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IoT-Based Digital Weighing System Using ESP32 and Load Cell for Rice MillingOperations

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Abstract
The advancement of Internet of Things (IoT) technology in industrial sectors has driven the need for more accurate and integrated automation systems, particularly in production weighing processes. PT. Jaring Solusi Persada Tulungagung Branch required improvements in measurement accuracy, real-time data recording, and monitoring of rice milling operations. This research aims to design and develop an IoT-based digital weighing system using ESP32 and load cell to enhance operational efficiency and reduce weighing errors. The research method applied is Research and Development (R&D) using a Prototyping approach, encompassing hardware design, software development, load cell calibration, and direct system testing in the operational environment. The system utilizes the HX711 module as a signal amplifier for the load cell, with ESP32 as the main microcontroller to process weight data and transmit information in real-time via Bluetooth to a Flutter-based mobile dashboard application. Testing results indicate that the system achieved 0% error rate in weighing accuracy tests across six trials with load variations of 1–20 kg. Actuator response testing was conducted using a servo motor as a prototype actuator to simulate the operation of an industrial pneumatic valve during system validation. The results showed an average response time of 0.80 seconds and an average overshoot of 0.72% of the target weight, indicating stable performance of the proposed control mechanism under prototype-scale testing conditions.

1. Introduction

Advances in Internet of Things (IoT) technology have significantly transformed industrial operational systems through the ability of physical devices to connect to each other and exchange data in real time over communication networks [1] ,[2]. IoT technology enables data exchange between microcontrollers, sensors, and various electronic devices to support integrated monitoring and automation systems [3] .The implementation of digital technology in industrial environments has been proven to increase operational productivity, operational effectiveness, and data accessibility [4] . In the agricultural processing sector, particularly the rice milling industry, the existence of an accurate and integrated weighing system is a crucial requirement for maintaining production quality, yield consistency, and operational efficiency [5] . Digital transformation in industrial systems also supports faster decision-making processes through real-time monitoring mechanisms and automatic data acquisition [6].In addition to technological aspects, ease of use of the user interface and ease of use of the system are also important factors in determining the effectiveness and level of user acceptance of digital monitoring systems [7]. Conventional weighing systems still used in various small and medium-scale rice milling industries generally rely on mechanical or semi-digital methods. These systems still rely on manual recording processes that are prone to human error, workflow inefficiencies, information processing delays, and difficulties in data management and retrieval [8]. Various previous studies have shown that digitalization of operational processes and supply chains can improve management information, increase operational efficiency, and support improvements in overall supply chain performance compared to conventional manual procedures [9].Furthermore, the application of information technology has also been proven to increase productivity, both in terms of time efficiency and human resource optimization [10] . Therefore, the implementation of digital monitoring systems in industrial weighing applications is highly relevant to improve system reliability and operational efficiency.

PT. Jaring Solusi Persada, Tulungagung Branch, is a company engaged in network technology services and rice milling operations. Prior to this research, it was still using a mechanical and semi-digital weighing system. This condition caused the data recording process to be carried out manually, resulting in delays in production information and low operational efficiency [11] . In addition, the unavailability of a real-time monitoring system also complicated the production supervision process and historical data management. Similar findings in previous research indicate that the transformation from a manual system to a computerized system can increase work efficiency, reduce repetitive activities, and minimize human error in operational activities. On the other hand, IoT-based monitoring systems have been widely implemented to support remote monitoring processes through web-based and mobile applications so that users can obtain information on system conditions in real time more efficiently [12]. Previous research also shows that the implementation of IoT combined with the ESP32 microcontroller is able to support automatic monitoring and control systems that run effectively in a real-time environment [13]. Selecting the right microcontroller is a crucial aspect in developing an IoT system. Although the ESP8266 is widely used due to its relatively low implementation cost ,t has limitations in connection stability, memory capacity, and security for more complex industrial applications. The ESP32, as a development of the ESP8266, offers integrated WiFi and Bluetooth communication capabilities with higher processing performance and better multitasking support ESP8266 is widely utilized in IoT systems because it enables internet-based monitoring and control of electronic devices. Several previous studies have shown that the ESP32 performs well in IoT-based monitoring systems and digital weighing applications with low measurement error rates and stable real-time data communication. In addition, ESP-based communication protocols have also been shown to reduce transmission delays and support the implementation of more efficient real-time monitoring systems. The ESP32 also has the ability to process sensor data and run automatic control algorithms efficiently due to its strong computing and connectivity capabilities .With these characteristics, the ESP32 is considered suitable for application in industrial IoT applications that require reliable real-time monitoring and sensor integration [14].

In digital weighing systems, load cell sensors combined with the HX711 amplifier module are commonly used to obtain precise weight measurement results. The integration of the ESP32, HX711, and load cells enables real-time weight data acquisition, the implementation of automated control systems, and wireless data transmission to monitoring applications. IoT-based systems integrated with mobile and web-based monitoring platforms also provide users with the flexibility to monitor system conditions and obtain operational information in real time remotely [15] . In addition, IoT integration through a mobile-based monitoring dashboard can simplify operational monitoring processes and increase production data accessibility. Previous research also shows that users tend to prefer systems with simple and intuitive interfaces over systems with more complex technological features [16],[17]. However, most of the research that has been conducted still focuses on laboratory-scale digital weighing systems and has not integrated actuator-based automation and real-time production monitoring in actual industrial operational environments. Based on these problems, this study aims to design and develop an integrated Internet of Things (IoT)-based digital weighing system using ESP32 and load cells in rice milling operations at PT. Jaring Solusi Persada, Tulungagung Branch. The contributions of this study include: (1) design and implementation of an ESP32-HX711-based digital weighing system with finite state machine (FSM)-based actuator control; (2) development of a real-time Flutter-based IoT monitoring dashboard using Bluetooth communication with a simple and easy-to-use interface design to improve operational ease;(3) empirical validation of weighing accuracy in the measurement range of 1–20 kg; and (4) characterization of actuator response using the on-off control method with a cutoff offset compensation of 120 g to reduce overshoot during the automatic filling process.

2. Research Method

This research employed the Research and Development (R&D) method using a Prototyping approach. The research was conducted at PT. Jaring Solusi Persada Tulungagung Branch from February to April 2026. Figure 1 illustrates the research procedure adopted in this study.

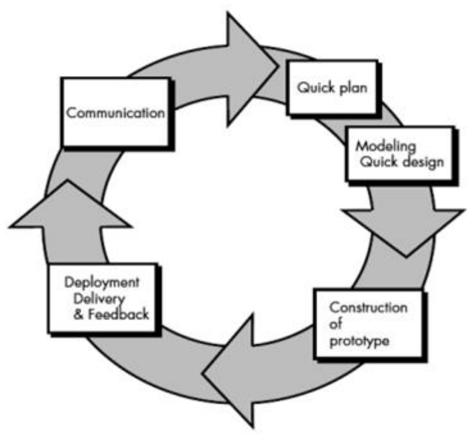

Figure 1. Research Procedure (Engineering Approach)

2.1 Hardware Design

The hardware system consists of: (1) an ESP32 microcontroller as the central processing unit, (2) an HX711 module as a 24-bit ADC load cell signal amplifier, (3) a 20 kg load cell sensor, (4) a 20x4 I2C LCD module for local weight display, (5) a 4x4 keypad for target weight input, (6) a relay module for actuator switching, and (7) a servo motor used as a prototype actuator to simulate the operation of an industrial pneumatic valve during system validation.Servo motors were chosen instead of pneumatic actuators because they are easier to implement, more economical for prototype development, and allow for repeatable actuator movements during laboratory-scale testing. Therefore, the servo actuator was used only to validate the proposed automatic filling control mechanism prior to future implementation using a real industrial pneumatic system.. Figure 2 shows the wiring schematic of the complete hardware system.

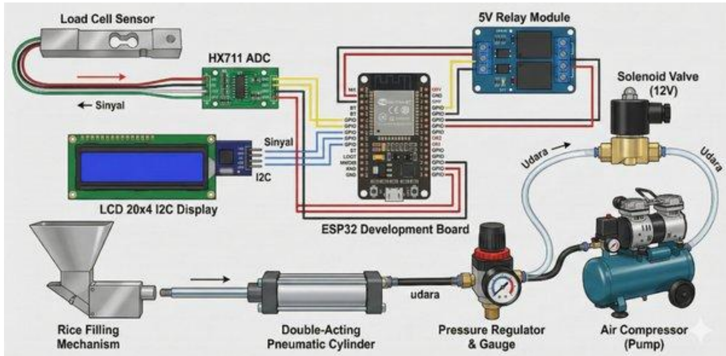

Figure 2. ESP32-HX711 Wiring Schematic and Load Cell Integration

The load cell calibration was performed by applying known reference weights and adjusting the calibration factor in the firmware. A calibration factor of 99 was determined as the optimal value for the 20 kg load cell, ensuring accurate weight readings across the full measurement range.

2.2 Software Design

The firmware was developed using Arduino IDE with C++ programming language. The firmware implements three FSM states: WEIGHING, OUTLET_DELAY, and DISPENSING, as defined in the source code. Figure 3 shows the complete system flowchart.

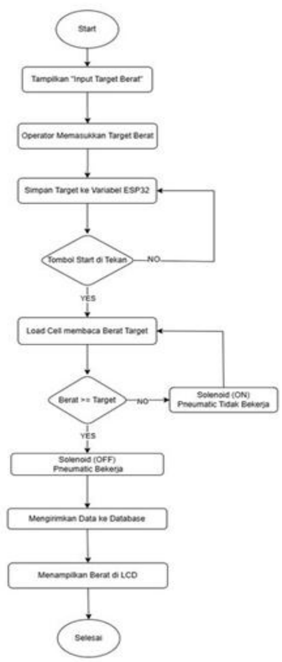

Figure 3. System Flowchart of the Digital Weighing System

The mobile monitoring dashboard was developed using the Flutter framework, communicating with ESP32 via Bluetooth Serial (BluetoothSerial library). The dashboard provides real-time weight display, target weight control, system status monitoring, graphical visualization, and a daily production recap feature.

2.3 Testing Methods

System performance was evaluated through two testing phases: (1) weighing accuracy testing—by comparing system readings to a reference load over six trials at 1, 3, 5, 8, 10, and 20 kg; and (2) actuator response testing—to evaluate the response time and overshoot of the automatic filling mechanism when the system stops material flow at various target weights. Actuator response testing was conducted at three target weight levels representing the lower, middle, and upper operating ranges of the system: 3 kg, 5 kg, and 20 kg. Each target weight was tested five times to analyze the consistency of actuator performance and the effectiveness of the 120 g breaker offset in compensating for material inertia when the valve is closed. Additional variations in target weight were conducted because filling rate and material flow characteristics can affect actuator response time and overshoot behavior at various load levels. This testing approach aimed to ensure that the on-off control mechanism was able to maintain acceptable overshoot tolerance and stable response performance across the operating range of 1–20 kg. The on-off threshold control method was implemented with a 120g cut-off offset to compensate for material inertia during the valve closing process. It should be noted that all actuator response tests were conducted using a servomotor prototype actuator, not an actual pneumatic solenoid valve. Therefore, the measured response times and overshoot values represent the performance of the proposed control mechanism under prototype conditions. Consequently, the results obtained should be interpreted as an evaluation of the control strategy and performance of the actuator prototype and should not be considered as direct validation of a full-scale industrial pneumatic system.

3. Result and Discussions

3.1 Hardware Implementation

In the prototype stage, a servo motor was used as a proxy for an industrial pneumatic cylinder to validate the system's control mechanism. Servo motors were chosen due to their availability, lower implementation cost, ease of integration with the ESP32 microcontroller, and ease of control during prototype-scale testing. The use of a servo motor allows for stable and repeatable actuator movements to evaluate the automatic filling mechanism before its implementation in a real industrial environment. However, servo motors and pneumatic solenoid valves have fundamentally different actuation characteristics. Servo motors provide proportional rotational control, while pneumatic solenoid valves operate using a binary open/close mechanism with a response influenced by air pressure. Therefore, the actuator response results obtained in this study, including an average response time of 0.80 seconds and an average overshoot of 0.72%, are specific to the servo motor-based prototype and cannot be directly generalized to industrial pneumatic systems. Further validation using actual pneumatic solenoid valves is required to ensure system performance under real industrial operating conditions. Consequently, all actuator performance results reported in this study, including response time and overshoot measurements, should be interpreted as servo motor prototype performance rather than validated pneumatic actuator performance.

Figure 4. Digital Weighing System Prototype

Figure 5. LCD Display

Figure 6. HX711 Circuit *Figure 7. Load Cell Circuit*

Figure 4 shows the complete hardware prototype used in this study, including the ESP32 controller, load cell sensor, HX711 module, display unit, and actuator mechanism. Figure 5 presents the results of weighing accuracy tests for reference loads between 1 kg and 20 kg. Figure 6 illustrates the actuator response performance in terms of response time and overshoot during the automatic filling process. Figure 7 shows the user interface of the mobile monitoring application used for real-time system monitoring and control.

3.2 Weighing Accuracy Test

Table 1 presents the results of the weighing accuracy test performed across six reference load values.

Table 1. Weighing Accuracy Test Results

Reference Load	Reading Result	Error (%)
1 kg	1.00 kg	0%
3 kg	3.00 kg	0%
5 kg	5.00 kg	0%
8 kg	8.00 kg	0%
10 kg	10.00 kg	0%
20 kg	20.00 kg	0%

Weighing accuracy tests demonstrated a 0% measurement error across reference loads ranging from 1 kg to 20 kg. Although the displayed error value is 0%, small deviations below the display resolution may still be present and invisible due to rounding. Nevertheless, these results demonstrate that the load cell calibration procedure and the HX711 signal conditioning module operate effectively throughout the test range. The results are consistent with previous studies using load cell sensors and the HX711 module for digital weighing applications. Previous studies have demonstrated that IoT-based digital weighing systems can achieve high measurement accuracy through proper calibration of the load cell and HX711 module [12]. The HX711 amplifier further contributes to measurement reliability by providing stable signal amplification and high-resolution data acquisition, thereby minimizing measurement deviation [13] . Likewise, reliable performance of load cell-based digital weighing systems has been consistently achieved when appropriate calibration procedures are applied [5] . Compared with those studies, the proposed system achieves comparable measurement accuracy while integrating automatic actuator control and real-time monitoring via a Flutter-based mobile application. Therefore, the developed system not only provides accurate weighing performance but also supports the automation and digital monitoring functions required in industrial rice milling operations.

3.3 Actuator Response Test Results

Table 2. Actuator Response Test Results

Target Weight	Trial	Response Time (s)	Final Weight (kg)	Overshoot(%)
3 kg	1	0.78	3.02	0.67
3 kg	2	0.81	3.03	1.00

Target Weight	Trial	Response Time (s)	Final Weight (kg)	Overshoot(%)
3 kg	3	0.79	3.02	0.67
3 kg	4	0.82	3.02	0.67
3 kg	5	0.80	3.01	0.33
5kg	1	0.79	5.03	0.60
5kg	2	0.82	5.04	0.80
5kg	3	0.80	5.03	0.60
5kg	4	0.81	5.04	0.80
5kg	5	0.78	5.03	0.60
20kg	1	0.80	20.15	0.75
20kg	2	0.83	20.14	0.70
20kg	3	0.79	20.13	0.65
20kg	4	0.81	20.16	0.80
20kg	5	0.80	20.14	0.70

According to Table 2, the actuator demonstrated stable performance at all tested target weight levels. Response times ranged from 0.78 to 0.83 seconds, with an overall average of 0.80 seconds. The final weight measurements were very close to the specified target weight, resulting in an average overshoot of 0.72%. The average actuator response time of 0.80 seconds and the average overshoot of 0.72% indicate that the applied on-off control strategy was able to maintain stable filling performance throughout the operating range. The relatively small overshoot value indicates that the 120 g cutoff offset successfully compensated for material inertia during the valve closing process. These findings are consistent with previous studies on automated dispensing and weighing systems. Previous research has shown that actuator response delay and material flow inertia are key factors influencing the accuracy of automated filling processes [10] . In addition, precise actuator control has been recognized as essential for maintaining stable operation and minimizing deviations from target values in ESP32-based automatic metering systems [18]. Compared with these approaches, the proposed system achieves lower overshoot while maintaining consistent response times across a wide range of target weights. These results indicate that the implemented control mechanism is suitable for automatic filling applications requiring stable and repeatable performance. These results demonstrate that the proposed control mechanism is capable of maintaining consistent filling performance and minimizing overshoot under servo motor prototype testing conditions. Because the experiments were conducted using a servo motor as a proxy actuator, the reported response time and overshoot values should be interpreted as prototype validation results rather than as confirmed performance of an industrial pneumatic valve system. A comparable weight-based automatic filling strategy using an ESP32 microcontroller and a load cell has also been reported to stop the dispensing process once the target weight is reached, supporting the use of load cell feedback as a reliable basis for actuator cutoff decisions in automated filling systems [20].

3.4 IoT Monitoring Implementation

The IoT monitoring dashboard was implemented as a Flutter mobile application connected to the ESP32 via Bluetooth Serial.

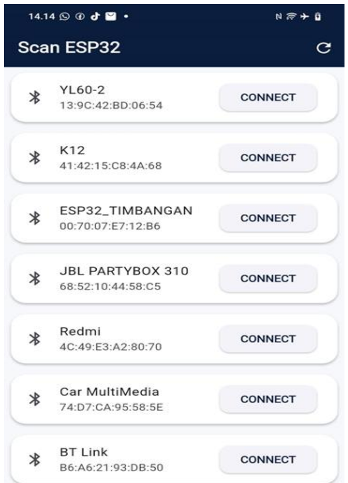

Figure 8. IoT Dashboard - Device Scanning

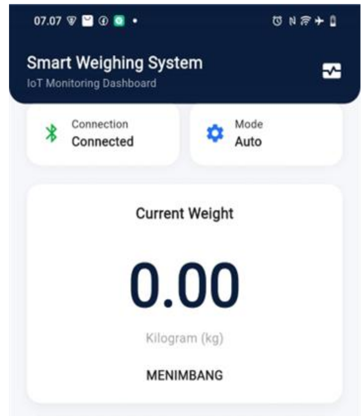

Figure 9. Bluetooth Connection Status

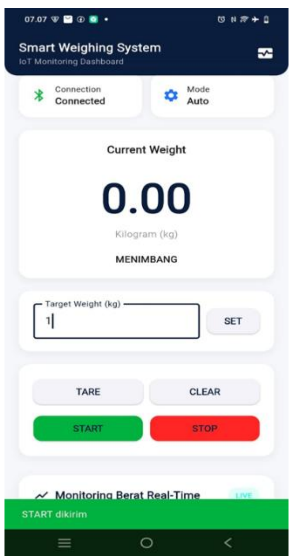

Figure 10. Main Operational Dashboard

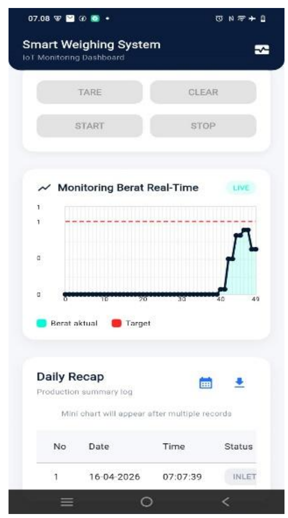

Figure 11. Real-Time Weight Graph & Daily Recap

Figure 8 shows the device scanning process performed by the Flutter application to detect the ESP32_TIMBANGAN device. Once the device is detected, the user can select it from the available device list to establish a Bluetooth connection. Figure 9 shows the successful Bluetooth connection status with a green notification indicator. Figure 10 shows the main operational dashboard with real-time weight display, target weight input, and control buttons (TARE, SET TARGET, START, CLEAR). Figure 11 shows the real-time weight graph and Daily Recap feature that records each filling cycle's timestamp and weight.

Data is transmitted from the ESP32 to the Flutter application in the format B:[weight],T:[target],S:[status] at 200 ms intervals, ensuring smooth real-time visualization. Bidirectional communication allows the operator to send commands (TARE, CLEAR, START, TARGET:[value]) from the mobile application to the hardware, enabling full remote control of the weighing process. The developed monitoring dashboard successfully enables real-time data visualization and bidirectional communication between the ESP32 microcontroller and the Flutter mobile application. This functionality allows operators to monitor system conditions, adjust target weights, and record production data directly through mobile devices. The results obtained in this study are consistent with previous IoT monitoring research. Previous studies have demonstrated the effectiveness of ESP32-based IoT systems in providing reliable real-time monitoring and wireless data transmission [1] . Furthermore, continuous real-time data acquisition through IoT-based monitoring platforms has been shown to enhance information accessibility and operational oversight [7] .Compared to previous research that primarily focused on monitoring functions, the proposed system integrates weight measurement, automatic actuator control, and production history recording in a single application. This integration improves operational efficiency and reduces reliance on manual recording processes in rice milling operations. This finding aligns with a related study on a Flutter-based mobile application for real-time IoT sensor monitoring, which reported high user satisfaction with the interface and data processing speed, indicating that the Flutter framework is well suited for delivering a simple and responsive monitoring experience in industrial IoT applications [19].

3.5 System Limitations

Several limitations were identified in this study. The on-off control method still causes a small overshoot due to actuator response delays and material inertia during the valve closing process, although a cutoff offset of 120 g was implemented to mitigate these effects. Bluetooth communication also limits the monitoring range to approximately 10 meters, making it less suitable for large-scale industrial environments than WiFi- or cloud-based systems. Furthermore, load cell readings are sensitive to mechanical vibrations and power fluctuations, which can affect measurement stability during operation. The system has also only been tested on a laboratory prototype scale and has not been validated under long-term industrial operating conditions, so further testing at an industrial scale is still needed before its implementation.

4. Conclusions and Future Works

This research successfully designed and developed an IoT-based digital weighing system using ESP32 and load cell for rice milling operations at PT. Jaring Solusi Persada Tulungagung Branch. The system achieved 0% weighing error across all tested reference loads (1–20 kg), demonstrating excellent calibration performance. The servo motor prototype actuator used to simulate an industrial pneumatic valve demonstrated an average response time of 0.80 seconds and an average overshoot of 0.72%, indicating stable performance of the proposed automatic filling control mechanism during prototype-scale validation.within acceptable tolerances for on-off controlled weighing systems. The Bluetooth-based IoT integration with the Flutter mobile dashboard enables real-time weight monitoring, remote target setting, and automated production history recording, significantly improving operational efficiency and reducing human error compared to conventional manual methods. For further development, several improvements are recommended, including the implementation of two-stage (fast and slow) filling control or predictive control to minimize overshoot, the addition of digital filtering methods such as moving averages or Kalman filters to improve sensor stability, the integration of cloud-based storage using MQTT or HTTP protocols for long-term data analysis, and the use of higher-precision load cells for large-scale industrial applications. Furthermore, future research should replace the proxy servo motor with a real industrial pneumatic solenoid valve and re-validate the actuator response under real-world rice milling conditions to ensure that the reported response time and overshoot performance are applicable to industrial environments. Further validation under long-term industrial operating conditions is also required before practical implementation.

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