and then the result is returned to the edge device. The system processes these computing tasks on edge devices close to the data source, reducing the time and delay of data transmission, so that the system can complete processing and response in almost real time.

Table 2. Data Response Time

Data Point	pretreatment	Set alarm	Previously(ms)	Now use time(ms)
J1 axis posture	N	Y	200~300	40~50
AGV velocity	N	Y	200~300	35~40
Position 1 Information	N	N	150~200	10~25
Overrun alarm	N	Y	250~300	15~30
voltage	Y	Y	500~600	45~65
temperature	Y	N	400~500	35~45
Abnormal servo communication	N	Y	200~300	20~30

Fig. 5 is the pose data change curves of the J2 axis of the manipulator in the actual assembly process. The left diagram is the curve generated by collecting data using equal time intervals. The time interval is 500ms, and the number of data points collected is 1000. The right diagram is the curve generated by using the data collected by the adaptive frequency conversion data acquisition method in the same assembly process. As shown in the right figure, the collected J2 axis data points are 477, and the data points are reduced by 52.3 % compared with the equal time interval method. Although the amount of data is less, it can be seen from the comparison of the curves that the reflection of the data change trend is basically consistent with the equal time interval method. It can be seen that the adaptive frequency conversion data acquisition method is used for data acquisition. While ensuring accuracy, it reduces data redundancy, reduces data transmission pressure, and improves real-time performance and processing speed.

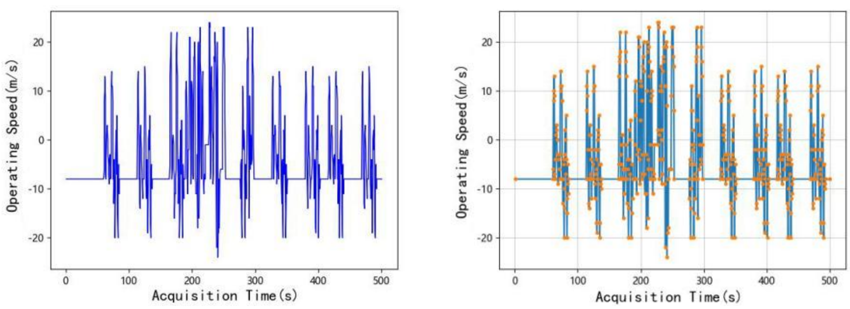

Fig. 5 J2 axis data acquisition comparison diagram

After a long period of on-site operation, the system is more effective in the management of production. The time to achieve equipment response from production instructions is stable within 50ms. The speed of system processing information is increased by about 40 %. The equipment response is more rapid in the automated assembly process. The production process can be monitored in real time on the monitoring screen, and the analysis of historical data provides data support for production business decision-making.

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6. Generalize

This paper mainly studies a cloud-edge collaborative architecture MES system based on the revolving door algorithm. It uses a combination of cloud computing and edge computing, and uses a microservice architecture when software is deployed to achieve intelligent collaboration of the cloud edge, clarify the cloud and edge business responsibilities, and improve the processing speed and real-time performance of the system. The adaptive frequency conversion data acquisition method is used, and the calculation and transmission resources are dynamically allocated, which reduces the redundant data, reduces the system response time and enhances the fault tolerance. Through this system, each link of the production process can be displayed and tracked in real time, and a unified environment for the integration and collaboration of each business link is constructed to improve the transparency of the production process, adapt to the trend of intelligent manufacturing, and improve the quality and efficiency of production.

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