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The Application of IoT-Empowered Intelligent Control System for High-Speed Dispersing Equipment in Textile Printing and Dyeing Additives Production

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Abstract

This paper focuses on the textile printing and dyeing additives production sector, targeting the high-speed dispersing equipment, a crucial production device. A smart control system based on Internet of Things (IoT) technology has been developed and applied. By installing high-precision sensors on the equipment to real-time monitor 12 key parameters such as rotational speed and temperature, and leveraging advanced AI algorithms to dynamically optimize the stirring process, the system has been proven effective. It can reduce labor costs and reliance on skilled workers. Based on these achievements, a universal intelligent equipment upgrade framework for the textile printing and dyeing additives industry is proposed, aiming to provide references for other enterprises' intelligent transformation within the industry. This research not only offers strong support for Wuxi Lianda Chemical's production efficiency improvement and cost control, but also paves a new way for the sustainable development and intelligent upgrade of the whole textile printing and dyeing additives industry.

Keywords: Internet of Things (IoT), textile printing and dyeing additives, high-speed dispersing equipment, intelligent control system, production efficiency, energy consumption reduction, product quality, intelligent upgrade, universal upgrade framework, AI algorithm optimization, real-time data acquisition, dynamic parameter adjustment, green and sustainable development

1. Introduction

1.1 Development Status and Challenges of the Textile Printing and Dyeing Additives Industry

As an important branch of the chemical industry, the textile printing and dyeing additives industry has seen a continuous growth in market demand along with the ongoing development of the global textile industry. In recent years, the stricter environmental policies and consumers' increasing demand for high-quality textiles have driven the expansion of the industry scale, with a particularly prominent demand for efficient, environmentally-friendly and multifunctional textile printing and dyeing additives. However, traditional production processes mainly rely on manual operation and experience, which have many limitations. They include low production efficiency that cannot meet the needs of large-scale production, high energy consumption that increases production costs, unstable product quality that cannot guarantee consistency, and the rising labor costs that add to the production burden of enterprises.

1.2 Development and Application Trends of IoT Technology in the Industrial Field

Meanwhile, the rapid development of IoT technology has brought new opportunities to traditional manufacturing. IoT, through various information-sensing devices such as sensors, Radio Frequency Identification (RFID) technology, Global Positioning System (GPS), etc., can real-time collect data of any objects or processes that need to be monitored, connected and interacted with. It then sends the data to the data processing center via a data transmission network for intelligent processing. Its basic architecture consists of the perception layer, transmission layer and application layer, which are responsible for data collection, transmission and processing, respectively. The application of IoT technology in intelligent manufacturing has achieved remarkable results. For example, by installing sensors on production equipment to real-time collect equipment operation data, combined with big data analysis and artificial intelligence algorithms, predictive maintenance of equipment can be realized, improving the equipment operation efficiency and reliability (Xiong, X., Zhang, X., Jiang, W., Liu, T., Liu, Y., & Liu, L., 2024). In addition, IoT technology is also widely used in production process optimization, quality control, supply chain management and other fields, significantly enhancing the intelligent level of manufacturing.

1.3 Research Purpose

This research aims to empower traditional textile printing and dyeing additives production with IoT technology, and develop a smart control system for high-speed dispersing equipment based on IoT. By real-time collecting key parameters and combining AI algorithms to optimize the stirring process, significant improvements in production efficiency, energy consumption reduction and product quality stability are expected. Based on the actual operation data of Wuxi Lianda Chemical, the role of this system in reducing labor costs and stabilizing product consistency will be analyzed. Meanwhile, a universal intelligent equipment upgrade framework for the textile printing and dyeing additives industry will be proposed to provide references for the industry's intelligent upgrade.

2. Technical Principle and Current Status of "High-Speed Dispersing Equipment for Softener Production"

2.1 Working Principle of High-Speed Dispersing Equipment

High-speed dispersing equipment is one of the indispensable devices in the production of textile printing and dyeing additives, especially playing a key role in the softener production process. Its core function is to fully mix raw materials through the high-speed rotation of stirring blades, ensuring uniform distribution of components, thereby improving product quality and production efficiency. The equipment is usually driven by a motor, with the rotational speed controlled by a frequency converter to meet the needs of different production stages. The design and layout of the stirring blades are crucial to the mixing effect. Reasonable blade shape and angle can generate effective turbulence to accelerate the dispersion process of raw materials. Meanwhile, the temperature control inside the equipment is also an important factor affecting product quality. Through the built – in heating or cooling system, the reaction process is ensured to proceed at an appropriate temperature, thus guaranteeing the stability and consistency of the product.

2.2 Current Operation Status and Problems of Traditional High-Speed Dispersing Equipment

Despite the wide application of high-speed dispersing equipment in the production of textile printing and dyeing additives, there are still many problems in the operation of traditional equipment. Firstly, the parameter settings of traditional equipment mostly rely on manual experience and fixed patterns, lacking real-time monitoring and dynamic adjustment capabilities. This leads to the inability to flexibly adjust stirring speed and temperature according to raw material characteristics and production needs during the production process, thereby affecting production efficiency and product quality. Secondly, traditional equipment has high energy consumption. Due to the lack of precise control means, it often needs to run for a long time to achieve the ideal mixing effect, which not only increases production costs but also causes unnecessary environmental burden. In addition, the stability of product quality is difficult to guarantee. Due to the instability of manual operation and equipment performance fluctuations, the consistency of the product is poor, and batch-to-batch differences are prone to occur. Finally, the maintenance cost of traditional equipment is high. Due to the lack of real-time monitoring and fault early warning functions, equipment failures are often difficult to detect in advance, leading to increased repair costs and extended production downtime.

2.3 Application Potential of IoT Technology in High-Speed Dispersing Equipment

The rapid development of IoT technology provides new ideas and methods to solve the problems existing in traditional high-speed dispersing equipment. By installing various sensors such as rotational speed sensors, temperature sensors, pressure sensors, etc. on the equipment, key parameters during the equipment operation process can be real-time collected. These data are transmitted to the central control system via a wireless network, combined with advanced data analysis and artificial intelligence algorithms to realize dynamic optimization of the stirring process. For example, based on the real-time collected rotational speed and temperature data, the system can automatically adjust the stirring speed and heating power to ensure that the production process is always in the best state. In addition, IoT technology can also realize remote monitoring and fault early warning of equipment. By real-time analyzing equipment operation data, potential failures can be detected in advance to reduce downtime and maintenance costs. Through the application of IoT technology, not only can production efficiency be significantly improved and energy consumption reduced, but also the stability and consistency of product quality can be enhanced, providing strong support for the intelligent upgrade of the textile printing and dyeing additives industry.

3. Development of Intelligent Control System for High-Speed Dispersing Equipment Based on IoT

3.1 System Architecture Design

To achieve intelligent control of high-speed dispersing equipment, a complete IoT system architecture has been designed. The architecture consists of the perception layer, transmission layer, data processing layer and application layer. In the perception layer, a variety of high-precision sensors, including rotational speed sensors, temperature sensors, pressure sensors, etc., have been installed to real-time collect key parameters during equipment operation.

3.2 Research on Intelligent Control Algorithm

The intelligent control algorithm is the core part of the entire system. A deep learning algorithm has been adopted to optimize the stirring process. Specifically, the Long Short-Term Memory (LSTM) model has been chosen, as it can effectively deal with time-series data and capture the dynamic relationships between parameters. Production data from Wuxi Lianda Chemical over the past year, including rotational speed, temperature, pressure, energy consumption and product quality indicators, etc., have been used for model training. The training dataset contains over 10,000 samples, each with 12 feature parameters (Liu, Z., 2022). After multiple rounds of training and validation, the LSTM model constructed has achieved an accuracy rate of 92.5% and a recall rate of 90.3% on the test set.

Table 1.

Project	**Description**
Core part	Intelligent control algorithm
Algorithm type	Deep learning algorithm
Specific model	Long Short-Term Memory (LSTM)
Training result	Test set accuracy rate: 92.5% Test set recall rate: 90.3%

3.3 System Integration and Testing

After the completion of system architecture design and algorithm development, system integration and testing have been carried out. First, hardware integration of sensors, wireless communication modules, edge-computing devices and cloud-based servers has been conducted to ensure the compatibility and communication stability between various components. Then, field tests have been performed on Wuxi Lianda Chemical's thousand-ton-class production line. The test results show that with the application of the intelligent control system, the production efficiency of softeners has been increased by 40%, and the unit energy consumption has been reduced by 20%. During the testing process, the stability and reliability of the system have also been assessed. The system has been continuously operated for 30 days without any failures, and the stability of data collection and transmission has reached 99.5%. This indicates that the intelligent control system not only can significantly enhance production efficiency and product quality, but also possesses high stability and reliability, meeting the demands of industrial production.

4. Application Practice of Intelligent Control System in Wuxi Lianda Chemical

4.1 Overview of Wuxi Lianda Chemical's Thousand-Ton-Class Production Line

The thousand-ton-class production line of Wuxi Lianda Chemical Co., Ltd. is one of the company's important production facilities, mainly producing textile printing and dyeing additives, including softeners, detergents and refining agents. Since its commissioning in 2015, the production line has been using traditional production processes and equipment. Before the implementation of the intelligent control system, the production efficiency of the production line was relatively low. In terms of energy consumption, the average energy consumption per batch was 150kWh (Huang, J., & Qiu, Y., 2025), and labor costs accounted for 30% of the total production costs. The consistency of product quality was poor, with a product pass rate of 90% (Liu, Z., 2025). These current situations indicate that there is a significant room for improvement in efficiency, energy consumption and quality of the production line.

Table 2.

Project	Description
Traditional production mode	Production efficiency: Low Energy consumption: 150kWh per batch Labor cost proportion: 30% of total production costs Product quality consistency: Poor Product pass rate: 90%

4.2 Implementation Process of Intelligent Control System

In order to improve production efficiency, reduce energy consumption and enhance product quality, Wuxi Lianda Chemical decided to introduce an intelligent control system based on IoT. The implementation process includes system installation and debugging, personnel training and technical support, as well as production line transformation and optimization. High-precision sensors, including rotational speed sensors, temperature sensors and pressure sensors, have been installed on the high-speed dispersing equipment to real-time collect key parameters during the equipment operation process. At the same time, industrial-grade wireless communication modules have been installed to ensure stable data transmission to the data processing layer. Edge-computing devices have been deployed beside the production line for data preprocessing and preliminary analysis. The preprocessed data is transmitted to the cloud-based server for further analysis and storage. The intelligent control system has been developed in the cloud, integrating advanced AI algorithms and user-friendly interface design. Production line operators have been trained on the system, including the use of sensors, operation of the data collection system, and operation of the intelligent control system interface. A technical support team has been provided to be responsible for the daily maintenance and troubleshooting of the system. A remote monitoring and fault early warning mechanism has been established to ensure real-time monitoring of equipment operation status and early detection of potential failures. Based on the suggestions of the intelligent control system, the stirring blades of the high-speed dispersing equipment have been optimized in design to improve mixing efficiency. The control strategy of the heating and cooling system has been adjusted to ensure that the reaction process proceeds at the optimal temperature, and the production process has been optimized to reduce unnecessary waiting time and intermediate links.

4.3 Application Effect Analysis

The application of the intelligent control system on Wuxi Lianda Chemical's thousand-ton-class production line has achieved significant results. The production time has been shortened from 6 hours per batch to 3.6 hours per batch, increasing production efficiency by 40% and raising annual production capacity from 5,000 tons to 7,000 tons, an increase of 40%. The energy consumption per batch has been reduced from 150kWh to 120kWh, resulting in a 20% decrease in unit energy consumption (Huang, T., Yi, J., Yu, P., & Xu, X., 2025). With the increased automation level of the system, the intensity of manual operation has been significantly reduced, and the proportion of labor costs in total production costs has decreased from 30% to 20% (Yu, D., Liu, L., Wu, S., Li, K., Wang, C., Xie, J., ... & Ji, R., 2025). The consistency of product quality has been significantly improved, with the product pass rate rising from 90% to 95% (Li, X., Cao, H., Zhang, Z., Hu, J., Jin, Y., & Zhao, Z., 2024). By real-time monitoring and dynamic control, batch-to-batch differences have been reduced, enhancing the market competitiveness of the product.

Table 3.

Project	Traditional production mode	After application of intelligent control system
Production time	6 hours per batch	3.6 hours per batch
Production efficiency	-	-
Annual production capacity	5,000 tons	7,000 tons
Energy consumption per batch	150kWh	120kWh
Labor cost proportion	30%	20%
Product pass rate	90%	95%

5. A Universal Upgrade Framework for Intelligent Equipment in the Textile Printing and Dyeing Additives Industry

5.1 Key Elements for Intelligent Equipment Upgrade

In the textile printing and dyeing additives industry, the intelligent upgrade of equipment is the key to achieving intelligent and efficient production processes. The key elements for intelligent equipment upgrade include the enhancement of intelligent perception capabilities, the strengthening of data processing and analysis capabilities, and the improvement of automation and intelligent control levels. The enhancement of intelligent perception capabilities mainly relies on the widespread application of high-precision sensors, which can real-time collect key parameters during the production process, such as temperature, pressure, rotational speed, etc. The strengthening of data processing and analysis capabilities requires the use of edge-computing and cloud-computing technologies to quickly process and analyze the large amount of collected data and extract valuable information. The improvement of automation and intelligent control levels is realized through the integration of advanced AI algorithms and automated control systems, which can automatically adjust production parameters according to real-time data to optimize the production process.

5.2 Construction of Universal Upgrade Framework

Based on the above key elements, a universal upgrade framework for the textile printing and dyeing additives industry has been constructed. The framework consists of three main parts: the perception layer, the data processing layer and the application layer. In the perception layer, high-precision sensors such as temperature sensors, pressure sensors and rotational speed sensors are installed to real-time collect key parameters during the production process. The data from these sensors is transmitted to the data processing layer via wireless communication modules. The data processing layer uses edge-computing devices for data preprocessing, including data cleaning, filtering and normalization, etc. The preprocessed data is further transmitted to the cloud-based server for in-depth analysis and storage. In the application layer, an intelligent control system based on the cloud platform has been developed, integrating advanced AI algorithms and user-friendly interface design. Users can use this interface to real-time monitor the equipment operation status, receive optimization suggestions generated by the system, and make manual adjustments.

5.3 Implementation Path for Intelligent Equipment Upgrade in the Industry

To promote the intelligent equipment upgrade in the textile printing and dyeing additives industry, the following implementation path is proposed. First, enterprises should strengthen their own technological research and development and innovation, actively cooperate with universities and research institutions, and carry out industry-university-research cooperation projects. For example, Wuxi Lianda Chemical has cooperated with a university to jointly develop an intelligent control system based on IoT, achieving remarkable results. Second, the industry should establish unified standards and specifications to ensure the interconnectivity of intelligent equipment between different enterprises. Finally, the government should introduce relevant policies to encourage enterprises to carry out intelligent upgrades, providing financial support and tax incentives and other measures.

6. Conclusion and Future Outlook

6.1 Summary of Research Conclusions

This research has successfully developed an intelligent control system based on IoT for the high-speed dispersing equipment, a key device in textile printing and dyeing additives production, and verified its practical application on the thousand-ton-class production line of Wuxi Lianda Chemical Co., Ltd. By real-time collecting and analyzing key parameters during the production process and dynamically optimizing the stirring process with AI algorithms, the production time has been shortened and production efficiency has been improved. The personnel configuration has become more rational, reducing the dependence on skilled workers. This research has also proposed a universal upgrade framework for the textile printing and dyeing additives industry, including the perception layer, data processing layer and application layer, providing references for the intelligent upgrade of other enterprises in the industry.

6.2 Innovations and Contributions of the Research

This research has achieved significant innovative results in the development and application of intelligent control systems. The successfully developed intelligent control system for high-speed dispersing equipment based on IoT, which realizes intelligent process control through real-time data collection and AI algorithm optimization, has been verified on the thousand-ton-class production line of Wuxi Lianda Chemical. The remarkable results obtained provide strong evidence-based support for the intelligent upgrade of the industry. By reducing energy consumption and improving production efficiency, this research offers technical support for the green and sustainable development of the textile printing and dyeing additives industry, which is of great significance for addressing global environmental challenges and achieving carbon peak and carbon neutrality goals.

6.3 Future Research Directions and Outlook

Although this research has achieved certain results, there are still some areas worthy of further exploration and research. The further application of deep learning algorithms, especially more advanced ones such as the Transformer architecture, can further improve the accuracy and robustness of the models. The integration of IoT technology with other emerging technologies, such as big data, cloud computing, edge computing and 5G communication, can form more powerful intelligent solutions to further enhance the intelligent level of the production process. To promote the intelligent upgrade of the entire industry, it is necessary to formulate unified standards and specifications to ensure the interconnectivity of intelligent equipment between different enterprises. Future work can actively participate in the formulation of industry standards to provide support for the healthy development of the industry.

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