Design of Energy Refinement Management System for Agricultural Machinery Painting Based on Internet of Things

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Abstract. At present, because of extensive energy management methods and manual meter reading collection methods, the domestic agricultural machinery manufacturing industry has caused serious energy waste in agricultural machinery production line, which can not meet the energy management needs of modern agricultural machinery enterprises. In view of the above problems, after thorough analysis of agricultural machinery production process and its demand for energy management, this paper takes full advantage of the characteristics of low cost and comprehensive perception of the Internet of Things, puts forward an energy refinement management system of painting workshop based on the Internet of Things, and achieves energy consumption tracking of production workpieces and energy refinement management of workshop. BP neural network is used to predict energy consumption and diagnose energy saving in workshop. Finally, the test application in the demonstration project shows that the system can real-time and accurate monitor the abnormal situation of energy consumption and energy consumption in the workshop, and realize the fine management of energy in the agricultural machinery painting production line, thus saving production energy and improving enterprise efficiency.

1. Introduction
As a big energy-consuming country, China clearly pointed out in the 13th Five-Year Plan that we should save energy and reduce consumption. However, at the present stage, the collection of energy data in agricultural machinery production still uses manual methods, which leads to problems such as waste of energy and poor management in agricultural machinery manufacturing. With the maturity of the Internet of Things and other technologies, it is possible to collect and manage the production and energy consumption data of the workshop in a unified way, which reduces the drawbacks of inaccuracy of manual meter reading and data not real-time[1]. Experts at home and abroad have carried out extensive research on the application of Internet of Things in the field of energy management, and have achieved certain results. For example, the user-centered energy management system based on the Internet of Things proposed in literature [2] realizes the management of energy consumption in smart home. In [3], in order to solve the problem of excessive energy consumption, a unified framework for energy-saving optimization and scheduling of smart cities based on Internet of Things was designed, and its feasibility was proved by simulation.

Due to the low requirement of agricultural machinery manufacturing technology and high cost of energy refinement management system, there are still few energy management systems for agricultural
machinery painting. Therefore, in this paper, a new energy refinement management system based on the Internet of Things (IOT) is developed, which is a low-cost equipment-area-workshop system. On the basis of realizing data overall perception, the relationship between equipment energy consumption and operation parameters is established by tracking the energy consumption of the workpiece. In order to optimize the operation parameters of the equipment, the horizontal comparative analysis of the equipment is carried out. At the same time, the energy management granularity of the production line is refined vertically to regions, teams and equipment to provide data support for optimizing the process and summing up team operation experience. Combining BP neural network to realize energy consumption prediction, timely diagnosis and analysis for abnormal energy use of equipment or region, so as to reduce abnormal energy use of equipment, improve service life of equipment, and realize fine management of energy.

2. IoT-based energy management architecture

2.1. Paint shop process and equipment composition
There are two main sections in the painting workshop, one is the pre-treatment electrophoresis section, the other is the spraying section, which includes midway and finish paint[4]. After each part is finished, it needs to be dried and cooled, and finally the exhaust gas will be treated uniformly. These two sections plus drying and exhaust gas treatment equipment account for more than 90% of the total number of workshop equipment. The process flow chart is shown in Figure 1.

![Coating process flow chart](image)

Figure 1. Coating process flow chart.

The pre-treatment electrophoresis section is composed of individual tanks, each of which belongs to a process unit and is equipped with pumps, fans, etc. Drying and strong cooling system mainly includes air supply and exhaust system, equipped with high power fans and gas heating devices. The spraying system consists of air conditioning systems and ventilation systems. It is responsible for the intermediate coating and topcoat work and each of system is equipped with high-power fans, water pumps and gas heating devices. The exhaust gas treatment system consists of a filtration system, a heating and humidity control system, a zeolite runner system and an RTO system. It is responsible for the treatment of exhaust gases in the paint booth and the drying chamber and the most widely used equipment is high-powered fans and gas heating devices[5].

Therefore, the main energy-consuming equipments in painting workshop are high-power fan, water pump, air conditioning and heating device. Therefore, eliminating the ineffective power consumption of equipment, managing the energy consumption of equipment under normal operation, and strengthening the coordinated operation of various processes are very important for the refined management of the overall energy in the workshop.

2.2. Hierarchical Management Architecture
Traditional energy management system of agricultural machinery painting is mostly based on measurement data, and its granularity is relatively coarse. The management does not cover all teams and equipment, nor integrates production performance and process parameters, nor does it carry out energy management from the height of the overall cooperative operation of the workshop. Based on the terminal acquisition module of the Internet of Things, the system adopts four-tier management mode to manage the data of workshop energy and equipment electrical parameters layer by layer. First is the overall perception of workshop data, including production data and energy consumption data.
On the basis of the data, the correlative analysis of equipment parameters and energy consumption data is carried out, and the area, team and equipment are managed in detail, and the rationality of energy utilization of equipment or area is obtained, so as to optimize the workshop process, equipment operation parameters, adjust production rhythm and so on, and constantly tap the potential energy-saving space. Through the performance management of team energy consumption, and then constantly sum up energy-saving experience, refined management of workshop energy. The first layer is the collection of electrical parameter data of the underlying device. The second layer is the collection of data on the energy consumption of the area and the team. The third layer is data storage. And the fourth layer is the correlation analysis of the energy consumption data and production information of the entire workshop. The block diagram is shown in Figure 2.

Figure 2. Energy refined management architecture block diagram.

Figure 3. System network architecture.
2.3. Network Architecture

In order to realize the refined management of workshop energy, the first step is to complete the comprehensive perception of the operation status of equipment and other parameters in the workshop, and to collect the energy consumption data of various regions and teams. For example, the temperature and humidity value in spray paint rooms, the operation status of RTO and other equipment in exhaust gas treatment system, the occupancy, arrival and deceleration signals of workpieces in conveying system, etc. And three-phase current, voltage, power, harmonic and other parameter information of high-power fans, pumps and other equipment. The network architecture of the system is divided into four layers, the first layer is the data acquisition layer, the second layer is the network communication layer, the third layer is the data management layer, and the fourth layer is the application layer[6].

System network architecture diagram shown in Figure 3.

Data acquisition layer: This layer contains equipment for each PLC, smart meter, three-phase electrical parameter module, concentrator, etc. The PLC is responsible for the collection of production data, and the three-phase electrical parameter module is responsible for the collection of parameters such as energy consumption of each device. The concentrator is responsible for the collection of data of each smart meter.

Network communication layer: It is the intermediate link of data acquisition and storage analysis. The core part is the switch. The SCALANCE X400 is used to set up the workshop communication network. The communication protocol uses the standard TCP/IP protocol.

Data service layer: Mainly composed of database and intelligent decision center. The database contains real-time and historical databases. Intelligent decision center contains various data processing algorithms, such as energy-saving prediction algorithm, energy diagnosis algorithm, etc., used to process and analyze energy consumption data and equipment information, optimize production processes, improve equipment energy efficiency, etc.

Application display layer: Mainly composed of various terminals such as mobile phones, desktops, large screens, etc. It is convenient for users to view the energy consumption of the workshop in the form of APP or WEB, so as to effectively carry out production management.

3. Fine Energy Management Function

3.1. Energy Consumption Tracking of Spraying Workpiece

Tracking and calculating the energy consumption of each component is the premise of realizing energy refinement management. Key information such as component number, component production quantity, component production time in each process is obtained from ERP system and workshop production system. Energy consumption of each region and group is collected in real time by energy meter, and the time granularity is accurate to second. According to the distribution and configuration of energy meter in workshop, the energy consumption tracking calculation of each component in pretreatment electrophoresis, drying and spraying processes can be completed. The energy consumption of components in each process can be tracked by adding the energy consumption of components in each process.

3.2. On-line Monitoring of Equipment Energy Consumption

The three-phase current, voltage, harmonic, power factor, energy consumption and other electrical parameters information of the equipment are collected real-time through the electrical parameter detection module, so as to realize the real-time monitoring of the electrical parameters and energy consumption information of the equipment. Further, through the analysis and processing of electrical parameters of equipment, energy-saving diagnosis and fine energy management of equipment can be realized.
3.3. Statistical analysis of data
Through on-line analysis and decision-making of energy-saving optimization strategy group, process structure and equipment parameters can be further optimized. Further, through the analysis of historical data, the prediction of energy consumption information of single vehicle is realized. At the same time, the forecast of overall energy consumption trend is realized by combining ERP production plan. Combined with electricity price, the cost is forecasted and analyzed, and the production strategy of peak load shifting is implemented. The system collects the electrical parameters of the equipment in real time through the electrical parameter module, and informs the workshop managers of the abnormal energy-using equipment in time for investigation. The system diagnoses the use cycle of key energy-using equipment and recommends energy-saving equipment to purchasers. Through the workshop allocation of energy meter, on the basis of accurately collecting energy data, the management granularity is refined, and the refined statistical analysis of energy data for each group and region is realized.

3.4. Fine report management
Report management is the standard of modern system. The system realizes the report classification management of different fault information according to the fault type. For workshop energy consumption, energy consumption report is refined to workshop, region and equipment. And the system establish maintenance and diagnostic report forms of equipment according to electrical parameters of equipment. At the same time, the system further refines the report management of ERP production plan and energy loss report. On this basis, the detailed query of report forms can be realized through logical formula, and the efficiency of enterprises can be improved. And all kinds of reports have the function of data export, so as to provide help for energy refinement management of workshop.

4. Key Technologies and Implementation

4.1. Data collection and integration

4.1.1. Production data collection. The production data is mainly the daily production data of the PLC in the workshop. It can be directly connected to the PLC and industrial network on site through the OPC server. Then through the data interaction between the OPC client and the server, the collection of PLC data is realized[7]. The data flow chart of the OPC client is shown in Figure 4.

![Figure 4. Production data collection.](image)

4.1.2. Energy data collection. Intelligent meters are responsible for the collection and statistics of energy consumption and other data in various regions, including regional electricity, water, gas, etc. Intelligent meters communicate with concentrator via 485 bus. As a kind of IoT intelligent hardware, the concentrator uses the industry standard RS485 and the underlying instrument to communicate and collect the data of the intelligent meter. The uplink uses TCP/IP protocol to communicate with the
server, and the collected data is uploaded in the standard XML format. The concentrator acquisition process is shown in Figure 5.

4.1.3. Equipment electrical parameter collection. The electrical parameter detection module can collect the three-phase current of the device (Ia, Ib, Ic), line voltage (Ua, Ub, Uc), three phase power, reactive power (Q), power factor (cosφ), Harmonic, power (E) and other information. And the electrical parameter detection module can upload data to the server for storage analysis via Ethernet. Therefore, through the comprehensive perception of the Internet of Things, it is possible to fully cover, multidimensional, and hierarchically collect information on energy consumption in various areas of the workshop and electrical parameters of major power-consuming devices.

4.2. Data storage
The system data is stored using the MySQL database. As a relational database, MySQL database is widely used in small and medium-sized systems because of its small size, fast speed, low cost and open source[8]. Database table contains device table, area table, etc. The database relationship E-R model is shown in Figure 6.

4.3. Energy consumption prediction and diagnosis algorithm

4.3.1. Energy Consumption Prediction Based on BP Neural Network. In this paper, BP neural network is used to predict energy consumption of single equipment. Because the energy consumption of the workshop is affected by factors such as the temperature and humidity of the outdoor environment, the energy consumption of each area of the workshop is first obtained from the historical database, then the daily temperature and the number of production workpieces are obtained from the weather bureau
and ERP respectively. Further, the data is statistically classified by day and then normalized. Finally, the data is imported into the BP neural network model, and the prediction results are analyzed. The flow chart of BP neural network prediction is shown in Fig 7.

![BP neural network prediction flow chart](image)

**Figure 7. BP neural network prediction flow chart.**

The general steps are to initialize the network parameters first, then output hidden layer and output layer, and use the error as feedback to update the weights. Finally, when the prediction error reaches the expectation or the number of iterations reaches the maximum, the output is obtained.[9]

Through the prediction of the energy consumption of the monomer, it can provide a powerful basis for the energy warning and energy cost optimization control of the equipment. At the same time, based on the single vehicle energy consumption and ERP production data, the future workshop energy consumption can be predicted, and then the peak-valley electricity price can be used to estimate the cost, so as to help enterprises to use peak-valley electricity price for flexible production, and optimize the energy cost structure.

4.3.2. Energy diagnosis. Based on the BP neural network, the energy consumption of the device can be predicted, and the device can be used to set an alarm. When the energy consumption of the equipment exceeds the predicted value, the relevant electrical parameters of the equipment are extracted for correlation analysis. Aiming at the current, voltage, harmonic and service life of the equipment, the target positioning comparative analysis is carried out to find out the causes of the problems, and show it in the form of histogram, polygraph or pie chart to facilitate managers to find out the causes of abnormalities. Finally the system will generate diagnostic reports. The diagnostic flow chart is shown in Figure 8.

![Energy Diagnostic Flow Chart](image)

**Figure 8. Energy Diagnostic Flow Chart.**

At the same time, after a long period of data accumulation, horizontal comparison analysis of the operating parameters of the same equipment can be performed to optimize the operating parameters of the equipment and continuously tap the energy saving potential of the equipment. Further, the
equipment for low energy consumption can be selected for the next time to purchase, which lays a foundation for the future energy saving of the workshop.

5. Case application
Taking an agricultural machinery painting workshop as the research object, 35 key energy-consuming equipments in the workshop, such as adsorption fan, axial fan and heating device in spraying system, are equipped with electrical parameter detection module. In addition, 28 intelligent meters are added to electrophoresis, drying and spraying areas of pretreatment, so as to realize the comprehensive collection of energy consumption in each area of workshop. After several months of operation, the energy consumption per unit time of the equipment is reduced by 3% on average, the energy consumption ratio of the general plant is reduced by 4.5%, and the economic loss caused by the failure of the equipment is reduced by adjusting the operating parameters of the fan and other equipment.

As shown in Figure 9, through on-line monitoring of the energy consumption meter in the workshop, the online status of the instrument can be grasped in real time. For the off-line or faulty instrument, the workshop managers can be notified timely for maintenance, so as to reduce the loss of energy consumption data caused by the instrument failure. Figure 10 is an overview of workshop energy consumption. It is convenient to view past historical data through time selection. Through pie chart, we can know the distribution of energy consumption in workshop, and help managers to manage energy consumption in high energy consumption areas. At the same time, the energy consumption change of each region is monitored by histogram, and the relevant equipment or regional information is extracted from the abnormal time point of energy consumption, so that the abnormal energy consumption can be checked in time. Figures 11 and 12 are the harmonic and cycle voltages of adsorbing fans. Through the detection of the electrical parameters of fans and other equipment, we can find the problems existing in the operation of the equipment and remove the problems as soon as possible, so as to achieve early operation and maintenance, and prevent the waste of energy consumption caused by the aging of the equipment and the shutdown caused by the equipment failure.

6. Conclusion
This paper builds a low-cost and easy-to-deploy energy-saving management system architecture for agricultural machine painting workshops based on the Internet of Things technology to meet the energy management needs of agricultural machinery production lines. Through the workshop-area-equipment pyramid management mode, the workshop energy consumption is refined and managed, which realizes the comprehensive mastery and real-time monitoring of the workshop energy. Then we
develop the energy refined management system of the agricultural machine painting workshop based on the B/S architecture model, data acquisition and storage analysis technology. Finally, the test application in the demonstration project shows that the system can real-time and accurate monitor the abnormal situation of energy consumption and energy consumption in the workshop, and realize the fine management of energy in the agricultural machinery painting production line, thus saving production energy and improving enterprise efficiency.

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