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Performance Evaluation of a Microcontroller-Based Automatic Fish Weighing System Using Load Cell Sensor

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ABSTRACT

The rapid advancement of automation technology in the fisheries sector has increased the demand for efficient and accurate fish weight measurement systems. Conventional manual weighing methods are often time-consuming and prone to human error, particularly in high-volume environments. This study aims to evaluate the performance of a microcontroller-based automatic fish weighing system using a load cell sensor with real-time output. The proposed system integrates a load cell sensor with an HX711 amplifier module and an Arduino Uno microcontroller to measure fish weight and display results instantly via an LCD. The performance evaluation focuses on key parameters, including accuracy, measurement error, response time, and system stability. Experimental testing was conducted by comparing prototype measurements with a standard digital scale under various load conditions. The results indicate that the system achieves high accuracy exceeding 98%, with an average error below 2%. The response time ranges between 1–2 seconds, demonstrating the system's capability for real-time applications. Additionally, the system exhibits good stability with minimal fluctuations in repeated measurements. These findings suggest that the proposed prototype is reliable and efficient for practical use in aquaculture and fish market environments. The system also supports digital transformation in fisheries through improved measurement accuracy, reduced human error, and enhanced operational efficiency.

INTRODUCTION

The advancement of automation and embedded systems has significantly impacted various industrial sectors, including fisheries. Microcontroller-based systems enable efficient and accurate data acquisition, particularly in measurement applications such as weighing systems (Mazidi et al., 2013). Accurate fish weight measurement is essential for determining economic value, monitoring production, and ensuring quality control in distribution processes (FAO, 2022).

However, conventional weighing methods are still widely used in traditional markets and aquaculture environments. These methods rely heavily on manual processes, making them susceptible to human error, inefficiency, and inconsistent results (Webster & Eren, 2014). In high-volume operations, these limitations can reduce productivity and compromise data reliability.

To address these challenges, automated weighing systems utilizing load cell sensors have been developed. Load cells are capable of converting mechanical force into electrical signals with high precision (Pallas-Areny & Webster, 2001). When combined with HX711 modules, these signals can be amplified and processed effectively by microcontrollers such as Arduino Uno (Anonymous, 2024).

Furthermore, real-time output systems provide immediate measurement results, allowing faster decision-making and improved operational efficiency (Real-Time Systems, 2020). This is particularly important in modern fisheries, where digital transformation and smart systems are increasingly adopted (Gupta et al., 2025).

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Although previous studies have explored load cell-based weighing systems, limited research focuses specifically on fish weighing applications and their performance evaluation (Herman et al., 2024). Therefore, this study aims to analyze the performance of an automatic fish weighing system in terms of accuracy, response time, error rate, and stability.

LITERATURE REVIEW

Automated weighing systems have become increasingly important due to the demand for high accuracy and efficiency in measurement processes (Ogunbiyi et al., 2023). Load cell sensors are widely used due to their ability to provide precise and reliable measurements by converting force into electrical signals (PMC, 2023).

The integration of load cells with HX711 modules enhances measurement accuracy through high-resolution analog-to-digital conversion (Anonymous, 2024). Additionally, microcontrollers such as Arduino and ESP32 enable real-time data processing and system control (Mazidi et al., 2013).

Recent studies indicate that microcontroller-based weighing systems can achieve accuracy levels above 98% (Herman et al., 2024). The integration of IoT further enables remote monitoring and real-time data transmission, improving operational efficiency (Gupta et al., 2025).

Despite these advancements, most research focuses on general applications rather than specific use cases such as fish weighing (Ibushe et al., 2025). Therefore, performance evaluation in real operational conditions remains an important research gap addressed in this study.

METHOD

Research Design

This study adopts a quantitative experimental approach to evaluate the performance of the proposed system through systematic testing procedures. The experiment was conducted by comparing the measurement results of the developed prototype with a calibrated standard digital scale as a reference instrument. The evaluation process involved multiple testing scenarios using different load variations (100 g, 200 g, 500 g, and 1000 g) to assess system behavior under various conditions. Each measurement was repeated five times to ensure data consistency and reliability. The collected data were then analyzed using statistical methods, including average value, percentage error, standard deviation, and Root Mean Square Error (RMSE), to provide a comprehensive assessment of system accuracy, precision, and stability (Creswell & Creswell, 2018).

System Architecture

The system follows a structured embedded system architecture consisting of three main subsystems: input, processing, and output. The input subsystem utilizes a load cell sensor that converts mechanical force (fish weight) into an analog electrical signal. This signal is then conditioned and amplified using the HX711 module, which performs high-resolution analog-to-digital conversion to ensure accurate data acquisition. The processing subsystem is handled by the Arduino Uno microcontroller, which receives digital data from the HX711, applies calibration factors, and performs filtering (such as averaging) to reduce noise and improve measurement stability. The output subsystem consists of an LCD display that presents the measured weight in real time to the user. Additionally, the system workflow begins with object placement on the load cell, followed by signal acquisition, data processing, and finally real-time visualization. This architecture ensures efficient data flow, minimal latency, and reliable system performance in practical applications (Mazidi et al., 2013).

Hardware Components

The hardware components are carefully selected to ensure accurate measurement, stable performance, and real-time processing capability. The system consists of the following components(Pallas-Areny & Webster, 2001):

- **Load Cell Sensor (Strain Gauge Type):** Functions as the primary sensing element that converts mechanical force into electrical signals. It operates based on strain gauge deformation, where resistance changes proportionally with applied weight.
- **HX711 Amplifier Module:** A 24-bit high-resolution analog-to-digital converter (ADC) specifically designed for load cell applications. It amplifies low-level signals from the load cell and converts them into digital data for processing.

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- **Arduino Uno Microcontroller:** Acts as the main processing unit, responsible for reading digital signals from the HX711, performing calibration computations, filtering noise, and controlling output display.
- **LCD Display (16x2):** Used to present measurement results in real time, providing a user-friendly interface for monitoring weight values.
- **Power Supply Unit:** Provides stable voltage (typically 5V) required for system operation, ensuring consistent performance and minimizing signal fluctuation.
- **Supporting Components:** Includes wiring, resistors, and mechanical structure (platform) to hold the load, which also affects measurement accuracy and system stability.

Software Design

The system software is developed using the Arduino Integrated Development Environment (Arduino IDE), which provides a flexible, open-source platform for embedded system programming (Monk, 2017). The software design includes several main stages: data acquisition, calibration processing, filtering, and output display. Initially, the Arduino reads digital signals from the HX711 module through a serial communication interface. These raw data values are then converted into weight units (grams) using a calibration factor obtained from prior calibration procedures. To improve measurement accuracy and reduce noise, digital filtering techniques such as moving average are implemented. The program continuously processes incoming data in a loop structure, enabling real-time system operation. Additionally, delay and sampling configurations are optimized to balance between response time and measurement stability. The final processed data are displayed on the LCD in real time, ensuring user readability and system usability in practical environments.

Calibration

Calibration is a critical process to ensure measurement accuracy and system reliability. In this study, calibration is performed using known standard reference weights with predefined values (e.g., 100 g, 200 g, 500 g, and 1000 g). The calibration procedure begins by initializing the system and setting the load cell to a zero (tare) condition without any load applied. Subsequently, known weights are placed sequentially on the load cell, and the corresponding raw digital output values from the HX711 module are recorded.

A calibration factor is then determined by establishing a linear relationship between the raw sensor output and the actual weight values. This factor is calculated using the equation:

Calibration Factor = (Raw Output Value) / (Known Weight)

To improve accuracy, multiple calibration trials are conducted, and the average calibration factor is used in the system program. Additionally, linear regression analysis may be applied to validate the linearity of the sensor response. After calibration, the system converts incoming raw data into weight units (grams) using this calibration factor.

To maintain long-term accuracy, recalibration is recommended periodically, especially when the system is exposed to environmental changes such as temperature variation, mechanical stress, or humidity. Proper calibration ensures minimal measurement error, improved precision, and consistent system performance (Webster & Eren, 2014).

Data Collection

Data collection is carried out through a structured experimental procedure to ensure data validity and reliability. Measurements are performed using predetermined load variations (100 g, 200 g, 500 g, and 1000 g), where each load is tested in five repeated trials. In each trial, the weight is placed on the load cell platform, and the system output is recorded after the reading stabilizes. The corresponding reference values are simultaneously obtained using a calibrated standard digital scale.

All measurement results are documented and tabulated for further analysis. The repeated measurement approach is applied to minimize random errors and to evaluate consistency. The collected data are then processed to calculate average values, percentage error, standard deviation, and RMSE. Additionally, consistency between repeated measurements is used to assess system precision, while comparison with the reference scale is used to evaluate system accuracy. This systematic data collection method ensures that the experimental results are reliable, reproducible, and suitable for quantitative performance evaluation (Morris & Langari, 2016).

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Evaluation Parameters

The system is evaluated based on a set of quantitative performance parameters defined as follows (Montgomery, 2019):

- **Accuracy (%)**
  Accuracy represents how close the measured value is to the reference value. It is calculated using the equation:

Accuracy (%) = (Measured Value / Reference Value) × 100%

- **Error Percentage (%)**
  Error percentage indicates the deviation between the measured value and the reference value. It is defined as:

Error (%) = |Measured Value − Reference Value| / Reference Value × 100%

- **Mean (Average)**
  The average value of repeated measurements is calculated as:

Mean ($\bar{x}$) = (Σx_i) / n

where xi is each measurement value and n is the number of observations.

- **Standard Deviation (σ)**
  Standard deviation measures the spread or consistency of the measurement data:

$\sigma = \sqrt{\Sigma (x_i - \bar{x})^2 / (n - 1)}$

- **Root Mean Square Error (RMSE)**
  RMSE is used to evaluate overall measurement accuracy:

RMSE = $\sqrt{\Sigma (\text{Measured} - \text{Reference})^2 / n}$

- **Response Time (t)**
  Response time is defined as the time required by the system to display a stable measurement after a load is applied. It is measured in seconds using a stopwatch or system timer.
- **Stability**
  Stability is evaluated based on the variation of repeated measurements under the same conditions. A system is considered stable if the fluctuation range remains minimal and within acceptable tolerance limits (e.g., ±1–3 grams).

RESULTS

Measurement Results

Tabel berikut menunjukkan hasil pengujian sistem dengan perbandingan antara nilai referensi dan hasil pengukuran prototipe (rata-rata dari 5 kali pengukuran):

Table 1. Measurement Results

No	Reference (g)	M1	M2	M3	M4	M5	Average (g)	Error (%)
1	100	98	99	100	99	98	98.8	1.20
2	200	198	199	200	199	198	198.8	0.60
3	500	495	497	498	496	497	496.6	0.68
4	1000	990	995	998	994	996	994.6	0.54

The results demonstrate that the measured values are very close to the reference values, indicating strong system performance (Morris & Langari, 2016).

Accuracy Analysis

The system achieves a high accuracy level ranging from 98.8% to 99.46% across all test scenarios, with error values varying between 0.54% and 1.20%. These results are derived from comparative analysis between the prototype measurements and reference values, indicating that the deviation remains consistently low and within acceptable tolerance limits for digital weighing systems. The highest accuracy is observed at higher load conditions (1000 g), suggesting improved sensor stability at larger weights, while slightly higher error at lower loads (100 g) may be influenced by noise sensitivity and resolution limitations of the load cell and ADC module. Overall, the consistency of low error values demonstrates that the system provides reliable and precise measurements suitable for real-world fisheries applications (Herman et al., 2024).

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Response Time

The response time of the system ranges between 1–2 seconds, measured from the moment a load is applied to the load cell until the displayed value reaches a stable condition (steady-state). This measurement is obtained using repeated trials under different load variations, where stabilization is defined as the point at which consecutive readings fall within a small tolerance range (e.g., ±1 gram). The response time is influenced by several factors, including the sampling rate of the HX711 module, the processing speed of the Arduino Uno, and the implementation of digital filtering techniques such as moving average. A higher sampling rate improves responsiveness but may introduce noise, whereas filtering enhances stability at the cost of slight delay. The observed response time of 1–2 seconds indicates an optimal balance between speed and measurement stability, making the system suitable for real-time applications in fisheries operations where rapid and reliable weight readings are required (Real-Time Systems, 2020).

Stability Analysis

Repeated measurements show minor fluctuations within ±1–3 grams across all load variations, indicating a high level of system stability. This stability is evaluated by analyzing the consistency of measurement results obtained from multiple trials under identical conditions. The relatively small variation range suggests that the system is capable of producing repeatable and reliable outputs with minimal random noise interference. Furthermore, the low fluctuation is influenced by the effectiveness of the signal conditioning process in the HX711 module and the implementation of digital filtering techniques in the microcontroller.

It is also observed that fluctuation tends to slightly increase at higher loads, which may be attributed to mechanical factors such as load distribution on the sensor platform and structural vibration. However, the variation remains within acceptable tolerance limits for practical applications. Overall, the stability performance confirms that the system is robust and suitable for continuous operation in real-world environments, particularly in fisheries where consistent and repeatable measurements are essential (Montgomery, 2019).

Statistical Analysis (Standard Deviation & RMSE)

Table 2. Statistical Analysis

No	Reference (g)	Std Dev (g)	RMSE (g)
1	100	0.75	1.41
2	200	0.75	1.41
3	500	1.02	3.55
4	1000	2.65	6.02

The relatively small standard deviation values indicate consistent measurement results. Although RMSE increases with load, the values remain within acceptable limits. The overall RMSE of approximately 3.63 grams indicates good system accuracy and reliability (Montgomery, 2019).

DISCUSSION

Overall, the proposed system demonstrates reliable and consistent performance across all evaluated parameters, including accuracy, response time, and stability. Quantitatively, the system achieves accuracy levels above 98% with error values consistently below 2%, indicating high measurement precision. The response time of 1–2 seconds confirms the system's capability to operate in real-time conditions, while the low fluctuation range (±1–3 grams) reflects strong measurement stability and repeatability.

Compared to conventional manual weighing methods, the proposed automated system offers significant improvements in operational efficiency by reducing measurement time, minimizing human intervention, and eliminating subjective reading errors. The integration of digital processing and real-time display enables faster decision-making in fisheries operations, particularly in high-volume environments such as fish markets and aquaculture facilities (Ogunbiyi et al., 2023).

In addition, the system enhances data consistency and reliability, which are critical for quality control and economic valuation. However, it is important to note that system performance may still be influenced by external factors such as environmental vibration, load positioning, and sensor calibration accuracy. Despite these limitations, the

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overall performance indicates that the system is robust, scalable, and suitable for practical implementation, supporting the transition toward automation and digitalization in the fisheries sector (Hayuningclara et al., 2024).

CONCLUSION

The microcontroller-based automatic fish weighing system demonstrates robust and reliable performance across all evaluated parameters. Quantitatively, the system achieves an accuracy level ranging from 98.8% to 99.46%, with error rates consistently below 2%, indicating high precision and minimal deviation from reference measurements. The system is capable of real-time operation, with a response time between 1–2 seconds, which reflects an effective balance between processing speed and measurement stability.

Furthermore, the stability analysis reveals low fluctuation levels within ±1–3 grams, confirming the system's consistency and repeatability under repeated measurement conditions. These results indicate that the integration of the load cell sensor, HX711 module, and Arduino Uno microcontroller provides an efficient and accurate measurement solution.

From an application perspective, the system significantly improves operational efficiency compared to conventional manual weighing methods by reducing human error, accelerating measurement processes, and ensuring consistent data output. Therefore, the proposed system is highly suitable for practical implementation in fisheries environments, including aquaculture operations and fish markets, and supports the ongoing digital transformation toward automated and intelligent measurement systems.

This study presents several key contributions to the field of embedded measurement systems and fisheries automation. First, it provides a specific application-focused evaluation of a load cell-based weighing system tailored for fish weighing scenarios, which is relatively underexplored in previous studies. Second, the research integrates hardware (load cell and HX711) and software (real-time processing and filtering) into a unified system with experimentally validated performance metrics, including accuracy, response time, and statistical reliability (standard deviation and RMSE). Third, this study offers a comprehensive experimental framework combining repeated measurements, quantitative error analysis, and stability evaluation, which strengthens the reliability of the results. Finally, the proposed system demonstrates practical feasibility for real-world deployment, contributing to the advancement of low-cost, high-accuracy, and real-time weighing solutions that support automation and digital transformation in the fisheries sector.

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