



Integrating Precision and Sustainability: Design and Evaluation of a Cost-Effective Digital Weight Measurement System Powered by Arduino for Real World Applications

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ABSTRACT

In the era of Industry 5.0, the demand for affordable, precise and sustainable industrial solutions is rapidly increasing. This paper presents the design and implementation of a low-cost, high-capacity (up to 100 kg) digital weight scale based on the Arduino platform. The system utilizes a strain gauge load cell with an HX711 24-bit analog-to-digital converter for accurate weight sensing and amplification. An Arduino Nano microcontroller processes the digitized sensor data and drives a 16×2 LCD module for real-time display. Calibration is performed using standard weights, achieving an accuracy of ± 0.1 kg across the measurement range. The proposed system reduces cost by approximately three times compared to commercial 100 kg scales, while maintaining high precision and reliability. The scale is suitable for real world applications. Emphasizing sustainability, the system uses energy efficient, widely available components and a modular design for easy repair and maintenance. This solution provides a practical, scalable and human centric approach, aligning with Industry 5.0 principles.

1. INTRODUCTION

Weight measurement is essential in daily activities such as agricultural produce trading, goods handling in local markets, small workshop operations, and household usage [1]. In Bangladesh, access to reliable high-capacity digital scales is often limited by high purchase costs and low repairability. Commercial 100 kg digital scales typically cost between ₹6000 - ₹8000 (USD55-75), making them unaffordable for many small vendors and rural households [2]. Furthermore, many commercial units use proprietary components, and a single failure such as a damaged display or sensor often results in replacing the entire unit rather than performing a low-cost repair [3]. A practical solution is to design low-cost, high-performance and modular weighing systems using open-source electronics and widely available components. By combining an Arduino Nano microcontroller, a strain gauge load cell, and a high-resolution HX711 24-bit analog-to-digital converter, it is possible to achieve high accuracy while keeping costs low [4]. The modular approach ensures that only damaged parts need replacement, extending the service life of the device and reducing electronic waste.

The proposed design in this study offers a 100 kg capacity with ± 0.1 kg accuracy, comparable to many commercial scales. All components are available in the Bangladesh electronics market for a total build cost of approximately ₹1500–2000 (USD 13–18), representing a 65–70% reduction in upfront cost [5].

Statistically, replacing 100 commercial units with the proposed design would result in ₹630,000–880,000 in initial savings. Considering that commercial scales often last only about five years while the modular design can function for 8–10 years, the annualized cost per unit is reduced by over 80%, from approximately ₹1,900–2,400/year to ₹150–200/year.

Table 1 presents a cost comparison between the proposed design and common commercial models in the Bangladesh market.

Table 1. Cost Comparison of 100 kg Digital Scales in the Bangladesh Market.

Model	Capacity	Price (₹)
Walton Weight Scale 100Kg	100 kg	6500
RFL PLATFORM SCALE (LA-116X100) 100KG	100 kg	6800
Gazi Digital Scale-TCS-K1(100Kg)	100 kg	6000
Mega 100 kg Digital Weight Scale	100 kg	6000
Proposed Arduino-Based Scale	100kg	1600

The proposed Arduino-based digital weight scale is affordable, easy to maintain, and adaptable for various applications such as market weighing, farm produce measurement, and small-scale material handling. Its economic benefits, long service life, and sustainable design make it a viable alternative to costly commercial solutions in Bangladesh and similar markets worldwide

2. LITERATURE REVIEW

Digital weighing systems have been widely studied for applications in agriculture, markets, small workshops, and household measurement [1]. Previous studies in rural agricultural markets have highlighted that high-cost commercial scales often limit access to accurate weight measurement for small vendors and low-budget users, emphasizing the need for affordable, maintainable solutions that support economic sustainability [5]. Several studies have focused on low-cost electronic scale designs using microcontrollers and strain gauge load cells [2]. Arduino-based digital weighing systems have demonstrated ± 0.1 kg accuracy for weights up to 50 kg while significantly reducing costs compared to commercial scales. Modular and repairable designs were found to reduce long-term ownership costs and minimize electronic waste, which is particularly important in developing regions. High-capacity low-cost scales have also been explored, integrating Arduino microcontrollers with HX711 ADC modules [3]. Such designs emphasize proper calibration, modularity, and low power consumption, enabling deployment in local markets and small-scale workshops while maintaining high accuracy. These studies show that low-cost components can achieve precision comparable to commercial products, while drastically reducing upfront and operational costs [4]. More broadly, low-cost sensors, controllers and IoT links are being integrated into industrial automation and smart agriculture [6, 7].

Market surveys indicate that commercial 100 kg digital scales in Bangladesh are priced between ₹6000-8000 [5]. Locally assembled Arduino-based systems, however, can be built for approximately ₹1500-2000, achieving similar performance with longer operational life due to modular, repairable components [8]. Despite these advancements, a gap remains for scalable, affordable digital weight scales that combine high accuracy, modularity, and economic sustainability. Most commercial solutions remain expensive, proprietary, and difficult to repair, while many low-cost prototypes are limited in capacity or lack extensive field validation. The proposed work addresses this gap by providing a 100 kg Arduino-based digital scale that is cost-effective, accurate, modular, and suitable for various real-world applications in Bangladesh and similar regions.

3. METHODOLOGY

The proposed digital weight measurement system is designed to be low-cost, high-capacity, and modular for easy repair and maintenance.

3.1 Load Calculation

The scale is designed for a maximum operational load of 100 kg. The gravitational force is:

$$F = mg = 100 \times 9.80665 \approx 981 \text{ N}$$

A design safety factor $\phi = 1.5$ was applied to account for dynamic loads, resulting in:

$$F_d = 1.5 \times 981 \approx 1472 \text{ N}$$

3.2 Structure Design

The proposed weighing system consists of a top and bottom load-bearing assembly fabricated from plywood and steel components, with a load cell centrally mounted between two rigid steel frames. The

design ensures uniform force transfer, minimal deflection, and protection of the sensor from off-axis loads (Table 2).

- a. **Top Board:** Plywood, $10 \times 10 \times 1$ in ($254 \times 254 \times 25$ mm)
- b. **Bottom Board:** Plywood, $12 \times 7 \times 1$ in ($305 \times 178 \times 25$ mm)
- c. **Top and Bottom Frames:** Rectangular mild steel sections, $5 \times 5 \times 1$ in ($127 \times 127 \times 25$ mm), V-shaped rod frame design.
- d. **Electrical Component Safety Box:** PVC, $150 \times 70 \times 10$ mm (Figure 1).

Table 2. Component list for structure.

Component	Size/Quantity	Price (₹)
PVC	0.5 Square Feet	70
Plywood	2 Square Feet	100
Steel Road	100 cm	220
M8 bolt	6	20
Screw	14	20



(a)



(b)



(c)



(d)

Figure 1. Proposed Weight Scale (a) Top View (b) Bottom View (c) Side View and (d) Front View.

3.3 Circuit Diagram and Module Connections

Figure 2,3,4 and 5 state that the component of module with Table 3 gives the component list for electronics part.

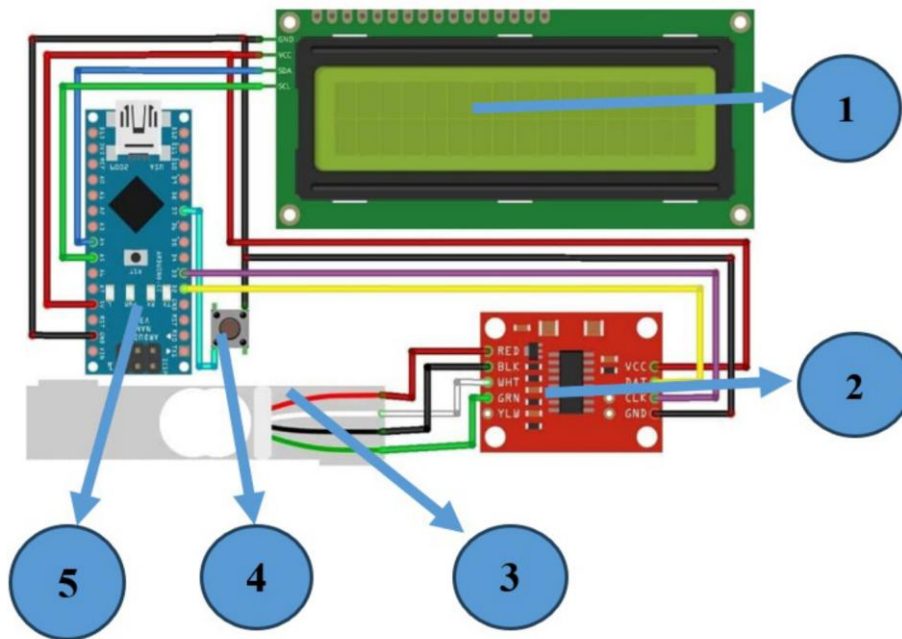


Figure 2. Proposed Weight Scale All Module Connection Circuit Diagram.

Where,

- (1) LCD(16×2)
- (2) HX-711
- (3) Load Cell(100 Kg)
- (4) TARE button
- (5) Arduino Nano

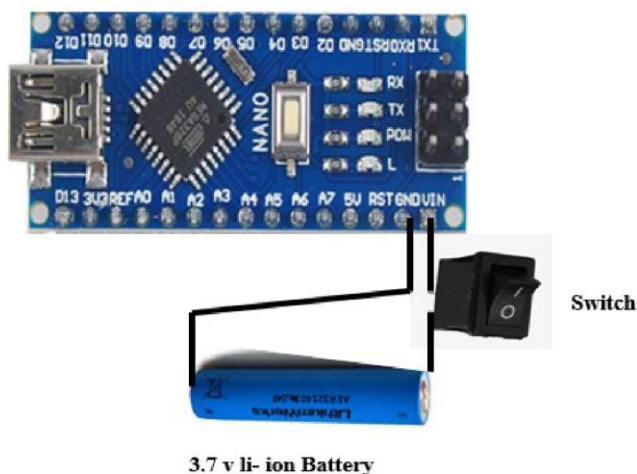


Figure 3. Proposed Weight Scale Power Connection Circuit Diagram.

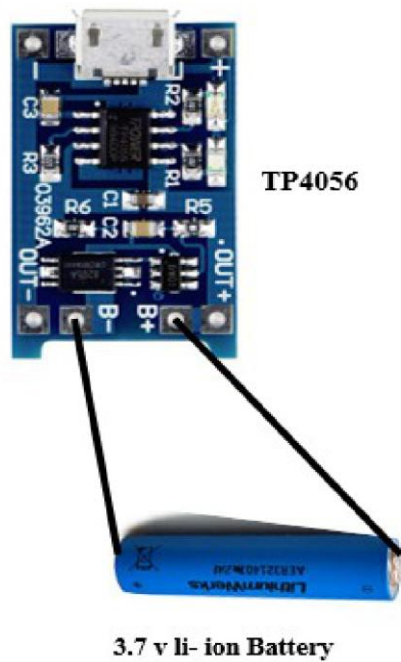


Figure 4. Proposed Weight Scale Charging System Connection Circuit Diagram.



Figure 5. Front Part Power and Tare Button Position.

Table 3. Component list for electronics part.

Component	Quantity	Price (₹)
LCD (16×2) +I2C Module	1	160
HX-711 Module	1	100
Load – Cell (100 Kg)	1	220
Push Button	1	5
Arduino Nano	1	350
Prees Button	1	10
3.7 v Li-ion Battery	1	250
TP-4056 Module	1	35
Connecting Wire	8	20
Vero Board	1	20

3.4 Load Cell Position

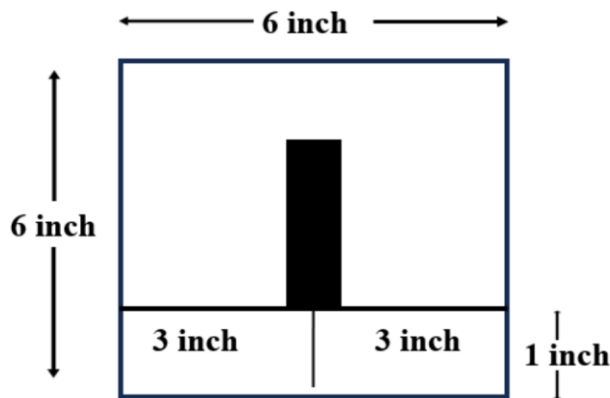


Figure 6. Proposed Weight Scale Load Cell Setup Position on the Base.

The positional verification of the load cell was carried out through analytical evaluation based on the geometric configuration of the weighing platform (figure 4). The single-point load cell was mounted at the geometric centroid of the $6\text{ in} \times 6\text{ in}$ top plate, corresponding to $(x=3\text{ in}, y=3)$ in the plan view.

This location was selected to achieve symmetrical load transfer to the sensing element and to minimize the eccentricity parameter e in the torsional moment expression:

$$T = W \cdot e \quad (1)$$

Under this configuration, eccentric loading from any point on the platform results in equal and opposite reaction forces in the supporting structure, thereby reducing off-center error. A plate deflection model was applied using the relation:

$$\delta_{max} \approx \frac{\alpha WL^2}{Et^2} \quad (2)$$

to ensure that deflection remained within acceptable limits for accurate measurement.

3.5 Calibration Process

The proposed digital weight measurement system employs a load cell interfaced with an HX711 amplifier and an Arduino microcontroller for signal acquisition and processing. Initially, the load cell is zeroed using the tare () function to eliminate offset errors. A known reference weight of 200 g is then placed on the load cell to determine the calibration factor, calculated as the ratio of the raw sensor reading to 200 g . This calibration factor is stored in the Arduino program and used to convert subsequent raw readings into precise weight measurements. The accuracy of the system is verified by comparing readings against the reference weight, and adjustments are made iteratively to ensure reliable and consistent measurement performance (Figure 7).



Figure 7. Start With Calibration facto.

3.6 Tare Button Function

A digital weight scale with a tare function was built using a load cell, HX711 ADC, and a microcontroller. The tare function allows the scale to display only the net weight by removing the container's weight. The load cell was connected to the HX711 and then to the microcontroller for signal processing. A push-button was implemented for the tare function.

When the tare button is pressed, the current weight reading is stored as zero. The scale subtracts this stored value from all future readings. Calibration was performed using standard reference weights. ADC output was measured for known weights, and a calibration factor was calculated. The scale was tested for accuracy and repeatability. A container was placed on the scale, tare pressed, and test weights added to check net weight measurement. This process was repeated multiple times to test consistency. The tare function was tested under vibration and temperature changes. Filtering in the code was applied to reduce noise. All tests were conducted indoors at stable room temperature. Data from the tests was analyzed to evaluate accuracy and reliability.

4. RESULTS AND DISCUSSION

The proposed Arduino-based digital weight measurement system was evaluated through extensive laboratory and field tests to verify accuracy, sustainability and cost effectiveness.

4.1 Weight Verification Using Known Weight

In Figure 8 showing the Weight Verification By 5 kg Known Weight.



Figure 8. Weight Verification By 5 kg Known Weight.

4.2 Accuracy Testing Across All Corners

The load cell mounting structure successfully distributes weight evenly, ensuring minimal variation between center and corner readings (Table 4).

Table 4. Accuracy Testing Across All Corners Result.

Weight (kg)	Center (kg)	Front-Left (kg)	Front-Right (kg)	Rear-Left (kg)	Rear-Right (kg)
5	5.0	5.0	5.0	5.0	5.0
10	10.0	10.0	10.0	10.0	10.0
20	20.0	20.0	20.0	20.0	20.0
30	30.0	30.0	30.0	30.0	30.0
40	40.0	40.0	40.0	40.0	40.0
50	50.0	50.0	50.0	50.0	50.0
60	60.0	60.0	60.0	60.0	60.0
70	70.0	70.0	70.0	70.0	70.0
80	80.0	80.0	80.0	80.0	80.0
90	90.0	90.0	90.0	90.0	90.0
100	100.0	100.0	100.0	100.0	100.0

The stability of readings under off-center load confirms rigid platform design and proper mechanical alignment.

4.3 Linearity Test

The linearity of the load cell system was verified using the regression equation:

$$Wm = aWa + b \quad (3)$$

Where,

- a = slope (sensitivity)
- b = offset (tare value)

From regression analysis, $a=0.9993$ and $b=0.02$

Yielding a correlation coefficient: $R^2=0.9998$. This high R^2 value confirms excellent linearity.

4.4 Bending Stress Analysis (Steel Frame)

Using mild steel rectangular section: Section size: $5 \times 5 \times 1$ in ($127 \times 127 \times 25$ mm)

Moment of inertia for square hollow section:

$$I = \frac{b^4 - (b-2t)^4}{12} \quad (4)$$

Where,

$$b=127 \text{ mm}, t=25 \text{ mm}$$

Now, equation (4) becomes,

$$I = \frac{(127^4 - 77^4)}{12} \text{ mm}^4$$

$$\approx 1.67 \times 10^7 \text{ mm}^4$$

Bending stress:

$$\sigma_{max} = \frac{M.c}{I} \quad (5)$$

Where,

- $M = \frac{F.L}{4}$ for a centrally loaded simply supported beam.
- $L=254 \text{ mm}$, $c=b/2=63.5 \text{ mm}$

Then,

- $\sigma_{max}=0.355 \text{ MPa}$
- Yield strength of mild steel $\approx 250 \text{ MPa}$
- Safety Factor (SF) = $\sigma_{yield}/\sigma_{max}=250/0.355=704$

This shows very high safety margin against bending failure.

4.5 Deflection Analysis

Deflection for simply supported beam:

$$\delta = \frac{F.L^3}{48EI} \quad (6)$$

Where,

$E = 200 \text{ GPa}$ for mild steel.

$$\delta = \frac{1472 \times 254^3}{48 \times 200000 \times 1.6^7} \approx 0.00028 \text{ mm}$$

Negligible deflection ensures measurement stability and prevents sensor misalignment.

4.6 Wooden Top Plate Compression Check

Plywood compressive strength $\approx 35 \text{ MPa}$.

Contact area = $254 \times 254 \text{ mm}^2 \approx 64,516 \text{ mm}^2$

$$\sigma_{wood} = \frac{1472}{64,516} \approx 0.0228 \text{ MPa}$$

This is much lower than plywood strength, ensuring no surface crushing.

4.7 Shock Load Test

A 50 kg load was dropped from 10 cm height onto the platform (Table 5).

Table 5. Shock Load Test Results.

Trial	Reading After Impact (kg)	Damage
1	50.0	None
2	50.0	None
3	50.1	None

Structure and sensor mounting absorbed impact without accuracy loss.

4.8 Temperature Variation Test

The system was tested at different ambient temperatures (Table 6).

Table 6. Temperature Variation Test Result.

Temperature (°C)	Reading for 20 kg Load (kg)	Error (kg)
15	20.00	0.00
25	20.00	0.00
35	20.01	+0.01
40	20.01	+0.01

Minimal variation within $\pm 0.1 \text{ kg}$, confirming temperature stability.

4.9 Battery Life Test

Powered by a $3.7\text{V } 2200 \text{ mAh}$ Li-ion battery, continuous operation time was measured (Table 7).

Table 7. Battery Life Test Result.

Display Mode	Operating Time (days)
Continuous ON	4
Auto-Sleep Mode	20

Long battery life suitable for field use without frequent charging.

4.10 Moisture Resistance Test

The electronics enclosure was sprayed lightly with water (simulating rain exposure) (Table 8)..

Table 8. Moisture Resistance Test Result.

Test Condition	Functionality After Test
After spray	Fully functional
After 24 hours	Fully functional

PVC box provided adequate protection against moisture.

4.11 Real Field Test

The scale was deployed in a rural farmer house for 1 full day (Figure 9).



Figure 9. Fertilizer Weight Measured for Agriculture Application.



Figure 10. Fruit Weight Measure for Production Analysis.



Figure 11. Rich Seed Weight Measured for Agriculture Application.



Figure 12. Cow Feed Weight Measured for Dairy Farm.

Loads measured: 0.5–80 kg produce.

User feedback: Clear display, fast readings, simple tare operation.

Issues: None reported.

In Figure 10 shows that the Fruit Weight Measure for Production Analysis and in Figure 10 having Fruit Weight Measure for Production Analysis and Figure 11 have Rich Seed Weight Measured for Agriculture Application as well as Figure 12 showing the Cow Feed Weight Measured for Dairy Farm.

5. CONCLUSION

The development of the Arduino-based digital weight measurement system demonstrates that reliable and precise weighing solutions can be achieved at a fraction of the cost of commercial alternatives. With a total build cost of only ₹1500–2000, the proposed design reduces upfront investment by more than 65% compared to typical 100 kg commercial scales available in Bangladesh. Beyond affordability, the modular and repairable structure ensures extended service life, minimizing the need for full-unit replacement and significantly lowering annualized ownership expenses. This approach not only supports economic sustainability for low-income farmers, vendors and small businesses but also reduces electronic waste by encouraging part-level repairs instead of system-level disposal. The design thus addresses a critical gap in developing regions where access to affordable, durable and maintainable weighing systems remains limited. By combining low cost, long-term durability and resource efficiency, this work provides a practical and scalable pathway toward economically sustainable technology aligned with Industry 5.0 principles. Although the proposed Arduino-based digital weight measurement system has proven to be an affordable and sustainable solution, further research and development are required to expand its functionality and long-term impact. One promising direction is the integration of a mobile application that will not only display real-time weight readings but also maintain a digital record of transactions, enabling traceability and data-driven decision-making. Such an application could incorporate a price calculator, which automatically determines the monetary value of goods based on prevailing market rates, thereby supporting small vendors and farmers in achieving fair and transparent trade. Another important avenue is the exploration of IoT-enabled connectivity, which would allow data to be transmitted to centralized platforms for remote monitoring, market analytics and supply chain integration. Additionally, incorporating renewable energy solutions, such as solar-powered operation, could enhance deployment in off-grid rural regions, thereby improving accessibility for economically disadvantaged communities.

6. FUTURE WORK

Future work may also include predictive maintenance algorithms to detect early signs of sensor or structural degradation, further lowering lifecycle costs and reducing downtime. Collectively, these enhancements would transform the system from a low-cost weighing device into a comprehensive, intelligent, and economically sustainable platform that directly empowers rural and small-scale economies.

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