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Abstract:	The SEDI-E Smart Digital Weighing Scale is a low cost, IoT-enabled system designed to improve accuracy, transparency, and reliability in weight-based transactions. Built with Arduino and WiFi connectivity, it features a Unified Tare/Zero algorithm, dual-facing displays, and Secure Admin controls. It supports offline operation with automatic data recovery, making it ideal for low-infrastructure setting. It is validated for Class III accuracy, and offers over six hours of battery life and seamless cloud sync. Locally manufacturable and scalable, it empowers micro and small enterprises and promotes fair trade in Nigeria and similar markets.
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SEDI-E Smart Digital Weighing Scale: AN IoT-Driven Smart Weighing Scale for Transparent Trade and MSME Empowerment

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Abstract

The SEDI-E Smart Digital Weighing Scale (SEDI-ESmartScale) is a cost-effective, embedded system designed to enhance accuracy, transparency, and data traceability in weight-based transactions across retail and agricultural markets. Traditional weighing devices in developing economies often suffer from calibration errors, limited durability, and lack of integration with digital platforms, contributing to disputes and inefficiencies. To address these gaps, SEDI-ESmartScale incorporates an Arduino UNO microcontroller, an HX711 load cell amplifier for high-resolution signal conversion, and an ESP8266 WiFi module for cloud connectivity. The system features a novel Unified Tare/Zero algorithm that reduces user error, password-protected administrative controls to safeguard pricing data, and dual-facing digital displays to improve consumer confidence. Beyond connectivity, SEDI-ESmartScale operates in offline-first mode with automatic data caching and recovery, ensuring reliability in grid-unstable or low-infrastructure environments. Laboratory and field validations demonstrated Class III weighing performance with ±0.05% full-scale accuracy, seamless offline-to-online synchronization, and more than six hours of uninterrupted battery-backed operation. By combining affordability, local manufacturability, and IoT integration, SEDI-ESmartScale provides a scalable technological pathway for empowering small and medium-scale enterprises, advancing trade fairness, and reducing reliance on expensive imported weighing solutions in Nigeria and similar economies.

Keywords: Cloud integration, Consumer trust, Developing economies, Internet of Things, Local manufacturing, Smart Retail Technology, Unified Tare/Zero

1. Introduction

Weighing systems form a fundamental backbone of commerce in retail, agriculture, and logistics sectors. Accuracy and transparency in weight-based transactions directly affect consumer trust, vendor credibility, and overall market efficiency. However, in Nigeria and across many developing economies, the prevailing reliance on manual or poorly calibrated weighing devices contributes to disputes, revenue loss, and systemic inefficiencies. Imported smart weighing scales exist but remain prohibitively expensive and lack localized support, creating a gap for affordable, rugged, and digitally integrated solutions.

Recent advances in embedded systems and the Internet of Things (IoT) present opportunities for developing context-appropriate, low-cost smart devices that bridge this gap. Similar work in IoT-based measurement systems demonstrates potential for traceability and automation in small-scale commerce [1]. The SEDI-E Smart Digital Weighing Scale (SEDI-ESmartScale), developed at the Scientific Equipment Development Institute (SEDI), Enugu, an institute under the National Agency of Science and Engineering Infrastructure (NASENI), is one such innovation. Designed for small and medium enterprises (SMEs), it integrates precision sensing, IoT-enabled analytics, and local manufacturability to enable fair trade, digital inclusion, and scalable adoption.

1.1. Related Works

Weighing technologies have evolved from mechanical systems with limited precision to microcontroller-based electronic scales that use load cells and analog-to-digital converters (ADCs) like the HX711 for enhanced accuracy and digital integration [2]. Recent advances in embedded systems and IoT have enabled connected weighing solutions supporting real-time data sharing and enterprise integration, with demonstrated applications in agriculture, retail, and supply chains [1, 3]. However, such systems are often expensive, infrastructure-dependent, and optimized for industrial use rather than for small and medium enterprises (SMEs) in developing countries. In emerging markets where retail is largely informal, reliance on manual or standalone digital scales contributes to pricing inconsistencies, transaction disputes, and lack of traceability [4, 5]. Research highlights that IoT-enabled automation and audit trails can strengthen market transparency, but affordable, battery-backed solutions for rural and grid-unstable environments remain limited [6, 7, 8]. Moreover, conventional scales frequently separate tare and zeroing functions, creating usability issues, whereas studies in user interface design suggest that simplified, automated controls enhance adoption and reduce errors [9, 10].

1.2. Contribution and Organisation

The SEDI-ESmartScale addresses these gaps by offering:

1. A Unified Tare/Zero algorithm that intelligently distinguishes between zeroing and tare operations while enforcing overload safety.
2. An IoT-enabled platform with automatic offline failover, ensuring continuous operation regardless of network conditions.
3. Password-protected access control for administrative functions, introducing security features uncommon in low-cost scales.
4. A locally manufacturable design leveraging open-source microcontroller platforms (Arduino UNO, ESP8266), making the solution affordable and scalable for SMEs.

The remainder of the study is structured as follows: in Section 2, we outline the system architecture and design principles, offering a foundational understanding of the Smart Digital Weighing Scale. Section 3 defines the core innovations, emphasizing its uniqueness and technical advancements. Section 4 details the experimental validation, explores practical applications, and assesses the commercial viability of the system. Finally, Section 6 concludes the study with final remarks, summarizing insights and suggesting directions for future work.

2. System Architecture and Design

The SEDI-ESmartScale employs a modular design comprising sensing, processing, connectivity, and user interface subsystems.

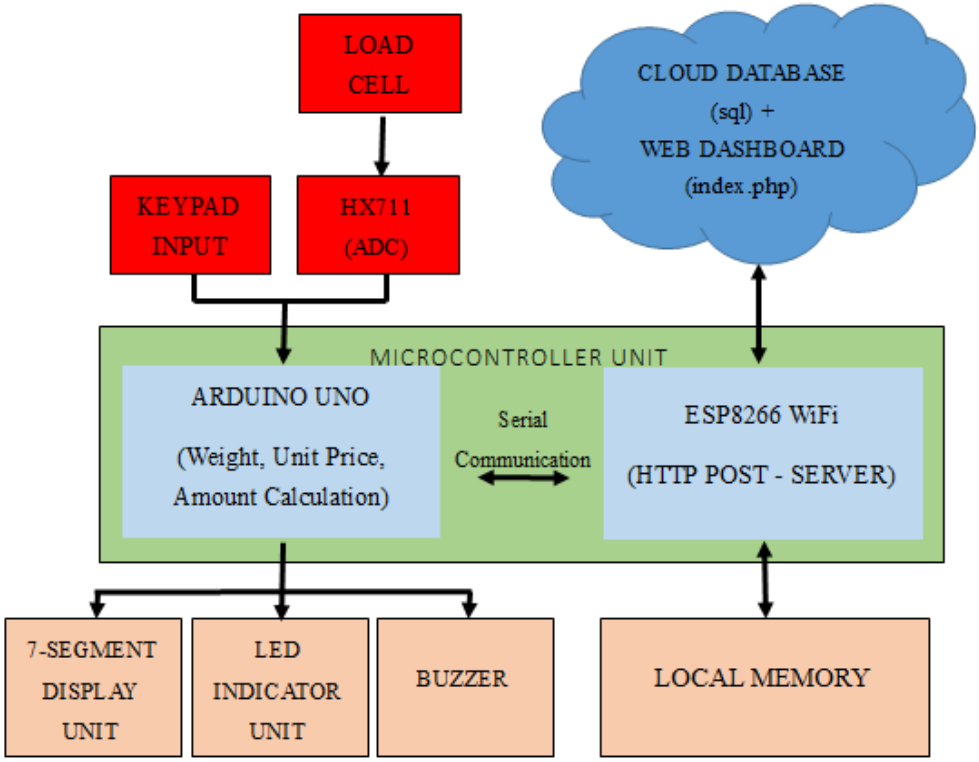

Figure 1: The block diagram of SEDI-ESmartScale

2.1. Hardware Components

The sensing unit uses a strain gauge load cell interfaced with an HX711 24-bit analog-to-digital converter for high-resolution signal acquisition. The processing unit is based on the ATmega328P microcontroller (Arduino UNO R3), selected for its balance of computational efficiency, local availability, and open-source firmware ecosystem. Dual-facing five-digit seven-segment LED displays provide simultaneous visibility for both vendor and customer, enhancing transaction transparency. A 5 x 4 keypad enables numeric entry, tare/zero, upload, memory recall and password-protected functions. Power is supplied via AC input with rechargeable lithium-ion battery backup, offering automatic switchover during outages.

Table 1: The Hardware components and description

Component	Function	Justification
Load Cell Sensor (200 kg capacity)	Measures applied weight; outputs analog signal	High sensitivity, durable for commercial use
HX711 24-bit ADC Module	Converts load cell analog signal to digital data	Industry-standard ADC for weighing systems
Arduino UNO (ATmega328P)	Core computation, weight calculation, keypad control, display management	Low-cost, open-source microcontroller with strong community support
ESP8266 WiFi Module	Transmits transaction data to a cloud server via HTTP POST	Compact, low-cost IoT connectivity solution
Triple 7-Segment Display Modules	Displays weight, unit price, and computed total amount (dual-view for vendor and customer)	Enhances customer transparency and trust
5x4 Keypad Matrix	Provides control inputs: ON/OFF, Unified Tare/Zero, Upload, Recall, Change Password input, Change Unit Price input, Unit toggle	Simplified user interface with multi-functional keys
Li-ion Battery Pack (3×3.7V)	Provides backup power during grid failure	Ensures uninterrupted operation in rural/grid-unstable regions
Charging Circuit with Auto-Switching	Seamlessly switches between AC and battery	Improves usability, ensures device uptime

2.2. Connectivity and Firmware Features

The ESP8266 WiFi module enables cloud integration, transmitting transaction data to a PHP/MySQL web server with support for analytics and reporting. Recognizing infrastructural challenges, the firmware supports offline-first operation: data is cached

locally and automatically synchronized upon network restoration.

Unique contributions include a Unified Tare/Zero algorithm designed to minimize calibration errors and improve ease of use, and multi-level password protection to secure administrative settings, preventing manipulation of unit price or calibration by unauthorized users.

3. The Core Innovation

SEDI-ESmartScale introduces several innovations beyond conventional weighing devices. First, unified Tare/Zero algorithm automatically determines whether to zero the scale or apply tare based on current load status. Second, the offline-to-online IoT resilience ensures reliability in low-connectivity environments, an essential feature for rural Nigerian markets. Third, its password-based security system offers a safeguard rarely present in low-cost devices and the ability to change the password and unit price remotely and locally. Importantly, the modular, open-source design facilitates local assembly and maintenance, reducing costs while enabling customization for diverse use cases.

4. Experimental Validation, Applications and Commercial Viability

The prototype underwent laboratory calibration and field testing. Using certified calibration weights (0.5–100 kg), the system achieved an accuracy of ±0.05% full scale (FS), aligning with Class III commercial weighing standards. Resolution was measured at 30 g. Connectivity tests simulated unstable WiFi conditions with 30% packet loss, yet all records were successfully cached and recovered post-reconnection, achieving 100% data integrity.

Battery endurance tests confirmed more than six hours of continuous operation under nominal load, with switchover from AC to battery occurring in under one second. Field trials in open-air markets highlighted improved transaction transparency, as vendors and customers alike reported increased trust due to the dual-display feature.

Figure 2: The SEDI-E Smart Digital Weighing Scale

4.1. Applications

SEDI-ESmartScale addresses diverse applications:

- Retail MSMEs and Market Vendors: Transparent weighing enhances consumer trust and reduces disputes.
- Agriculture: Fair produce valuation improves farmer incomes and enables digital record-keeping.
- Logistics: Integration into supply chains enables auditable records of goods in transit.
- Rural Commerce: The scale's offline capabilities and battery power make it suitable for rural markets.

4.2. Commercialization Potential

Commercial viability is strengthened by Nigeria's 39 million MSMEs [11, 12], the majority of which rely on weight-based transactions. The retail industry is a critical driver of Nigeria's economy, valued at approximately $125 billion annually as of

recent reports [13] [BusinessDay, Global Retail Index], with food and grocery retail alone estimated at $45.7 billion in 2020 [14] [Guardian Nigeria]. Imported smart scales cost several multiples of SEDI-ESmartScale's projected unit price, underscoring the affordability advantage.

The commercialization pathway includes hardware sales combined with optional subscription services for advanced analytics. Calibration, firmware updates, and after-sales support represent additional service-based revenue streams. Initial pilot deployments in Nigerian SME hubs are envisioned, followed by regional expansion into ECOWAS markets.

5. Conclusion and Future Work

The SEDI-E Smart Digital Weighing Scale (SEDI-ESmartScale) demonstrates that affordable, accurate, and IoT-enabled devices can be developed and manufactured locally to meet the unique needs of Nigeria's SME-driven economy. By addressing issues of accuracy, transparency, and connectivity, SEDI-ESmartScale has the potential to transform informal and formal trade practices while aligning with national industrialization goals.

Future R&D will focus on integrating mobile payment systems, developing higher-capacity models for industrial use, and exploring blockchain-enabled audit trails for trade transparency. Incorporating AI-based analytics for demand forecasting and supply optimization represents another pathway for scaling impact. By combining affordability, innovation, and local production, SEDI-ESmartScale stands as a benchmark for African-developed trade technology with global potential.

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