

Design and Development of An Iot-Based Digital Scale for Measuring Cement Weight Using A Load Cell Sensor at Pt Semen Tonasa, Balikpapan Branch

Tizar Fitrah Anugerah^{a,1}, Nanda Stya Hermawan^{b,2}, Abdul Rachman Manga^{a,3}

^a Informatics Engineering Study Program, Faculty of Computer Science, Universitas Muslim Indonesia, Jl. Urip Sumoharjo km. 05, Makassar 90231, Indonesia

^b STMIK PPKIA Pradnya Paramita, Jl. Laksda Adi Sucipto No.249a, Pandanwangi, Kec. Blimbing, Kota Malang, Jawa Timur 65126, Indonesia

¹ 13020220005@student.umi.ac.id ² nanda_19520002@stimata.ac.id ³ abdulrachman.manga@umi.ac.id

ARTICLE INFORMATION	ABSTRACT
Received: 27 – 08 – 2026 Revised : 02 – 09 – 2026 Published: 05 – 11 – 2026	Manual cement weighing in the industrial environment of PT Semen Tonasa, Balikpapan Branch, is considered inefficient and prone to human error. This study aims to develop a prototype Internet of Things-based digital conveyor weighing system capable of automatically measuring, sorting, and monitoring the weight of cement packages. The system is controlled by an ESP32 microcontroller integrated with a load cell sensor and an HX711 amplifier module to read the dynamic weight of packages moving on the conveyor. The conveyor belt is driven by a DC motor with a BTS7960-series driver, while a servo motor serves as the sorting arm actuator. The system is programmed to recognize a target cement weight of 500 grams with a tolerance of 10 grams. Remote monitoring is performed through a local web server dashboard with a client-server architecture that displays indicators and weighing history charts without excessively burdening the microcontroller memory. Test results show that the system successfully identifies peak loads dynamically, allows on-target packages to proceed, and automatically removes nonconforming packages. The device demonstrates very high accuracy, with an average reading error of only 0.63%. The system exhibits substantially better precision and operational consistency than conventional weighing methods.
Keywords: Internet of Things ESP32 Load Cell Digital Scale Local Web Server	

I. Introduction

Weighing accuracy is a crucial factor in the cement industry for maintaining product quality, operational efficiency, and customer trust [1]. In the case of PT Semen Tonasa, Balikpapan Branch, the current cement loading and weighing processes still face challenges related to inconsistent load weights, which are often below or above the specified tolerance limits. Manual weighing systems are highly susceptible to human error and require operators to repeat measurements periodically. This reduces production time efficiency [2].

To address these problems, advances in Internet of Things (IoT) technology offer integrated solutions that combine sensors, actuators, and network connectivity to develop precise automated systems [3], [4]. Various studies have demonstrated the effectiveness of combining IoT with load cell sensors for automatic weighing systems. Similar implementations have been successfully applied to smart inventory management systems [5], patient trolley load monitoring in hospitals [6], and automatic animal weighing systems in aquaculture [7] and livestock farming [8]. The use of microcontrollers such as the ESP32 and the HX711 amplifier module in these automation systems has been shown to provide highly accurate weight data conversion [9]. In addition, the reliability of the ESP32 has been widely recognized in its use as a control unit for various intelligent automation and industrial control systems, such as smart home monitoring and factory production [10], [11]. The stability of ESP32 data transmission has also been tested in the monitoring of various intelligent systems, including chemical production control [12]. This microcontroller can also execute physical actuator logic precisely to control mechanical arms using servo motors [13] and operate other automatic control devices [14]. To support system visualization, a responsive web-based monitoring interface is strongly recommended, as it has proven effective in providing real-time access to information without the risk of high latency [15].

II. Methods

This study implements a prototype IoT-based conveyor system for automatic cement weighing and sorting, using the ESP32 as the main controller. The methods encompass the design of the system architecture, the logical workflow, and functional testing scenarios.

A. Device Design

The physical prototype design is shown in Figure 1. The ESP32 microcontroller processes weight data from the load cell sensor and HX711 module. These data are displayed locally on a 16×2 LCD and transmitted to the web dashboard in real time, while also serving as the basis for controlling the conveyor DC motor through the BTS7960 driver and the sorting servo motor actuator.

In addition to processing input data, the ESP32 simultaneously performs actuation and IoT network communication functions. Based on the weight evaluation results, the microcontroller controls the speed of the conveyor drive DC motor through the BTS7960 driver and operates the servo motor actuator, which acts as a sorting arm (rejector) to remove packages that do not meet the tolerance limits. All operational data are then transmitted wirelessly over a Wi-Fi network to the local web dashboard, allowing operators to monitor indicators and charts remotely in real time.

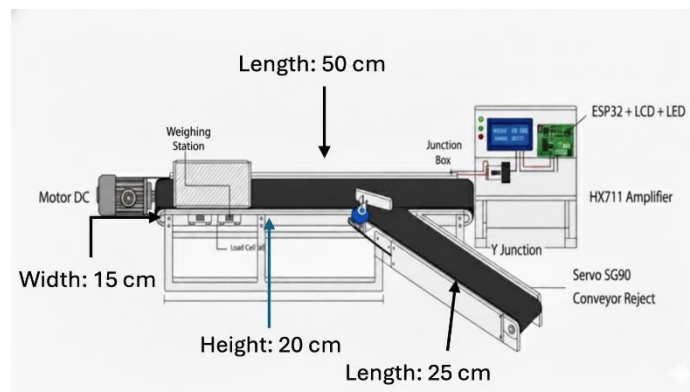


Figure 1. Device Design

B. System Architecture

As shown in Figure 2, the IoT-based system comprises three main layers: the perception layer, the network layer, and the application layer.

At the perception layer, a load cell sensor with an HX711 module dynamically measures the physical weight of packages. The NodeMCU ESP32 microcontroller operates at the intersection of the network and control layers, serving as both a data processor and a local Wi-Fi network provider. The ESP32 also controls the DC motor through a driver and the sorting servo motor. At the application layer, a monitoring website interface is accessed through a client laptop to visualize the data directly.

Based on the processed weight data, the ESP32 performs control functions for the actuator components. The microcontroller sends programmed instructions to control the conveyor DC motor speed through the motor driver and regulate the movement of the servo motor, which serves as a sorting arm mechanism (rejector). Finally, at the application layer, all weighing data and device operational status information are transmitted and visualized through the monitoring website interface. This interface can be accessed directly from a client laptop, enabling operators to monitor and evaluate production quality in real time.

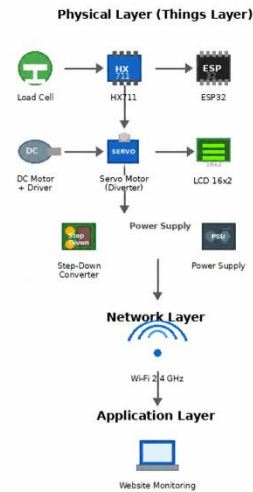


Figure 2. System Architecture

C. System Flowchart

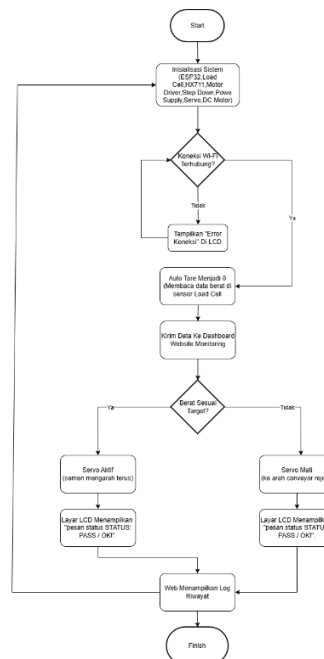


Figure 3. System Workflow

As shown in Figure 3, the system workflow begins with hardware initialization, during which the ESP32 microcontroller configures the load cell sensor, HX711 module, and motor actuators and establishes a Wi-Fi network connection to the local web server. Once the system is on standby and the main conveyor is running, the load cell sensor continuously reads the actual weight of each cement package passing over it. This data acquisition process dynamically detects the peak weight of the package, and the readings are immediately transmitted to the local web dashboard interface for real-time visualization.

Once the package weight has been obtained, the system enters a decision-making stage based on the programmed tolerance parameters. If the detected weight falls within the standard range of 490 to 510 grams, the system activates the "PASS" status. The servo motor remains in the straight position to allow the package to continue along the main distribution path, accompanied by an update to the normal status on the LCD. Conversely, if the package weight is outside the standard range, either below 490 grams or above 510 grams, the system immediately responds with the "REJECT" status. Under this abnormal condition, the ESP32 activates the servo motor to redirect and remove the nonconforming package, displays an error indicator on the LCD, and records the failure history in the dashboard log. After this sequence has been completed, the program loops back to the initial sensor-reading stage to process the next package.

D. Testing Parameters and Scenarios

The system was tested using a target cement package weight of 500 grams with a tolerance of ± 10 grams. Testing involved three load scenarios: on-target (~ 501 g), underweight (457 g), and overweight (557 g), each repeated 10 times. Weighing accuracy was evaluated using the percentage error relative to a standard load of 505 grams. Accuracy was calculated using Equation (1).

$$\text{Error} = \frac{\text{Measured Weight} - \text{Standard Weight}}{\text{Standard Weight}} \times 100\% \quad (1)$$

III. Results and Discussion

A. Results

The following presents the design and testing results of the prototype IoT-based conveyor system for automatic cement weighing and sorting, which dynamically weighs cement packages and sorts products automatically. The device uses a load cell sensor and HX711 module to detect the peak package weight, a BTS7960 motor driver to drive the main conveyor belt, an LCD as a local indicator, and a servo motor as the sorting arm actuator. The system automatically selects cement packages according to a target weight of 500 grams with a tolerance of ± 10 grams and promptly redirects packages to the rejection path when their detected weights do not meet the standard. All weight readings and machine decision statuses are visualized in real time on the local web server dashboard.

1) Hardware Implementation

Figure 4 shows the hardware implementation of the prototype automatic weighing and sorting conveyor system. Mechanically, the device is built on a sturdy frame, with a main conveyor path measuring 50 cm in length and an angled rejection conveyor path measuring 25 cm in length. At the weighing station, the load cell sensor is precisely integrated in a floating configuration directly beneath the main conveyor belt surface. This mechanical design is specifically intended to enable the sensor to respond to dynamic pressure from passing cement packages. All sensor signal processing is centralized in a control panel enclosure containing the ESP32 microcontroller, HX711 amplifier module, and 16 $\times$ 2 LCD, which serve as the local computation and data visualization components.

In addition to the sensor system, the prototype implementation integrates actuator components and reliable electrical management. The conveyor belt is driven continuously by a DC motor whose current supply is controlled through a high-power motor driver, the BTS7960 module, to ensure stable movement of heavy loads. A servo motor actuator is strategically positioned at the junction between the conveyor paths. This servo motor acts as a mechanical sorting arm (diverter) that automatically redirects cement packages to the rejection path when the system detects a weight outside the permitted tolerance. To keep all components operating without voltage-drop problems, the system uses centralized power management with a step-down module to supply current safely to the logic devices.

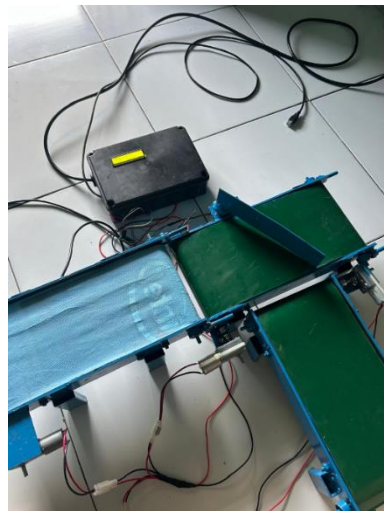


Figure 4. Hardware Implementation

2) Load Cell Sensor Accuracy Testing

The testing presented in Table 1 was conducted to determine reading accuracy while the conveyor was running under dynamic conditions. A standard load of 505 grams was used.

Table 1. Load Cell Sensor Accuracy Test Results

Trial	Standard Load (g)	Measured Load (g)	Difference (g)	Error (%)
1	505	501	4	0.79%
2	505	504	1	0.19%
3	505	504	1	0.19%
4	505	504	1	0.19%
5	505	501	4	0.79%
6	505	502	3	0.59%
7	505	499	6	1.18%
8	505	504	1	0.19%
9	505	500	5	0.99%
10	505	499	6	1.18%
Average	505	501.8	3.2	0.63%

Table 1 presents the results of load cell sensor accuracy testing while the conveyor system was operating dynamically. This test was specifically designed to validate sensor performance against the main cement package target weight of 500 grams. A standard load previously measured precisely using a digital scale, with a weight of 505 grams, was used as the reference. Data were collected through 10 consecutive test repetitions to ensure consistency (repeatability) and observe the stability of sensor readings in response to pressure from items continuously moving through the weighing area.

Based on the recorded test data, the integration of the load cell sensor and HX711 amplifier module demonstrated highly precise computational performance, with an average error of only 0.63%. The measurements showed that the average load recorded by the system was 501.8 grams, with the largest deviation from the standard load being approximately 6 grams. This high accuracy, with an error margin consistently well within the safe tolerance of ± 10 grams, demonstrates that the developed dynamic weighing system is highly reliable. These readings qualify as the main reference parameter for activating the automatic sorting actuator in the subsequent processing stage.

3) Automatic Sorting System Testing

The servo actuator was tested using the tolerance range of 490–510 grams. The test results in Table 2 show that the mechanical response operated as designed.

Table 2. Sorting Test Results

Test Scenario (10 Repetitions)	Actual Weight	System Decision (LCD)	Servo Response	Success Rate
On-Target Load	~501 grams	PASS (OK)	Straight (Passed Through)	100% (10/10)
Underweight Load	457 grams	REJECT (Underweight)	Path Closed (Rejected)	100% (10/10)
Overweight Load	557 grams	REJECT (Overweight)	Path Closed (Rejected)	100% (10/10)

The testing in Table 2 presents comparative results on processing time efficiency between the proposed automatic conveyor system prototype and the conventional manual weighing method. This test was designed to evaluate the average time required to complete one full cycle for each cement package, from initial weighing to sorting. In the manual method, the process was evaluated based on human physical performance, including activities such as lifting, weighing on a scale, and manually moving packages. By contrast, the processing speed of the IoT-based automation system depends entirely on its

mechanical specifications, particularly the rotational speed (RPM) of the DC motor actuator driving the main conveyor belt and the response speed of the servo motor arm.

Based on the comparative data, the manual method was faster in short-term testing, with an average processing time of approximately 5 seconds per package. However, this conventional method has a fundamental weakness because it is highly susceptible to physical fatigue and declining worker concentration, which can lead to human error over time. In contrast, the automatic conveyor system required approximately 15 seconds per package. Although processing was slower solely because of the limited motor RPM specifications at the prototype scale, the automated system offers a clear advantage in consistency and accuracy. The device can operate continuously without performance degradation, ensure that no nonconforming products escape monitoring, and integrate directly with real-time database logging, making it a much more reliable solution for long-term industrial applications.

4) Monitoring Dashboard Testing

Testing of the local web server interface showed that peak-weight data updates and status changes in Figure 5(a), (b), and (c), namely "STANDBY," "PASS," and "REJECT," were successfully visualized immediately on the chart. Data transmission latency from the ESP32 to the web interface was very low, at approximately 1 second, without causing memory problems in the microcontroller.

In terms of network and computational performance, testing of IoT integration with the local web interface demonstrated excellent reliability. The latency of data packet transmission from the ESP32 microcontroller to the client device browser was very low, at approximately 1 second. This transmission speed ensures that operators or supervisors can monitor production without significant information delays. In addition, the implementation of the client-server architecture on the local network proved efficient at the software level. Continuous data updates did not cause memory leaks or overload the microcontroller RAM, allowing the ESP32 to operate stably without freezing.

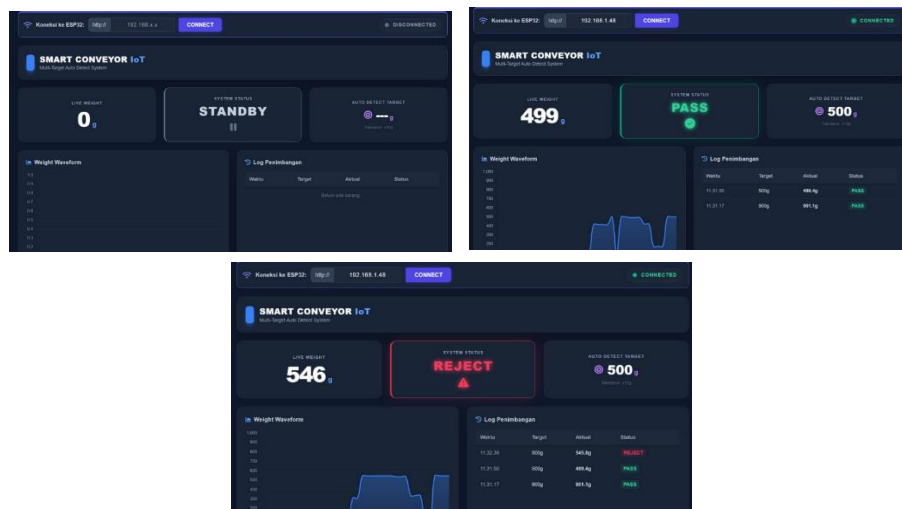


Figure 5. (a) Standby Condition, (b) Pass Condition, and (c) Reject Condition

B. Discussion

The test results show that the conveyor weighing system achieved very high accuracy, with an average reading error of only 0.63%. This value demonstrates that the load cell sensor and HX711 module can operate precisely in a dynamic environment while the conveyor is moving.

Operationally, the automatic sorting system using a servo motor achieved a 100% success rate. This can significantly reduce the risk of defective or nonconforming products reaching the distribution stage. Although the automatic system was slower than manual labor, with processing times of 15 seconds versus 5 seconds, respectively, its consistency and data integrity were substantially better because it was unaffected by human fatigue.

Integration with the website dashboard provides added value through data transparency. Real-time status monitoring, automatic history logging, and graphical visualization also make it easier to quickly identify trends in weight deviations.

IV. Conclusion

The IoT-based automatic conveyor system for cement weighing and sorting using the ESP32 was successfully implemented. Testing showed that the load cell sensor had a very low error rate of 0.63%, while the servo actuator achieved a sorting success rate of 100% against the specified tolerance limits. The local web server implementation proved effective in providing real-time visual monitoring and historical logs, making this system a much more consistent and reliable solution than conventional weighing methods.

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