Real-Time Warehouse Inventory Management System

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I. Introduction

Traditional warehouse inventory management systems rely heavily on manual data entry and periodic stock counting, leading to inaccuracies, labor inefficiency, and delayed inventory updates. In beverage distribution centers where high-volume operations demand precise inventory tracking, these conventional methods often result in stock discrepancies and operational delays.

This paper presents the Smart Inventory Pallet, an innovative IoT-based system designed to automate beverage warehouse inventory management through real-time weight monitoring and NFC-based vehicle identification. The system integrates load cell technology with wireless communication protocols to eliminate manual inventory processes while providing continuous, accurate stock updates through a web-based dashboard.

II. Literature Review

Recent advances in warehouse automation have emphasized the integration of IoT technologies for inventory management. Amazon's Dash Smart Shelf technology demonstrated the effectiveness of weight-based inventory tracking for consumer applications [1], while industrial implementations have focused on RFID and barcode systems. However, these approaches often require individual item tagging or complex infrastructure modifications.

Load cell-based inventory systems have gained attention for their accuracy and cost-effectiveness. The HX711 24-bit analog-to-digital converter has become the standard interface for precision weight measurements in embedded systems [2], offering high resolution and noise immunity suitable for industrial applications. Load cells demonstrate exceptional linearity and repeatability, making them ideal for continuous monitoring systems where consistent accuracy is critical [3].

NFC technology provides secure, contactless identification capabilities that enhance operational efficiency in warehouse environments. The integration of NFC-based operator identification with weight sensing systems offers a comprehensive approach to inventory tracking and accountability [4].

Current research gaps include the lack of integrated systems that combine weight-based tracking with operator identification for comprehensive inventory management in beverage distribution facilities.

III. Materials and Methods

A. Hardware Architecture

The Smart Inventory Pallet consists of a custom-built platform equipped with industrial-grade load cells connected to an HX711 24-bit ADC module. The ESP32 microcontroller serves as the central processing unit, interfacing with both the weight sensing system and an NFC reader module for operator identification.

B. Weight Calibration and Measurement

Initial system calibration involves storing a zero-weight reference value in ESP32 flash memory when the pallet is empty. The load cell generates analog signals proportional to applied weight, which the HX711 converts to digital values with 24-bit resolution. The ESP32 processes these measurements to calculate total pallet weight in real-time.

The HX711 raw digital output is converted to actual weight using the calibration equation (1):

$$W_{actual} = \left(ADC_{reading} - ADC_{offset}\right)/Scale_{factor} - (1)$$

where ADC_{offset} represents the $zero_{weight}$ digital reading stored during calibration, and $Scale_{factor}$ is determined by applying known calibration weights.

The net weight of bottles on the pallet is calculated by equation (2):

$$W_{bottles} = W_{actual} - W_{pallet} - (2)$$

where W_{pallet} is the tare weight of the empty pallet structure. Bottle count is determined using the division method equation (3):

$$N_{bottles} = \lfloor W_{bottles} \;/\; W_{unit} \rfloor \text{ - } (3)$$

where W_{unit} represents the weight of a single bottle stored in flash memory, and ⌊⌋ denotes the floor function to obtain integer bottle count.

C. Real Time Data Communication

The system employs MQTT protocol for real-time data transmission to a centralized broker. Weight measurements and NFC events are published every 3 seconds during active periods, ensuring immediate inventory updates.

When an operator removes bottles from the pallet, the system calculates the number of bottles taken using equation (4):

$$N_{removed} = \lfloor (W_{before} - W_{after})/W_{unit} \rfloor \text{ - } (4)$$

Where W_{before} and W_{after} represent the pallet weights before and after the transaction, respectively.

The updated inventory count is calculated as equation (5):

$$N_{current} = N_{previous} - N_{removed} - (5)$$

This transaction data, along with operator identification from NFC, is immediately published to the MQTT broker for real-time dashboard updates. The web-based dashboard subscribes to MQTT topics and displays real-time inventory status, transaction history, and operator activities.

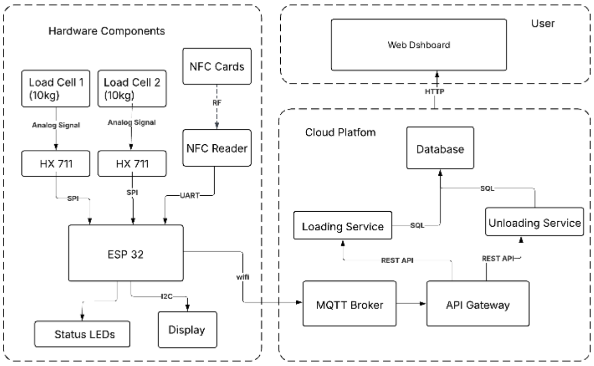

Fig. 1: Smart Inventory Pallet System Architecture

Figure 1 illustrates the complete system architecture, showing data flow from the physical sensors through the ESP32 microcontroller to the cloud-based inventory management platform.

IV. Results and Discussion

The Smart Inventory Pallet successfully demonstrated automated inventory tracking with high accuracy across multiple test scenarios. Figure 2,3 presents the system performance evaluation results.

The HX711 ADC signal stability test (Figure 2a) maintained consistent readings with minimal drift over the monitoring period. Calibration accuracy testing (Figure 2b) showed scaling errors below 2% for weights exceeding 200g, validating the effectiveness of the weight conversion method described in equation (1).

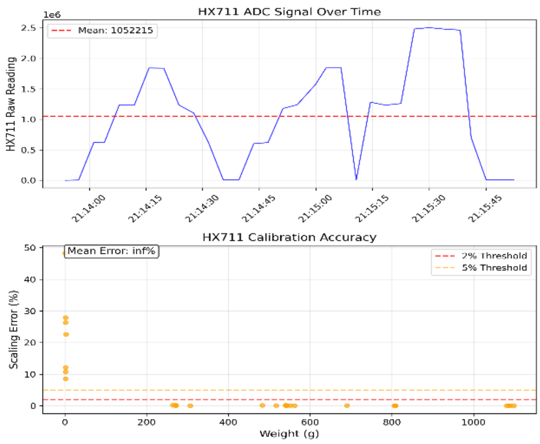

Fig. 2: HX711 Signal Analysis

Weight versus bottle count correlation (Figure3) demonstrated exceptional linearity with R^2=0.995. The measured slope of 267.4g per bottle closely matched the theoretical value of 275g per bottle, confirming the reliability of equations (2) and (3) for accurate bottle count determination.

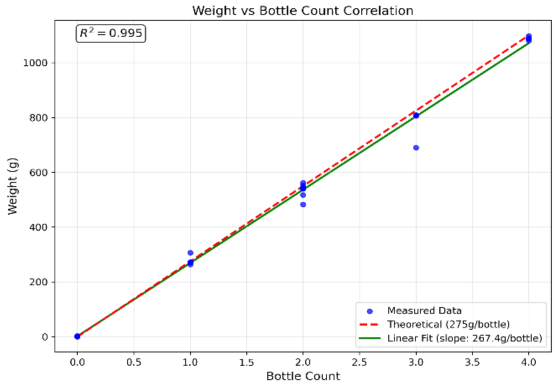

Fig. 3: Weight Vs Bottles

V. Conclusion

The Smart Inventory Pallet represents a significant advancement in warehouse automation technology, specifically addressing the challenges of beverage distribution inventory management. By combining precise weight sensing with NFC-based operator identification and real-time MQTT communication, the system provides comprehensive automation of inventory processes.

The solution offers substantial benefits including elimination of manual data entry, real-time inventory visibility, operator accountability, and reduced operational costs. Future enhancements will focus on predictive analytics integration, multi-pallet network deployment, and advanced reporting capabilities for enterprise-scale implementations.

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