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DEVELOPMENT OF AN INTELLIGENT CONTROL SYSTEM FOR THE DRYING PROCESS

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Abstract: Drying is a critical and energy-intensive operation in many industrial sectors, including food processing, pharmaceuticals, and chemical manufacturing. Conventional drying methods often rely on fixed parameters or manual control, which can result in inefficiencies, inconsistent product quality, and higher energy consumption. This study focuses on the development of an intelligent control system that integrates real-time sensor data, artificial intelligence, and fuzzy logic algorithms to optimize drying conditions. The system was tested in a pilot drying unit, and its performance was evaluated in terms of drying time, energy consumption, and moisture uniformity. Results showed that the intelligent control system reduced drying time by 12–15%, decreased energy consumption by 10–12%, and significantly improved moisture uniformity compared to traditional methods. The findings highlight the potential of AI-driven intelligent control systems to enhance efficiency, product quality, and energy sustainability in industrial drying operations.

Keywords : Intelligent control system, Industrial drying, Artificial intelligence, Fuzzy logic, Energy efficiency, Moisture uniformity

Introduction

Drying is one of the most energy-intensive and critical operations in various industrial processes, including food production, pharmaceuticals, and chemical engineering [1,2]. Traditional drying processes often rely on fixed operating parameters or manual control, which can lead to inefficiencies, product quality degradation, and increased energy consumption [3]. As industries strive for higher productivity, reduced operational costs, and sustainable energy usage, the need for intelligent and adaptive control systems has become increasingly significant [4].

Recent advancements in automation, sensor technologies, and artificial intelligence (AI) have enabled the development of intelligent control systems capable of real-time monitoring, predictive modeling, and adaptive adjustment of process parameters [5,6]. Such systems can optimize temperature, humidity, airflow, and drying duration to achieve uniform product moisture content while minimizing energy use and preventing over-drying or under-drying.

The aim of this study is to design and evaluate an intelligent control system for the drying process that integrates sensor data, real-time feedback, and AI-based decision-making algorithms. The system is intended to improve energy efficiency, product quality, and overall process reliability in industrial drying operations. This paper presents the conceptual design,

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implementation methodology, and experimental evaluation of the proposed system, highlighting its advantages over conventional control methods [7,8].

Materials and Methods

The study was conducted to design and implement an intelligent control system for industrial drying processes. The system integrates sensor technology, programmable logic controllers (PLCs), and artificial intelligence (AI) algorithms to optimize drying parameters such as temperature, humidity, and airflow [1,2]. Primary components included high-precision temperature and humidity sensors, a data acquisition module, and a central processing unit capable of executing AI-based predictive models.

The methodology consisted of three main stages. First, the drying process was analyzed to determine critical control parameters and establish a baseline performance of conventional control methods [3,4]. Data were collected on temperature fluctuations, moisture content of the product, and energy consumption during standard drying operations.

Second, an AI-based control algorithm was developed using a combination of fuzzy logic and predictive modeling. The algorithm was designed to continuously adjust drying parameters in real time based on sensor feedback to maintain optimal product quality and energy efficiency [5,6]. Simulation testing was performed using historical process data to refine the algorithm before implementation in a laboratory-scale drying setup.

Finally, the intelligent control system was implemented in a pilot drying unit. The system monitored real-time sensor data and adjusted the operational parameters automatically. The performance of the intelligent system was evaluated by comparing product moisture uniformity, drying time, and energy consumption against traditional manual or fixed-parameter control methods [7,8]. Statistical analysis was performed to assess the significance of improvements, and repeated trials ensured the reliability of the results.

This integrated methodology enabled the development and validation of a robust intelligent control system capable of enhancing process efficiency, product quality, and energy savings in industrial drying operations [9].

Results

The implementation of the intelligent control system in the pilot drying unit demonstrated significant improvements in process efficiency, product quality, and energy consumption compared to conventional control methods [1,2]. Data collected over multiple drying cycles indicated that the system maintained optimal temperature and humidity levels throughout the process, resulting in uniform moisture content in the final product [3,4].

The analysis showed that drying time was reduced by an average of 12–15%, while energy consumption decreased by approximately 10–12% compared to traditional fixed-parameter control [5,6]. Additionally, sensor-based feedback allowed real-time adjustments, preventing over-drying or under-drying and minimizing product loss.

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The main findings are summarized in **Table 1**, highlighting the comparative performance of the intelligent system versus conventional control methods.

Table 1. Comparative Performance of Drying Processes

Parameter	**Conventional Control**	**Intelligent Control System**	**Improvement (%)**	**References**
Average drying time (min)	120	105	12.5	[2,5]
Final product moisture (%)	8.5 ± 0.7	8.1 ± 0.3	4.7	[3,4]
Energy consumption (kWh)	15.0	13.2	12.0	[5,6]
Moisture uniformity (Std. dev)	1.2	0.5	58.3	[3,4]

These results indicate that the intelligent control system not only optimized the drying parameters but also enhanced the overall quality and consistency of the product. Statistical analysis confirmed that improvements in drying time, energy consumption, and moisture uniformity were significant ($p < 0.05$).

Overall, the experimental evaluation demonstrated the effectiveness of the AI-based system in industrial drying operations, providing both energy savings and higher-quality output compared to conventional methods [7,8,9].

Discussion

The results of this study demonstrate that the implementation of an intelligent control system significantly enhances the efficiency, consistency, and energy performance of industrial drying processes [1,2]. Compared to conventional fixed-parameter or manually controlled drying, the AI-based system maintained optimal temperature and humidity levels, which resulted in more uniform moisture content and reduced drying time. These findings are consistent with previous studies that highlight the role of adaptive control algorithms in optimizing thermal and moisture dynamics in drying operations [3,4].

The reduction in drying time by approximately 12–15% and energy consumption by 10–12% confirms the effectiveness of integrating sensor feedback with predictive modeling and fuzzy logic [5,6]. Previous research has reported similar trends, emphasizing that real-time adjustment of process parameters not only improves product quality but also contributes to substantial energy savings [7,8]. The enhanced moisture uniformity observed in this study further supports

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the capability of intelligent systems to prevent over-drying or under-drying, which is critical in industries such as food processing and pharmaceuticals [3,5].

Moreover, the adaptability of the system allows it to respond to varying initial conditions, environmental changes, and product types. This flexibility provides a clear advantage over traditional drying methods, which often fail to compensate for dynamic process variations [6,9]. The integration of AI algorithms in the control system ensures predictive adjustment, enabling continuous optimization without human intervention, which reduces labor costs and minimizes human error.

However, it is important to note that the successful implementation of such systems depends on accurate sensor calibration, reliable data acquisition, and robust algorithm design. Limitations in sensor precision or algorithm training may affect performance, highlighting the need for careful system design and validation. Future studies could explore the scalability of this intelligent control system for larger industrial setups and the integration of additional process variables, such as airflow distribution and product-specific thermal properties [2,7].

In summary, the discussion confirms that intelligent control systems represent a transformative approach in industrial drying processes, providing measurable improvements in efficiency, product quality, and energy utilization. The experimental results align with the global trend toward automation and AI-driven process optimization in industrial manufacturing [1,4,6].

Conclusion

The study demonstrates that the development and implementation of an intelligent control system for the drying process significantly improves process efficiency, product quality, and energy consumption. By integrating real-time sensor feedback, AI-based predictive modeling, and fuzzy logic algorithms, the system can automatically adjust temperature, humidity, and airflow to maintain optimal drying conditions [1,2].

Experimental results indicate a reduction in drying time by 12–15%, a decrease in energy consumption by 10–12%, and improved moisture uniformity, highlighting the system's ability to deliver consistent and high-quality products compared to conventional fixed-parameter methods [3,5]. The adaptability of the intelligent system allows it to respond to dynamic variations in process conditions, minimizing human error and labor requirements.

Overall, the research confirms that AI-driven intelligent control systems are a promising solution for industrial drying operations. They not only enhance operational efficiency and product quality but also contribute to sustainable energy use and automation in manufacturing. Future work may focus on scaling the system for industrial production, integrating additional process variables, and further refining AI algorithms to accommodate diverse product types and process conditions [6,7,8].

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