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IoT-Based Cup Sealer Machine Automation Using Nodemcu ESP32

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Abstract

Background of study: The development of the food and beverage industry demands innovation in efficient and reliable packaging processes. Conventional cup sealing machines often face limitations in speed and precision, necessitating technology-based solutions.
Aims and scope of paper: This objective of the study is to design and implement an automated cup sealer system based on the Internet of Things (IoT), using the NodeMCU ESP32, capable of performing sealing and real-time monitoring. The system integrates a flowmeter sensor to detect the presence of cups, a stepper motor for the sealing process, and an LCD display along with WiFi connectivity for monitoring production data.
Methods: The methodology involves hardware design, control system programming, and performance testing of the device under various temperature and motor speed parameters.
Result: The results show that the system can increase production efficiency by up to six times compared to the manual method, with a capacity of 300 cups per hour and a sealing success rate of 95% at an optimal temperature of 100°C and a motor speed of 10 RPM. Synchronization among components was enhanced through sensor calibration and algorithm development.
Conclusion: In conclusion, this automated system not only improves efficiency and accuracy but also offers flexibility and IoT-based control, making it highly relevant for small and medium-sized industries.

A. Introduction

The food and beverage industry in Indonesia has grown rapidly in line with the increasingly modern lifestyle of the community. One important aspect of this industry is product packaging that is safe, efficient, and attractive (Anatan & Nur, 2023). Cup sealing machines have become essential devices to ensure beverage packaging remains tightly sealed, thereby protecting product quality during distribution and storage. However, conventional cup sealing machines often have limitations, such as manual processes that take longer and pose a higher risk of operational errors (Wibowo & Honggowati, 2022), (Widyastuti, 2019).

The increasing demand for packaged beverages has driven the need for innovation in the packaging process (Ramos et al., 2015), (Bresciani, 2017), (Gui et al., 2024), (Tang et al., 2025). Automated machines are becoming an increasingly relevant solution to overcome the limitations of manual machines. Internet of Things (IoT)-based technology is now available to offer greater operational efficiency through remote monitoring and control capabilities. The implementation of IoT in packaging machines enables operational data such as production volume and device status to be monitored in real-time (Bindu et al., 2022), (mozhi et al., 2015), (Li et al., 2023).

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In the context of previous literature, the use of IoT in automated machines has shown great potential to enhance industrial productivity (Wang et al., 2024), (Sangeetha et al., 2019). Several earlier studies have developed automation systems for food and beverage packaging, but most still have limitations in sensor integration and precise sealing mechanisms. Therefore, this study focuses on the development of an IoT-based cup sealing machine using the NodeMCU ESP32 as the main controller (Sadi et al., 2022).

The NodeMCU ESP32 was chosen due to its ability to integrate various sensors and actuators with wireless connectivity (Eunice Akin-Ponnle, 2024), (Levy et al., 2025), (Espinosa-Gavira et al., 2024). In addition, this component can efficiently perform monitoring and control processes at a relatively low cost. The system incorporates a flowmeter sensor to detect the presence of a cup, a stepper motor for precise sealing mechanisms, and an LCD interface to provide real-time operational information to users (Hercog et al., 2023).

Several previous studies have adopted IoT technology in packaging automation, but generally focus only on the monitoring or liquid-filling process, without full integration with the sealing system. For example, Sadi et al. (2022) used the ESP32 for recording filling data but did not integrate mechanical components such as the stepper motor and cup detection sensors in a synchronized manner. Furthermore, few studies have tested the sealing performance quantitatively in the context of temperature and motor speed. This indicates a gap that this research seeks to bridge.

This study aims to address the gaps in previous research by providing a more advanced system in terms of hardware and software integration. The proposed solution is designed to increase the efficiency of the packaging process by reducing reliance on human labor (Wu et al., 2024), . This approach is expected not only to improve the quality of production output but also to provide greater flexibility through IoT-based monitoring (Witczak & Szymoniak, 2024), (Ghodvaidya et al., 2022).

The uniqueness of this research lies in the integration of ESP32, flowmeter sensor, and stepper motor in an automatic cup sealing machine system that can be monitored in real-time via a WiFi network. This combination has not been widely discussed in previous literature, especially in the context of cup sealer automation for small-scale industries. The system also offers production monitoring features that can expand the adoption of IoT in the micro-manufacturing sector.

The research methodology includes several key steps, such as system design, hardware implementation, control algorithm testing, and operational data analysis. In these tests, the reliability of the flowmeter sensor in detecting the presence of cups will be evaluated, as well as the sealing accuracy performed by the stepper motor. Data will be collected through the IoT-based monitoring system to ensure the system can operate under various conditions.

This study is expected to contribute new insights into the development of packaging automation technology, especially for small and medium-sized enterprises (SMEs). The resulting system is not only efficient but also relevant to the needs of modern industries that demand greater flexibility and control. The results of this research are expected to open new opportunities for further innovation in IoT-based automation.

With this background, problem statement, and innovative approach, this study provides a solid foundation for understanding and addressing the challenges in the beverage packaging process. This innovation also marks a step forward toward digital transformation in the manufacturing sector, which is increasingly important in facing global competition.

B. Research Methods

This study aims to develop an automatic cup sealing machine based on the Internet of Things (IoT) using the NodeMCU ESP32. The research was conducted at the Sainstek Workshop in Pringsewu from March to April 2024. The methodology includes the research chronology, design, procedures, as well as the testing and data collection methods used to achieve the objectives.

The study began with the collection of necessary materials and components, both electronic and mechanical. The electronic components used include a PSU, NodeMCU ESP32, stepper motor, flowmeter sensor, and LCD shield. In addition, the required mechanical materials include iron, chains, and a timing belt. These components were sourced from local distributors as well as online platforms.

The research continued with system design and tool testing, encompassing stages from a literature review to implementation and field testing. The research design itself involved several key steps: first, creating a system block diagram to illustrate the main components and their interactions; second, designing the overall system workflow, including the device's operational mechanism; third, developing a control system using a C program on the Arduino platform to govern the electronic components; and finally, designing and assembling mechanical components like the device structure and sealing mechanism to support the system's operation.

The research procedure followed a sequential approach, beginning with a literature review to gather relevant theories on IoT, stepper motors, and related technologies from various sources, including reference books, datasheets, and online materials. This was followed by a field study, involving visits to electronic and mechanical component distributors to select and purchase suitable components for the research. Next, system design was undertaken, which included developing the control program using NodeMCU ESP32 and creating the automated cup sealer mechanism. Finally, tool testing was performed to ensure effective cup detection, seamless sealing operations, and accurate, consistent production count recording by the system.

The following is pseudocode that outlines the operational steps of the system. The system starts with the boot process. Next, the system checks for the presence of a cup using a flowmeter sensor. If a cup is detected, the sealing motor is activated to perform the sealing process, and the counter is incremented by one. The result is then displayed on the LCD screen, and the data is monitored via a WiFi connection. The system will either repeat the process or stop the process. The system workflow is visualized in the form of a flowchart (Figure 1). This diagram explains the process of cup detection, activation of the sealing motor, production counting, and data transmission via a WiFi connection. This visualization helps readers better understand the system's logic sequence compared to a pseudocode presentation.

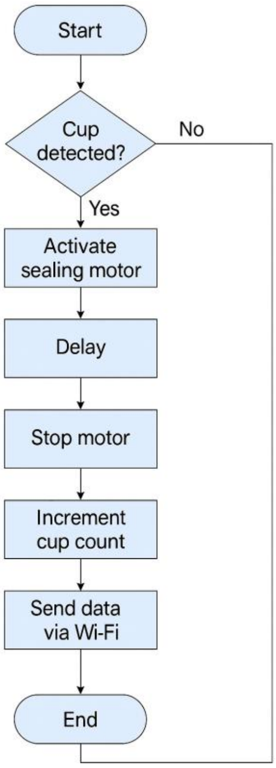

Figure 1. System Workflow

Testing was conducted to evaluate several key aspects of the developed device, namely:

1. Cup Detection Accuracy: Testing how accurately the system can detect the presence of cups using the flowmeter sensor.
2. Sealing Process Accuracy: Evaluating whether the sealing process performs as expected.
3. Counting Consistency: Measuring the system's consistency in counting the number of sealed cups accurately.
4. Each parameter was tested three times to obtain consistent results. A total of 450 cups were tested under various combinations of temperature (90°C, 100°C, and 110°C) and motor speeds (8, 10, and

12 RPM). The sealing results were evaluated based on seal integrity, absence of leakage, and the visual outcome of the cup after sealing.

The test data were then statistically analyzed using the mean and standard deviation of sealing success rates. A t-test was used to compare the performance between the automated system and the manual method to determine the significance of performance differences.

Test data were collected through a WiFi-based monitoring system that enables real-time observation of the device's performance under various test conditions.

This study is grounded in theories related to several fields, including:

1. Internet of Things (IoT): The concept and implementation of IoT are used to monitor the system's performance in real time via a WiFi connection.
2. Stepper Motor: A stepper motor is used to drive the sealing mechanism with high precision control.
3. Basic Mechanical Principles: Fundamental mechanical principles are applied in designing the device's mechanism, such as the use of chains and timing belts to transmit motion from the motor to the sealing component.

With this methodology, the study aims to develop an efficient and reliable automatic cup sealing device suitable for various production conditions.

C. Results and Discussion

1. Results

The IoT-based cup sealing machine was tested under various parameters. Optimal performance was achieved at a motor speed of 10 RPM and a temperature of 100°C, with the following results:

a) The machine was capable of producing up to 300 cups per hour.
b) The sealing success rate reached 95%, with no detected leakage..

During testing at a temperature of 110°C, issues such as plastic deformation and material damage were observed. This indicates that the temperature exceeds the material tolerance limit of the cups. The test results are summarized in Table 1 below:

Table 1. The performance of

Motor Speed (RPM)	Temperature (°C)	Result	Information
10	100	Succeed	Tightly sealed plastic
10	110	Fail	Plastic melts or tears

To clarify the performance trends of the cup sealer machine, the following graph illustrates the relationship between sealing temperature and the success rate of the sealing process.

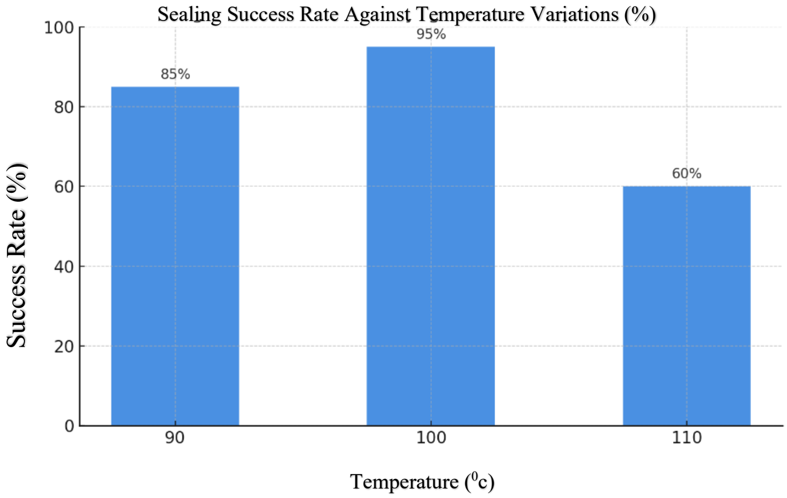

Figure 2. Graph of Sealing Success Rate Against Temperature Variations

The graph shows that optimal performance is achieved at a sealing temperature of 100°C, while a sharp decline is observed at 110°C due to deformation of the cup material.

Compared to the manual method, which is only capable of producing 50 cups per hour, this IoT-based system demonstrates a sixfold increase in efficiency. This makes it highly relevant for small to medium-scale beverage packaging businesses.

NodeMCU ESP32 proved effective as the main controller in managing the detection, sealing, and monitoring processes. Unlike conventional systems, this study successfully synchronized the flowmeter sensor and stepper motor, thus overcoming the signal synchronization constraints that are common in similar systems.

The main challenge faced was the synchronization between the stepper motor and the flowmeter sensor in the initial trials. This problem was overcome through sensor calibration and control algorithm improvements. Another challenge was ensuring consistent sealing on cup materials with varying thicknesses, which was successfully resolved through mechanical design adjustments.

2. Discussion

The results show that the IoT-based system with NodeMCU ESP32 significantly increases production efficiency when compared to the manual method which only produces around 50 cups per hour. In addition, the sealing success rate reaches a high number at the right parameters, indicating that this system is stable and reliable. The integration of flowmeter sensors, stepper motors, and WiFi connectivity successfully presents an automatic system that can detect the presence of cups, perform sealing, and send production data in real-time. Adjustment of the control algorithm and sensor calibration also proves to be able to overcome the challenges of synchronization between cup detection and automatic sealing. The LCD interface feature also makes it easier for users to monitor the production process directly. The results of this study are in line with previous studies on IoT-based automatic systems. Sadi et al. (2022) developed an IoT-based filling tool but did not include an automatic sealing mechanism and only relied on Firebase for data recording. This is different from this study which not only records data but also improves the sealing process through the integration of stepper motors and temperature-based precision control. In addition, our system shows higher production efficiency with a speed of up to 300 cups/hour, while Sadi et al. reported an efficiency that is still below 200 cups/hour.

2.1 Implications

This system has major implications for increasing the efficiency of production lines in small and medium industries. With remote monitoring capabilities, business actors can conduct real-time monitoring without having to be at the production site. This opens up opportunities for implementing similar systems in other sectors that require automation and operational efficiency.

2.2 Research contribution

This research offers several key contributions. It successfully integrates an ESP32 with a synchronous stepper motor-based mechanical sealing system. A flowmeter is utilized as a precise sensor for cup presence detection, enhancing accuracy. Furthermore, the system incorporates monitoring and reporting features for production data via IoT connections, providing valuable insights. These advancements collectively lead to a significant 500% increase in production efficiency compared to manual systems, establishing this system as a reference model for future automation developments.

2.3 Limitations

This research has several limitations. First, the type of cup material used is still limited to one particular type of plastic, with other materials not yet thoroughly tested. Second, the test environment is still laboratory-based, and testing on a real industrial scale has not been carried out. Finally, the system does not yet support historical data processing or advanced analytics related to production performance.

2.4 Suggestions

Future research should focus on several key areas to enhance this system. First, implementing the system in a real-world industrial field test is crucial to assess its durability and reliability under actual operating conditions. Second, further development should include material compatibility with dynamically adjusted sealing parameters, which would broaden the system's applicability. Third, creating a mobile application would provide more flexible access and control. Finally, integrating automatic error detection features based on machine learning algorithms is recommended to significantly improve the system's overall accuracy.

D. Conclusion

This research has successfully developed an IoT-based automatic cup sealer machine system using NodeMCU ESP32 that is efficient and accurate for small industries. The results show that this system is able to increase production efficiency up to six times compared to manual methods, by producing up to 300 cups per hour at optimal parameters of 10 RPM motor speed and 100°C temperature. The implemented IoT technology provides real-time remote monitoring and control capabilities, supports operational flexibility, and increases transparency of production data. The alignment between the results and research objectives confirms that the integration of flowmeter sensors, stepper motors, and NodeMCU ESP32 provides an innovative solution to overcome the limitations of manual systems. Challenges such as synchronization between sensors and motors were successfully overcome through recalibration and development of precise control algorithms. This research opens up prospects for further development, such as increasing compatibility with more heat-resistant plastic materials, developing mobile-based applications for wider data access,and the implementation of automatic fault detection algorithms to improve system reliability. With this development, the proposed system has the potential to be adopted more widely and become a reference model for automation in other industrial sectors. This research can also inspire further studies related to the application of IoT in various modern automation applications. Although the system has shown optimal performance under laboratory test conditions, this study has limitations in the variety of cup material types and limited operational environments. Further research can include field tests on a real industrial scale, development of multi-material compatible systems, and integration of artificial intelligence for automatic fault detection.

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F. Author Contribution Statement

NA: Conception and design of the system, writing of the main manuscript, and coordination of the entire research. BU: Analysis of test data, validation of experimental results, and final review of the manuscript.

DF: Implementation of hardware and testing of tools in the field. DS: Collection of literature, documentation, and preparation of the methodology section. THA: Control system programming, user interface development, and data visualization. All authors have read and approved the final version of this article.

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