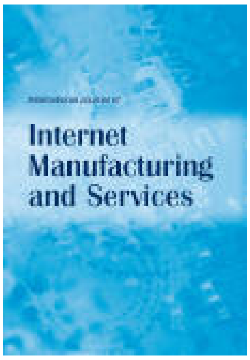

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A real-time data acquisition method of industrial production line based on OPC technology

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Abstract: In view of the low timeliness and accuracy of traditional production line data acquisition methods, this study proposed a real-time data acquisition method of industrial production line based on OPC technology. Considering the heterogeneity of industrial production line data sources, a data transmission scheme is generated based on OPC technology and multi-point communication with Modbus protocol after data preprocessing by piecewise linear interpolation method. Then, the improved decision tree algorithm is used to design the data processing mode. Finally, the current state of industrial production line data is judged by comparing the threshold value, and the real-time data collection of industrial production line is completed after the collection interval is determined. Experimental results show that the acquisition accuracy of this method is up to 96.8%, the maximum acquisition time is only 12.5 s, and the highest packet loss rate is only 1.89%, indicating that this method improves the acquisition quality.

Keywords: OPC technology; industrial production line; real-time data acquisition; piecewise linear interpolation; Modbus protocol; decision tree algorithm.

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1 Introduction

At present, the pace of industrial manufacturing to intelligent manufacturing is gradually accelerating, driving the transformation and upgrading of the global industrial manufacturing industry (Mu, 2020). As the core of industrial manufacturing, intelligent factory realises the analysis and control of the whole manufacturing process through computer network. Among them, the industrial production line realises the whole process automation by self-adjusting and self-learning according to the environment in a near real-time way. Fast and accurate data collection of industrial production line is one of the important conditions for intelligent manufacturing. By collecting industrial production line data in real time, the underlying production and processing equipment can be connected to the industrial network, and the processing process information of equipment can be acquired in real time (Liu et al., 2019; Mielczarek et al., 2021). Therefore, it is of great practical significance to study the efficient real-time data acquisition method of industrial production line.

At present, scholars in related fields have carried out research on data acquisition methods of industrial production lines. Geng et al. (2019) proposed an improved collection and storage method of industrial production data. This method designs an enhanced industrial big data platform, and tries to select the best compression and serialisation method for the industrial data platform by evaluating the impact of various compression and serialisation methods on the performance of the big data platform, so as to complete data compression and collection. However, the data compression time of this method is short, resulting in poor timeliness of the whole acquisition process. Guo et al. (2010) proposed a workshop production data acquisition and transmission method for intelligent manufacturing terminal. Based on the industrial control programmable logic controller (PLC) of workshop production line, data is collected through OPCUA, and then Restful server is built to realise data transmission, and the collected data is sent to the downstream digital twin workshop system in the form of JSON data string. The programming of this method is relatively simple, but there is a problem of data acquisition accuracy.

To solve the above problems, this study designed a new real-time data acquisition method of industrial production line based on OLE for process control (OPC) technology. The design ideas are as follows:

1 Firstly, data access specifications are analysed according to the relationship between users and servers, so that users have the ability to establish and operate group objects. Then OPC technology design standard automatic communication interface, and design and establish a unified industrial production line data access structure, so that it is connected to the communication interface, through the establishment of asynchronous data access mode effectively reduce multiple users of the same request, so as to lay a hardware foundation for the subsequent data acquisition.

2 Considering the heterogeneity of data sources of industrial production lines, the piecewise linear interpolation method is adopted to preprocess basic data, remove redundant and similar data, and improve the accuracy of data collection results.

3 For the preprocessed data, the industrial production line data transmission scheme is generated based on multi-point communication of Modbus protocol, and the preprocessed data is transmitted to the data management centre using ASCII transmission mode.

4 For the industrial production line data transmitted to the management centre, adopt the improved decision tree algorithm to screen and classify the similar data. Then the current state of industrial production line data is judged by threshold comparison, and the data collection interval of industrial production line is determined by calculating the deviation degree, so as to complete the real-time data collection of industrial production line and improve the timeliness of the collection process.

2 Application of OPC technology

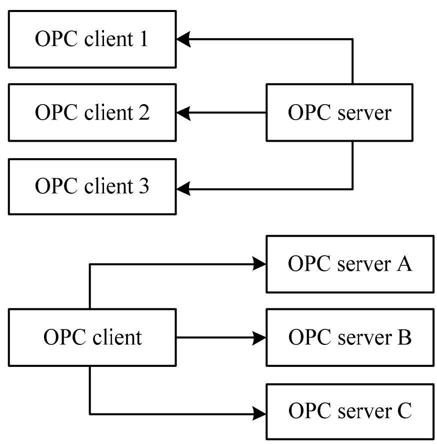
OPC technology belongs to object linking and embedding (OLE for process control), which is based on Windows operating platform and provides effective information integration and interaction functions for enterprise applications in industrial applications (Kaminski et al., 2021; Al-Khateeb et al., 2019). OPC is essentially a mechanism that enables systems to obtain and transfer data from the standard server/client mode to client applications. Its goal is to achieve better interoperability and compatibility in the process control industry, including field systems, instrumentation and commercial office applications.

Based on the above analysis, a unified data query structure of industrial production line is established according to the data access specification and data access mode. In this process, the standard interface of OPC server is used to lay a foundation for subsequent data collection.

2.1 Data access specification analysis

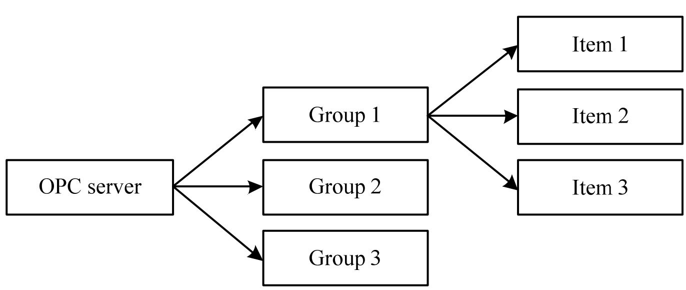
One user can connect to one or more servers, and multiple users can connect to one server at the same time. The connection between the user and the server is shown in Figure 1.

Figure 1 Connection between the user and the server



In Figure 1, the server object is used to provide information about the server object itself and to store group objects (Kohnhäuser et al., 2021; Beňo et al., 2019). Objects are used to provide information about group objects themselves and provide a mechanism for them to organise and manage projects. The relationships between servers, groups, and projects are shown in Figure 2.

Figure 2 Relationships between servers, groups, and projects

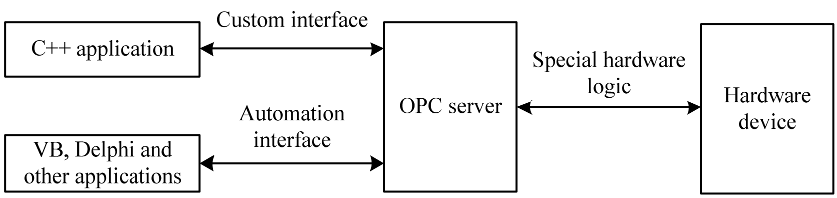


Server objects can communicate with or access data sources. The user communicates with the server through a specific interface. The system provides the client program with a dynamic ability to establish and operate group objects, and these created group objects can make the client operate, update data, etc.

2.2 Use OPC technology to build standard data interface

OPC technology provides two sets of interface standards: OPC custom interface and OPC automatic interface. Figure 3 shows the OPC interface types.

Figure 3 OPC interface type

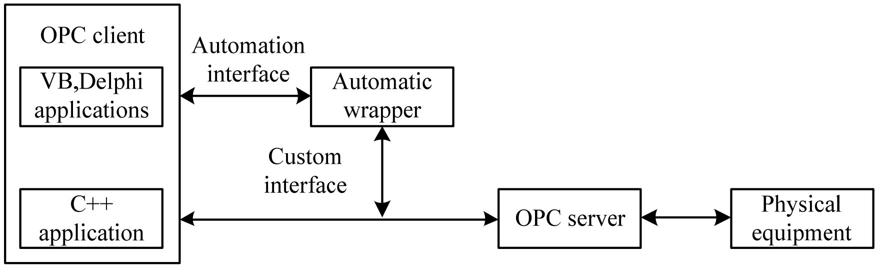


1 A custom interface is a required interface for an OPC server. It describes the interface of an OPC component object and its methods. It is suitable for high-level programming languages such as C++ and can achieve optimal performance.

2 Automated interface: optional, which allows users to use interpreted and macro languages on the OPC server. Users using Delphi and other languages usually use automatic interface, but in the process of running, because of the type of users to check, resulting in a lower efficiency of the system.

OPC servers must have custom interfaces that selectively perform automation. Currently, the OPC Foundation has launched a dynamic linker program, the Automated wrapper program, which allows user programs that support only automated interfaces to access server programs that support only custom interfaces through the wrapper, as shown in Figure 4.

Figure 4 OPC custom interface and automation interface



The automatic interface greatly facilitates the communication between the server and the client programs developed in different languages, and gives users greater freedom to choose development tools. Therefore, this study uses automatic interface to complete the subsequent data access.

2.3 Establish data access forms

After the OPC technology is used to design the standard automatic communication interface, a unified industrial production line data access structure is established in this study to connect the communication interface and lay the hardware foundation for the subsequent data acquisition.

Generally, data access modes fall into two categories: synchronous access mode and asynchronous access mode (Yao and Chen, 2021). In synchronous data access mode, the server accesses the data to the application as needed, and the application transmits the results after the query. The traversal access feature is as follows: when the application finishes reading the OPC item processing data, the application will wait until it finishes reading, and when the OPC item processing data is written, it will be executed. This approach can be used in situations where the user has very little data and is interacting with the server. However, network congestion or excessive user access may degrade the system performance.

Aiming at the above problems, the asynchronous data access mode is optimised in this study. In this mode, when the server receives a program request, the server immediately returns the method. After the data access is performed by the server, it is converted into a user program, and the original user program is treated as a server. The server actively triggers asynchronous access from the application and passes the results of the data access to the application. The application receives data from the server. Asynchronous access features are as follows: The process that reads and writes OPC project data immediately returns after the read request is executed. After reading, the application program will be invoked after the read is completed. When writing an OPC project, write the corresponding processing data into the development OPC project. In this way, the asynchronous mode can effectively reduce the same request from multiple users and reduce the consumption of CPU and network resources.

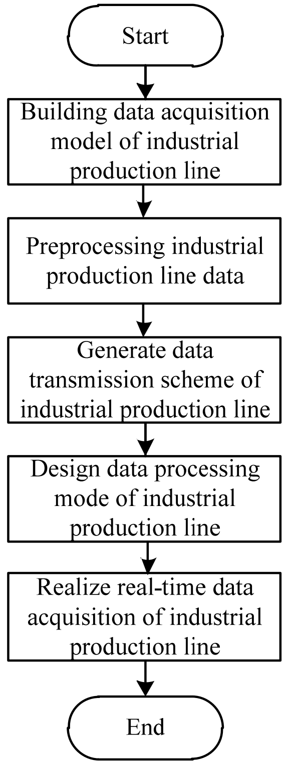
3 Real-time data acquisition method of industrial production line

In this study, the principle of OPC technology mentioned above is used to realise the communication with OPC server by asynchronous communication mode. The standard interface of OPC server is used to collect data in heterogeneous environment, and the collected data is stored in real-time database, and the data of industrial production line is processed.

Considering the heterogeneity of industrial production line data sources, the piecewise linear interpolation method is used to preprocess the data obtained initially. Firstly, the data transmission scheme of industrial production line is generated based on multi-point communication of Modbus protocol (Wang and Li, 2019). Then the improved decision tree algorithm is used to design the data processing mode of the industrial production line and eliminate the redundant information in the industrial production line data. Then, the current state of industrial production line data is judged by threshold comparison, and the interval of data collection is determined to complete the real-time data collection of industrial production line.

The acquisition process studied in this paper is shown in Figure 5.

Figure 5 Flowchart of industrial production line data real-time acquisition algorithm



3.1 Construct data acquisition module of industrial production line

The data access specification is analysed according to the relationship between user and server, and the user has the ability to establish and operate group objects. Then OPC technology design standard automatic communication interface, and design and establish a unified industrial production line data access structure, so that it is connected to the communication interface, through the establishment of asynchronous data access mode effectively reduce multiple users of the same request, so as to lay a hardware foundation for the subsequent data acquisition.

The heterogeneity of data sources should be taken into account when collecting various data from industrial production lines. The establishment of industrial production line data acquisition model mainly includes the following three sub-links:

First, design a common model with an abstract model at its core. Under the action of the abstract model, the relationship of each station in the industrial production line is displayed through the subordinate structure of the model, so as to build a public model with high flexibility according to the data mapping technology, which can be expressed as:

$$P(l) = \beta\left(D_L + S_M\right) \tag{1}$$

In formula (1), D_L represents the object type contained in the abstract model, S_M represents the attribute description contained in the abstract model, and β represents the relationship of each station in the industrial production line.

Then the object information of heterogeneous data source of industrial production line is selected as the public object information. Through in-depth analysis of private object information in heterogeneous data sources of industrial production lines, the specific mapping between private object information and public object information can be expressed as follows:

$$q(W) \rightarrow q(Wp) \tag{2}$$

In formula (2), $q(W)$ represents private object information in heterogeneous data sources of industrial production line, and $q(Wp)$ represents public object information in heterogeneous data sources of industrial production line. In the specific operation, the private object information is summarised, and the information related to the public object is extracted after naming. Place the corresponding public objects, private objects, and the mapping between them into the model.

Finally, the private data of heterogeneous data source of industrial production line is studied and its mapping relationship with public data service is presented. In the process of designing real-time data acquisition method of industrial production line, OPC technology is used to establish a unified data query structure of industrial production line and obtain its internal data information. The processing form of data acquisition module of industrial production line is as follows:

$$E_z = M_{zd}(T + q(W))\frac{P(l)}{q(Wp)} \tag{3}$$

In formula (3), M_{zd} represents various data in the data structure of industrial production line, and T represents the hierarchical structure of heterogeneous data source column of industrial production line. The industrial production line data acquisition model constructed above preliminarily obtains heterogeneous data of industrial production line, which serves as the basis of real-time data acquisition of industrial production line.

3.2 Preprocessing basic data

Considering the heterogeneity of industrial production line data sources, this study adopts piecewise linear interpolation method to preprocess basic data to remove redundant and similar data and improve the accuracy of data acquisition results.

Based on the above preliminary obtained heterogeneous data of industrial production line, a series of real-time heterogeneous data of industrial production line collected in a certain period of time is described as $z_1, z_2, \ldots, z_n$. Assuming that the time interval between z_i and z_{i+1} is equal, a series of heterogeneous data $z_1, z_2, \ldots, z_n$ are obtained within ΔT time interval, remove some redundant heterogeneous data of industrial production line, make the remaining heterogeneous data of industrial production line $z_i, z_{i+1}, \ldots, z_j$ and $z_1, z_2, \ldots, z_n$ is approximate, and the basic properties of the sequence are retained.

Considering the density of heterogeneous data of $z_1, z_2, \ldots, z_n$ industrial production lines and the high efficiency of data processing algorithm, a more complex algorithm cannot be adopted. Therefore, this paper adopts the piece-level linear interpolation method (Li et al., 2020; Di and Xu, 2019), which has a relatively simple algorithm, to preprocess the preliminary acquisition of heterogeneous data of industrial production lines from z_i and z_{i+1} followed by z_{i+2}.

If z_{i+2} is on a linear function determined by two points (x_i, z_i) and (x_{i+1}, z_{i+1}), the value of $M(x)$ at x_{i+1} is $M(x_{i+2})$, and the absolute value of the difference between $M(x)$ and z_{i+2} is within the allowed error bound $\alpha > 0$, then there exists:

$$\left|M\left(x_{i+2}\right)-z_{i+2}\right| \leq \alpha \tag{4}$$

Then remove the point z_{i+1}, and continue to judge z_{i+3}. If $|M(x_{i+2}) - z_{i+2}| > \alpha$, perform the same processing on x_{i+3} based on the data x_{i+1} and x_{i+2}. The start point and end point are retained during processing, that is, (x_1, z_1) and (x_n, z_n) points are retained.

Assuming that $M(x)$ is a linear function determined by the two points (x_k, z_k) and (x_{k+1}, z_{k+1}), the piecewise linear interpolation formula can be obtained:

$$M(x)=z_k \frac{z_{k+1}-z_k}{x_{k+1}-x_k}\left(x-x_k\right) \tag{5}$$

Then:

$$M\left(x_{k+2}\right)=z_k \frac{z_{k+1}-z_k}{x_{k+1}-x_k}\left(x_{k+2}-x_k\right) \tag{6}$$

In the same way, using the $M(x)$ calculation formula, it can be proved:

$$M\left(x_{k+1}\right)=z_k i\left(z_{k+1}-z_k\right)=i z_{k+1}-(i-1) z_k \tag{7}$$

Define that the elements in the set under discussion are orderly, that is, the sequence of set elements cannot be reversed.

3.3 Set up data transmission plan for industrial production line

The heterogeneous data of the industrial production line preliminarily obtained by the above pre-processing need to use effective data transmission scheme to quickly update diversified industrial production line data, so as to complete the unified format processing of industrial production line data. So, in this paper, the data transmission scheme of industrial production line is generated by multi-point communication with Modbus protocol, and the preprocessed data is transferred to the data management centre using ASCII transmission mode.

In the process of data collection and transmission, according to the requirements of data collection of industrial production lines, the data of industrial production lines are unified and standardised management, so as to solve the diversified problems in the process of data collection. Therefore, according to the characteristics of industrial production line data, combined with the multi-point communication protocol Modbus, this research generates industrial production line data transmission scheme.

First of all, Sqoop script is used as one of the important tools of data transmission scheme. Based on HQL statement, data text of production line of structural chemical industry is mapped to generate database table as follows:

$$S(K)=\gamma[q(W) \rightarrow q(Wp)] \tag{8}$$

In addition, in the process of writing Sqoop scripts, the incremental import work of collecting industrial production line data is realised. RTU is a high-concurrency transmission mode. In the process of real-time transmission of industrial production line data, according to the multi-point communication in the Modbus protocol, the real-time industrial production line data is divided into multiple industrial production line data areas, and concurrent transmission is completed.

Finally, transfer the collected unstructured and semi-structured industrial production line data to the industrial production line data management centre using ASCII transmission mode. Comprehensive analysis of the above two data transmission modes, under the effect of cluster management software, effectively schedule and collect industrial production line data. The RTU transmission mode is adopted to implement the transmission of industrial production line data, and the online distributed scheduling method is used to complete the real-time transmission of collected industrial production line data.

3.4 De

sign industrial production line data processing mode

In order to ensure the data collection quality of industrial production line, the improved decision tree algorithm (Zhu et al., 2020; Hu and Chen, 2019) is adopted to screen and classify the similar data in the industrial production line data transmitted to the management centre, and the similar data in the transmitted industrial production line data is removed through this industrial production line data processing mode.

In the process of industrial production line data transmission, it is easy to produce similar data due to the influence of equipment and environment. In the subsequent application of data collection, the above two kinds of data will have a great negative impact. Therefore, in the process of industrial production line data transmission, similar data should be divided. The expression formula of data similarity mode *G* is as follows:

$$G = \{g_1, g_2, \ldots, g_n\} \tag{9}$$

In formula (9), *g* represents the dataset of the decision tree, and *n* represents the number of attributes in the decision tree. In the application of the improved decision tree algorithm, the hash value is used to identify the redundant data contained in the industrial production line data, then the hash value calculation formula is:

$$Hash = \frac{\prod_{i=1} \varepsilon}{\delta} \tag{10}$$

In formula (10), *i* represents a certain collected data, *Hash* represents a hash value, ε represents a hash factor, and δ represents a calculation auxiliary parameter. According to the above-mentioned hash value calculation result, the multi-level redundant data in the transmission data is eliminated.

3.5 Real-time data acquisition of industrial production line is realised

According to the data collection, transmission and preprocessing technology of the industrial production line, the effective data collection of the industrial production line can be completed. In order to strengthen the real-time performance of industrial production line data collection, this study uses the threshold comparison method to judge the current status of industrial production line data, so as to determine the data collection interval of industrial production line, complete the real-time collection of industrial production line data, and improve the timeliness of collection.

The current collected industrial production line data value is expressed as H_0, and according to the industrial production line data with reference to the threshold H, it can be concluded that:

$$H = \begin{cases} H_{\min} & H_0 \le H_{\min} \\ H_{\max} & H_0 \ge H_{\min} \end{cases} \tag{11}$$

In formula (11), $H_{\min}$ represents the minimum threshold of data of this type of industrial production line, and $H_{\max}$ represents the maximum threshold of data of this type of industrial production line.

Based on the above calculation results, the data reference threshold of real-time data acquisition strategy of industrial production line is obtained. On this basis, the calculation results of data deviation degree of industrial production line are obtained:

$$H_C = \left| H_0 - H \right| \tag{12}$$

$$H_R = H_{\max} - H_{\min} \tag{13}$$

In formulas (12) and (13), H_C represents the difference between the collected industrial production line data and the reference threshold, and H_R represents the difference between the maximum and minimum thresholds. Based on the above calculation results, the adaptive strategy of industrial production line data collection is expressed as:

$$Z_\theta = \begin{cases} Z \times \left(1 - \dfrac{H_C}{H_R}\right) \times \left(1 - \dfrac{F_0}{F}\right) & H_C \le H_R \\ \mu & H_C \ge H_R \end{cases} \tag{14}$$

In formula (14), Z_θ represents the updated data collection interval of the industrial production line, Z represents the initial data collection interval value of the industrial production line, F_0 represents the initial energy of the network node, F represents the current energy of the network node, μ represents the lowest data collection interval of the industrial production line.

To sum up, the unified data access structure of industrial production line is established after the standard automatic communication interface is designed by using OPC technology. Then considering the heterogeneity of industrial production line data sources, the piecewise linear interpolation method is used to preprocess the basic data, remove the redundant and similar data, and then the improved decision tree algorithm is used to filter and classify the similar data. Finally, the current state of industrial production line data is judged by the way of threshold comparison, and the data collection interval of industrial production line is determined by calculating the deviation degree to complete the real-time data collection of industrial production line.

4 Experimental simulation and analysis

In order to verify the effectiveness of OPC-based real-time data acquisition method of industrial production line, the following experiments are designed.

4.1 Setting up the experiment environment

In order to verify the effectiveness of the real-time data acquisition method of industrial production line based on OPC technology, the industrial production line of a certain product is taken as the research object, and MatrikonOPC simulation server is selected as the experimental platform. Use Modbus/TCP protocol to communicate with OPC server as data source, select Modbus host simulator Modbus Poll and protocol conversion module to test its function for Modbus communication, configure a Siemens S7300 PLC as Profibus MPI protocol communication mode to provide protocol conversion module data. On this basis, through the establishment of OPC UA client, it is connected with the on-site industrial computer PLC of the industrial production line, and data collection is carried out. Random 1,000 pieces of continuous data are selected to export, and method of Geng et al. (2019), method of Guo et al. (2010) and method of this paper are used to collect real-time data of industrial production lines to verify the effectiveness of the proposed method.

4.2 Collect and compare the packet loss rate

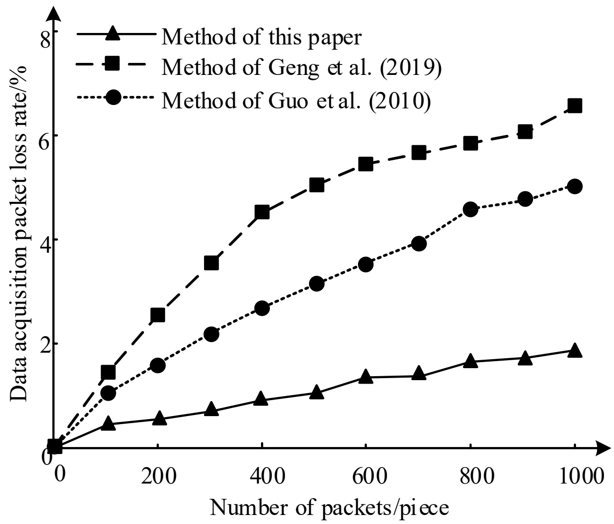
In order to verify the real-time data acquisition effect of industrial production line, the packet loss rate of data acquisition is taken as the evaluation index. The lower the packet loss rate of data acquisition, the better the real-time data acquisition effect of industrial production line is. The calculation formula is as follows:

$$D_B = \frac{D_S}{C_Z} \times 100\% \tag{15}$$

In formula (15), D_S represents the number of lost packets in the collection, and C_Z represents the number of collected packets. The packet loss rate comparison results of real-time data collection of industrial production line by different methods are shown in Figure 6.

Figure 6 shows that with the increase of the number of data packets collected, the packet loss rate of real-time data collection of industrial production line by different methods increases accordingly. When the number of data packets collected reaches 1,000, the packet loss rate of industrial production line data in real-time collection of method of Geng et al. (2019) is 6.52%, and the packet loss rate of industrial production line data in real-time collection of method of Guo et al. (2010) is 5.1%. However, the packet loss rate of real-time collection of industrial production line data by method of this paper is only 1.89%. It can be seen that the packet loss rate of real-time data collection of industrial production line by method of this paper is low, indicating that the real-time data collection effect of method of this paper is good.

Figure 6 Packet loss rate comparison results of different methods



4.3 Accuracy comparison

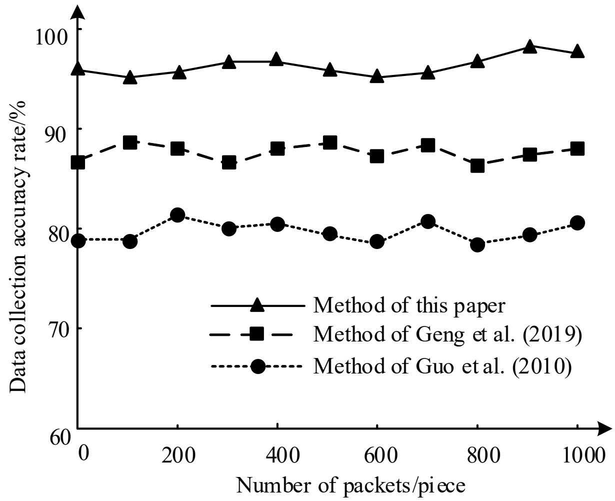
To further verify the accuracy of real-time data collection of industrial production lines, the accuracy of data collection is taken as an evaluation index. The higher the data acquisition accuracy is, the higher the real-time data acquisition accuracy of the industrial production line is. Its calculation formula is as follows:

$$A_C = \frac{Z_C}{C_Z} \times 100\% \tag{16}$$

In formula (16), Z_C represents the number of data packets correctly collected during collection. The comparison results of real-time acquisition accuracy of industrial production line data by different methods are shown in Figure 7.

According to Figure 7, when the number of data packets to be collected reaches 1,000, the real-time collection accuracy of industrial production line data of method of Geng et al. (2019) is 88.5%, and that of industrial production line data of method of Guo et al. (2010) is 80.2%. The real-time data collection accuracy of method of this paper is up to 96.8%. Therefore, method of this paper has a high real-time collection accuracy.

Figure 7 Comparison results of real-time acquisition accuracy of different methods



4.4 Comparison of collection timeliness

On this basis, the timeliness of industrial production line data collection is verified. In this validation, the time consuming of data acquisition process is taken as an evaluation index. The shorter the collection time, the higher the collection efficiency is. Table 1 shows the comparison results of acquisition process time using different methods.

Table 1 Comparison results of collection process time between different methods

Number of packets (piece)	*Method of this paper (s)*	*Method of Geng et al. (2019) (s)*	*Method of Guo et al. (2010) (s)*
200	3.2	6.2	9.1
400	5.9	9.5	13.4
600	8.2	13.3	17.6
800	10.6	16.8	21.8
1,000	12.5	19.7	25.2

The analysis of Table 1 shows that as the number of data packets collected increases, the acquisition process time of different methods increases. When the number of data packets collected reaches 1,000, the acquisition process of reference method of Geng et al. (2019) takes 19.7 s, and that of reference method of Guo et al. (2010) takes 25.2 s. However, the acquisition process of method of this paper takes only 12.5 s. Therefore, method of this paper takes a short time to collect data of industrial production lines, indicating that method of this paper has a high timeliness of collection.

5 Conclusions

This paper proposes a real-time data acquisition method of industrial production line based on OPC technology. Based on the principle of OPC technology and multi-point communication of Modbus protocol, real-time data acquisition of industrial production line is carried out. This method can improve the accuracy and efficiency of real-time data collection of industrial production line effectively.

But this method theory does not consider the compatibility of the system. Therefore, in the following research, drivers for other protocols can be further developed to enhance their compatibility. In addition, the influence of other pretreatment methods on the acquisition effect will be analysed.

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