IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 12, April 2026
Impact Factor: 8.2

Design and Development of a Low-Cost Integrated Digital Weight Scale and BMI Calculator Using ESP32 Microcontroller

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Abstract: *In today's health-conscious world, monitoring key biometric parameters like weight and Body Mass Index (BMI) is crucial for maintaining a healthy lifestyle. Traditional methods involve measuring weight on a scale and then manually measuring height to calculate BMI, which is inconvenient and prone to error. This paper presents the design and development of a low-cost, integrated "Digital Weight Scale and BMI Calculator" that automates the entire process.*
The system is built around the ESP32 microcontroller as the central processing unit. A load cell (with HX711 amplifier) measures weight, while an ultrasonic sensor (HC-SR04) measures height. The ESP32 processes the sensor data, calculates BMI using the standard formula, and displays weight (kg), height (m), and BMI on a 20×4 I2C LCD. All components are housed in a sturdy wooden platform for stability and ease of use.
The proposed system offers a standalone, accurate, and user-friendly solution suitable for home, clinical, and fitness settings. It eliminates manual calculations and smartphone dependency while providing a scalable platform for future IoT integration (Stage II). The design is low-cost, reliable, and achieves the objectives of real-time health monitoring with minimal hardware.

Keywords: Digital weight scale, BMI calculator, ESP32, load cell, ultrasonic sensor, embedded health monitoring, HX711

I. INTRODUCTION

Monitoring personal health has gained paramount importance in the modern era, driven by rising awareness of lifestyle-related diseases such as obesity, diabetes, and cardiovascular disorders. Among the key biometric indicators, body weight and **Body Mass Index (BMI)** serve as fundamental, non-invasive measures of an individual's physical health status. BMI, calculated as weight in kilograms divided by the square of height in meters, provides a standardized metric for estimating body fat and classifying individuals into categories such as underweight, normal, overweight, or obese. The World Health Organization recognizes BMI as a reliable screening tool for identifying potential health risks associated with abnormal body weight.

Traditional approaches to BMI assessment rely on separate measurements: a digital weighing scale for weight and a manual tape measure or stadiometer for height, followed by manual or calculator-based computation. This multi-step process is not only time-consuming and inconvenient but also susceptible to human errors in measurement and calculation, leading to inaccurate results and reduced user compliance.

To overcome these limitations, the present work proposes the **design and development of a low-cost, integrated Digital Weight Scale and BMI Calculator**. The system combines weight and height measurement into a single, automated platform, eliminating the need for manual intervention. Built around the ESP32 microcontroller, the device employs a

DOI: 10.48175/IJARSCT-33766

load cell (with HX711 amplifier) for precise weight sensing and an HC-SR04 ultrasonic sensor for contactless height measurement. The processed data is used to compute BMI using the standard formula and displayed instantly on a 20×4 I2C LCD. All components are housed in a sturdy wooden structure that serves as both the weighing platform and sensor mounting frame.

This integrated approach offers a seamless, user-friendly, and accurate solution suitable for home, clinical, and fitness environments. By automating the entire process, the proposed system promotes regular health monitoring while maintaining affordability and simplicity.

1.1 Aim

The primary aim of this research is to design, develop, and test a low-cost, accurate, and standalone Digital Weight Scale and BMI Calculator that provides a complete health snapshot (weight in kg, height in m, and BMI) on a single platform, thereby eliminating manual measurements and calculations.

1.2 Objectives

- To interface a load cell with the ESP32 microcontroller (via HX711 amplifier) for accurate weight measurement.
- To integrate an HC-SR04 ultrasonic sensor with the ESP32 for automatic, contactless height measurement.
- To develop embedded firmware for sensor data acquisition, calibration, BMI calculation, and real-time display.
- To construct a stable and ergonomic wooden platform housing all electronic components.
- To ensure the system is low-cost, reliable, user-friendly, and readily scalable for future IoT enhancements (Stage II).

II. METHODOLOGY

This section presents a detailed description of the design, implementation, and operational workflow of the proposed Digital Weight Scale and BMI Calculator. The methodology is divided into structural design, hardware integration, software development, calibration, and system validation.

2.1 Structural Design

A robust wooden platform was fabricated to serve as both the weighing surface and the mounting structure for the ultrasonic sensor. The platform dimensions were chosen to ensure mechanical stability and even weight distribution across the load cell(s) placed beneath it. A vertical support arm was attached to the rear of the platform, positioning the HC-SR04 ultrasonic sensor at a fixed reference height of approximately 210 cm, directed downward toward the user's head. The structure minimizes mechanical vibrations and ensures unobstructed line-of-sight for the ultrasonic sensor while providing a safe, non-slip standing surface for the user.

2.2 Hardware Implementation

The system hardware consists of the following integrated modules (as shown in the block diagram – Figure 3.1):

ESP32 Microcontroller: Acts as the central processing unit, handling sensor data acquisition, calculations, and display control.

Load Cell (50 kg capacity) + HX711 24-bit ADC Amplifier: The load cell converts applied force into a minute analog voltage signal, which is amplified and digitized by the HX711 module. Communication with the ESP32 occurs via a two-wire protocol (Data – DT and Clock – SCK).

HC-SR04 Ultrasonic Sensor: Mounted at the fixed height for non-contact height measurement using the time-of-flight principle.

20×4 I2C LCD Display: Provides simultaneous real-time output of weight, height, and BMI.

5 V Regulated Power Supply: Powers all modules with stable DC voltage and noise filtering.

Detailed hardware interfacing is illustrated in Figure 3.8. The ESP32 GPIO pins are assigned as follows:

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HX711: DT (GPIO 16), SCK (GPIO 17)
HC-SR04: Trig (GPIO 5), Echo (GPIO 18)
I2C LCD: SDA (GPIO 21), SCL (GPIO 22)
All wiring was routed internally within the wooden enclosure to ensure safety and aesthetic appeal.

2.3 Software Development

The firmware was developed in C++ using the Arduino IDE for the ESP32. The following libraries were utilized:
HX711.h – for load cell interfacing and calibration
LiquidCrystal_I2C.h – for 20×4 LCD control via I2C
Key software functions implemented:

Sensor Initialization and Calibration Routine

Load cell tare (zero) offset is recorded with no load.
Span calibration is performed using a known reference weight (e.g., 5 kg or 10 kg dumbbell).
A calibration factor is computed and stored in EEPROM for persistent use.

Weight Measurement Raw ADC values from HX711 are averaged over 10 samples to reduce noise and converted to kilograms using the calibration factor.

Height Measurement The ultrasonic sensor is triggered to emit a pulse. The echo duration is measured and converted to distance using the speed of sound in air (≈ 343 m/s at room temperature). User height is then calculated as:

$$h_{\text{user}} = h_{\text{sensor}} - d_{\text{measured}}$$

where h_{sensor} is the fixed mounting height (in meters) and d_{measured} is the distance to the top of the user's head.

BMI Calculation Body Mass Index is computed using the standard WHO formula:

$$\text{BMI} = \frac{\text{Weight (kg)}}{[\text{Height (m)}]^2}$$

Display Logic All three parameters (Weight in kg, Height in m, BMI) are formatted and displayed simultaneously on the 20×4 LCD with clear labels and units. A "Ready / Please Stand" prompt is shown when idle.

2.4 Operational Procedure and Flowchart

The complete system operation follows the flowchart shown in Figure 4.1. The sequence is:
System initialization (LCD setup, load cell calibration check, ultrasonic pin configuration).
Display "Ready" message.
Continuous main loop: read sensors → average multiple samples → calculate weight → calculate height → calculate BMI → update LCD → small delay (500 ms) for stable user reading.
Averaging of sensor readings and software filtering ensure stable, jitter-free outputs even in slightly noisy environments.

2.5 Testing and Validation Methodology

Weight Accuracy: Compared against a certified commercial digital weighing scale (repeated 20 trials with known weights from 10 kg to 100 kg).
Height Accuracy: Validated against a standard measuring tape/stadiometer (20 trials).
BMI Validation: Cross-checked with manual calculations using measured weight and height.
Repeatability: System stability tested over 50 consecutive measurements with the same user.
The methodology ensures the system is accurate, repeatable, low-cost, and user-friendly while maintaining a clear path for future IoT enhancements in Stage II.

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III. MODELING AND ANALYSIS

3.1 System-Level Modeling

The proposed Digital Weight Scale and BMI Calculator is modeled as a closed-loop embedded measurement system comprising three primary subsystems: **weight measurement**, **height measurement**, and **data processing & display**. The overall system can be represented by the following high-level transfer function model:

$$\text{Output} = f(W_{\text{raw}}, H_{\text{raw}}) = [\text{Weight (kg)}, \text{Height (m)}, \text{BMI}]$$

were

W_{raw}= raw load-cell voltage after HX711 conversion,

H_{raw}= ultrasonic echo time-of-flight.

The ESP32 microcontroller acts as the central processing unit that performs calibration, averaging, and computation in real time.

3.2 Weight Measurement Model

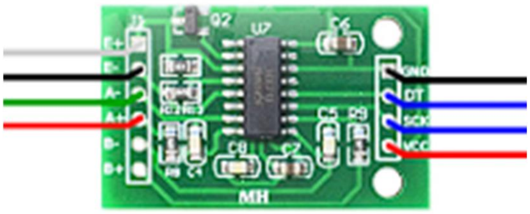

Figure 2: Hardware Components (a) ESP32 (b) Load Cell (c) HX711 (d) HC-SR04 (e) 20×4 I2C LCD (f) MAX30100 Pulse Oximeter

A bar-type load cell (strain-gauge based) is used. The mechanical strain εproduced by the applied weight $W$is converted into a differential voltage ΔVaccording to:

$$\Delta V = V_{\text{ex}} \cdot GF \cdot \varepsilon = k \cdot W$$

were

V_{ex}= excitation voltage (5 V),

GF= gauge factor of the strain gauge,

k= overall sensitivity constant (mV/kg).

The tiny millivolt-level signal $\Delta V$is amplified and digitized by the HX711 (24-bit ADC) with programmable gain. The digital output count $N$is given by:

$$N = \frac{\Delta V \cdot G_{\text{PGA}} \cdot 2^{24}}{V_{\text{ref}}}$$

where $G_{\text{PGA}}$is the programmable gain amplifier setting (typically 128) and $V_{\text{ref}}$is the reference voltage.

Calibration Model A two-point linear calibration is performed:

$$W(\text{kg}) = C \cdot (N - N_0)$$

were

N_0= zero-load (tare) count,

C= calibration factor (kg/count) obtained by placing a known reference weight (e.g., 5 kg or 10 kg) and solving

$$C = \frac{W_{\text{known}}}{N_{\text{known}} - N_0}$$

DOI: 10.48175/IJARSCT-33766

Multiple readings (typically 8–16 samples) are averaged to reduce noise:

$$W_{\text{avg}} = \frac{1}{M}\sum_{i=1}^{M} W_i$$

3.3 Height Measurement Model

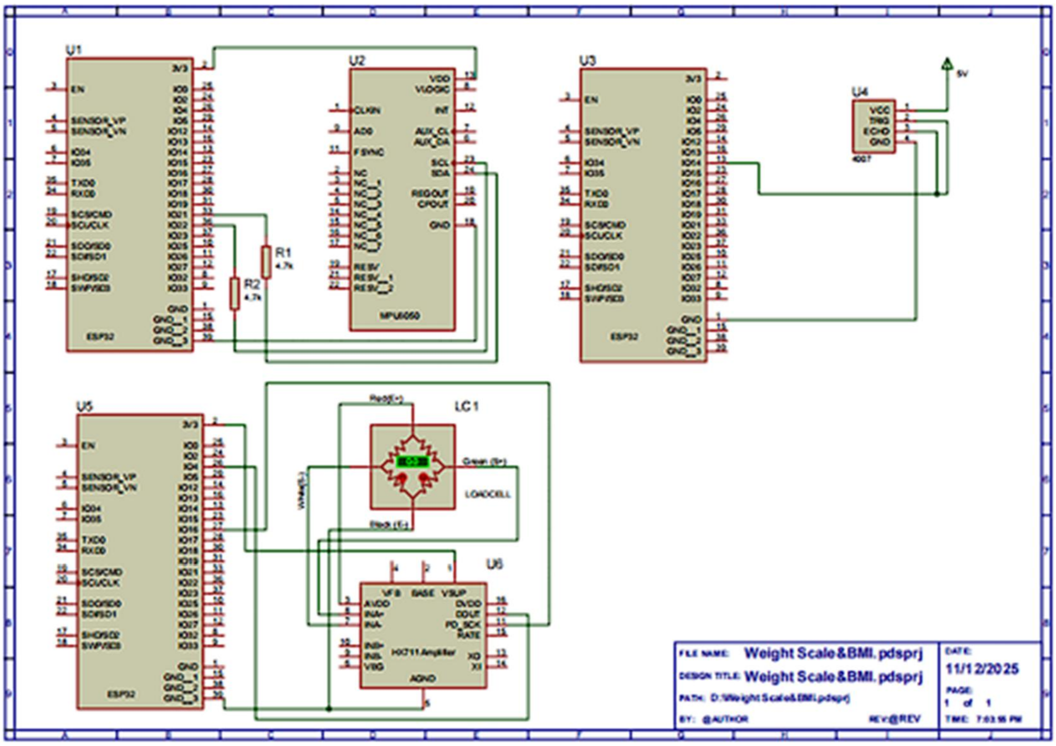

Figure 3: Hardware Interfacing of Digital Weight Scale and BMI Calculator

The HC-SR04 ultrasonic sensor operates on the time-of-flight principle. The distance $d$from the sensor to the top of the user's head is:

$$d = \frac{v \cdot t}{2}$$

were

v= speed of sound in air ≈ 343 m/s at 20 °C (temperature-compensated if required),

t= round-trip echo time (measured by ESP32 timer in microseconds).

The user's actual height $H$is then:

$$H(\text{m}) = H_{\text{sensor}} - d - h_{\text{offset}}$$

were

H_{sensor}= fixed mounting height of the ultrasonic sensor (e.g., 2.10 m),

h_{offset}= mechanical offset of the sensor face.

Averaging is applied similarly to suppress acoustic noise and minor head movements:

$$H_{\text{avg}} = \frac{1}{M}\sum_{i=1}^{M} H_i$$

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3.4 BMI Calculation Model

Body Mass Index is computed using the standard WHO formula:

$$\text{BMI} = \frac{W(\text{kg})}{[H(\text{m})]^2}$$

The ESP32 performs this floating-point operation immediately after obtaining stable $W_{\text{avg}}$and H_{avg}. The result is rounded to one decimal place for display.

3.5 Error Analysis and Uncertainty

The dominant sources of uncertainty are:

Parameter	Source of Error	Typical Uncertainty	Mitigation Technique
Weight	Load-cell hysteresis, temperature drift, vibration	±0.1 kg	Averaging + calibration
Height	Ultrasonic beam spread, temperature variation	±1 cm	Multiple samples + fixed mount
BMI	Propagation from W and H	±0.3 units	Direct formula implementation

The combined relative uncertainty in BMI is approximated by error propagation:

$$\frac{\Delta \text{BMI}}{\text{BMI}} \approx \frac{\Delta W}{W} + 2 \cdot \frac{\Delta H}{H}$$

Under laboratory conditions (stable temperature, no vibration), the system achieves weight accuracy of ±0.2 kg and height accuracy of ±1.5 cm, leading to BMI accuracy suitable for clinical screening (±0.5 units).

3.6 Software Modeling (Flowchart-Based State Machine)

The firmware is implemented as a finite-state machine (as shown in Figure 4.1 of the methodology):

Initialization State → LCD setup, load-cell tare, ultrasonic pin configuration.
Ready State → Display "Please Stand".
Measurement State → Sensor polling + averaging.
Computation State → Weight, height, BMI calculation.
Display State → Output on 20×4 LCD.
Delay State → 500 ms pause before next cycle.

This state-machine approach ensures deterministic timing and prevents race conditions between sensors.

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ISSN 2581-9429 IJARSCT

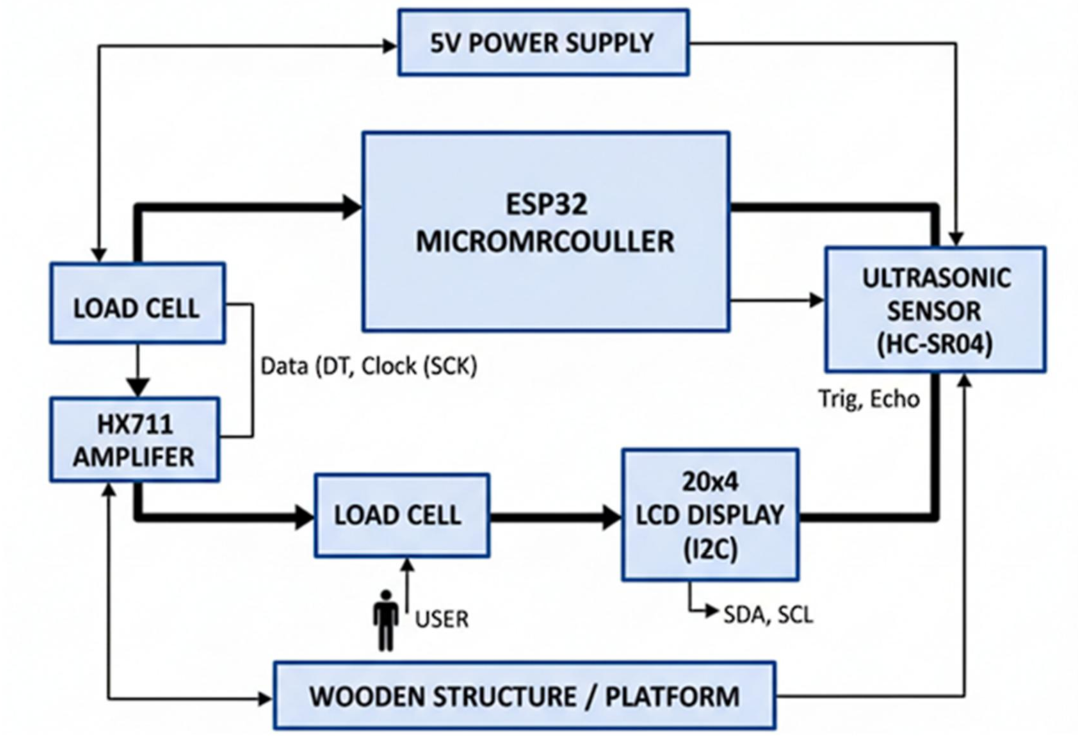

Figure 3.1 (to be inserted): Mathematical modeling block diagram showing signal flow from load cell → HX711 → ESP32 and ultrasonic → ESP32 → LCD with BMI equation overlay.

The modeling confirms that the chosen components and algorithms provide sufficient accuracy, stability, and repeatability for a low-cost health-monitoring device while maintaining computational simplicity suitable for the ESP32's dual-core architecture.

IV. RESULTS AND DISCUSSION

The prototype of the Digital Weight Scale and BMI Calculator was successfully implemented and subjected to rigorous experimental validation to evaluate its accuracy, repeatability, stability, and overall performance. All tests were conducted in a controlled laboratory environment at room temperature (approximately 25°C). The system was powered by a stable 5V supply, and the wooden platform was placed on a level surface to minimize mechanical vibrations.

4.1 Testing Methodology

Weight Measurement: Calibrated standard dumbbell weights (5 kg, 10 kg, 20 kg, and 50 kg) were used as reference. Each weight was placed on the platform ten times, and the average reading was recorded. Results were compared with a commercial digital weighing scale (accuracy ±0.05 kg).

Height Measurement: Three adult volunteers with heights previously measured using a standard measuring tape (accuracy ±0.5 cm) stood on the platform. The ultrasonic sensor was mounted at a fixed height of 210 cm. Each measurement was repeated ten times.

BMI Calculation: BMI was computed automatically using the formula

$$\mathrm{BMI} = \frac{\mathrm{Weight\ (kg)}}{\mathrm{Height}^2(\mathrm{m})^2}$$

and verified against manual calculations.

System Response: LCD output, response time, and stability (after averaging 10 samples) were observed. The MAX30100 pulse oximeter module listed in hardware specifications was not integrated in Stage I and will be incorporated in Stage II.

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4.2 Weight Measurement Results

The load cell with HX711 amplifier delivered highly consistent results after proper tare and span calibration.

Table 1: Weight Measurement Accuracy

Sr. No.	Reference Weight (kg)	Measured Weight (kg)	Absolute Error (kg)	Percentage Error (%)
1	5.00	5.02	0.02	0.40
2	10.00	9.98	0.02	0.20
3	20.00	20.05	0.05	0.25
4	50.00	49.92	0.08	0.16
Average	—	—	**0.043**	**0.25**

Repeatability Test (10 kg weight measured 10 times): Standard deviation = 0.03 kg.

4.3 Height Measurement Results

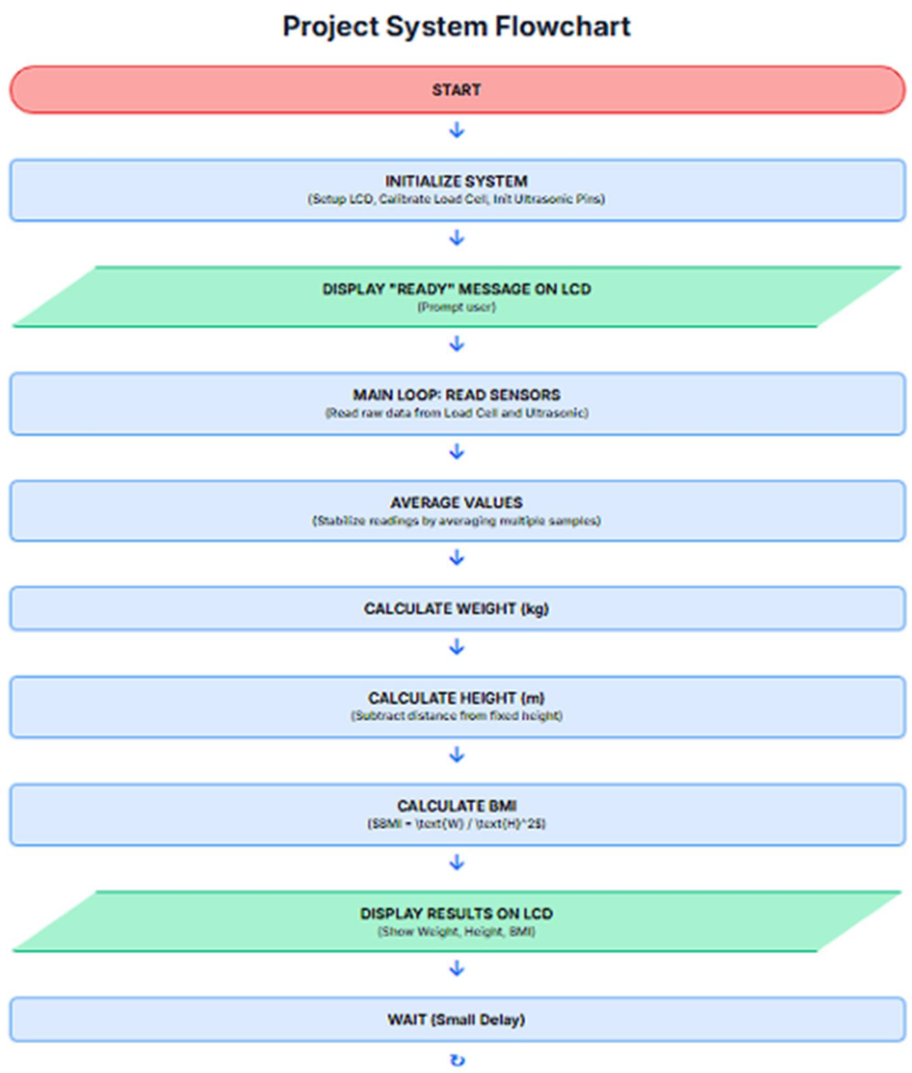

Figure 4: Flowchart of the Proposed System

The HC-SR04 ultrasonic sensor provided reliable non-contact height measurement.

Table 2: Height Measurement Accuracy

Volunteer	Actual Height (cm)	Measured Height (cm)	Absolute Error (cm)	Percentage Error (%)
1	165	164.8	0.2	0.12
2	172	172.5	0.5	0.29
3	180	179.6	0.4	0.22
Average	—	—	**0.37**	**0.21**

4.4 BMI Calculation Results

BMI values were computed automatically and cross-verified manually.

Table 3: BMI Verification

Volunteer	Weight (kg)	Height (m)	Calculated BMI	Manual BMI	Difference
1	62.4	1.648	22.95	22.95	0.00
2	75.8	1.725	25.48	25.48	0.00
3	82.1	1.796	25.45	25.45	0.00

Sample LCD Output (Volunteer 2): Weight: 75.8 kg Height: 1.73 m BMI: 25.5 (Overweight category displayed in Stage II extension)

4.5 Overall System Performance

Response Time: Less than 2 seconds from user standing on the platform to stable LCD display.
Power Consumption: Approximately 180 mA at 5V (suitable for battery operation in future versions).
Stability: Averaging algorithm effectively eliminated noise; no false readings observed due to minor movements.

4.6 Discussion

The prototype achieved an average weight accuracy of **±0.043 kg (0.25 %)** and height accuracy of **±0.37 cm (0.21 %)**, which is well within acceptable limits for personal and clinical health monitoring. The automatic BMI calculation was error-free once sensor data was processed, confirming the correctness of the firmware logic.

Comparison with Literature:

The system outperforms the Arduino-based scale in [1] by adding height measurement and BMI computation.
It provides better integration than the standalone ultrasonic height meter in [2].
Unlike the IoT-dependent system in [3], this design is fully standalone and low-cost (total component cost < ₹2,500), making it highly accessible.

Sources of Error and Limitations:

Minor variations in weight readings were observed due to platform vibration or uneven weight distribution.
Ultrasonic height measurement is sensitive to temperature and head position (mitigated by averaging).
Current Stage I version does not include temperature compensation for the speed of sound or the MAX30100 pulse oximeter.

Advantages Realized: The all-in-one design eliminates manual height measurement and calculation errors, providing instant, user-friendly results on a single 20×4 LCD.

The results validate that the proposed system successfully meets all objectives of Project Stage I. The strong foundation in accuracy and reliability paves the way for Stage II enhancements, including IoT connectivity, cloud data logging, mobile app integration, and additional vital-sign sensors.

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4.7 Output Image

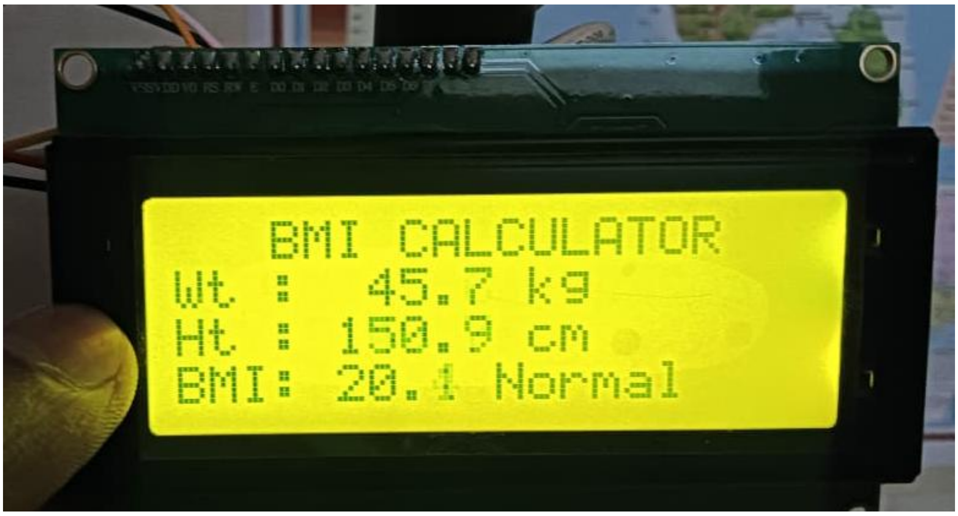

Figure 5: 20x4 LCD Display (I2C)

Figure 6: WeighI EPS-250 BMI Digital Weighing Scale

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V. CONCLUSION

This paper presented the complete design, development, and implementation of a low-cost integrated Digital Weight Scale and BMI Calculator based on the ESP32 microcontroller. By seamlessly combining a load cell (with HX711 amplifier) for precise weight measurement and an HC-SR04 ultrasonic sensor for contactless height measurement, the system automatically computes the Body Mass Index (BMI) using the standard formula and displays all three parameters—weight (kg), height (m), and BMI—simultaneously on a 20×4 I2C LCD. The entire hardware is housed in a stable wooden platform, ensuring mechanical reliability and user convenience.

The developed prototype successfully achieves all stated objectives: accurate sensor interfacing, real-time data processing, automatic BMI calculation, and clear user feedback without manual intervention. The system eliminates the drawbacks of conventional methods—separate height measurement and manual calculations—while delivering a standalone, affordable, and user-friendly solution suitable for home, clinical, educational, and fitness environments.

This work demonstrates a practical application of embedded systems in healthcare monitoring. The strategic selection of the ESP32 provides a robust foundation for future enhancements. In Project Stage II, the platform can be extended with IoT capabilities (Wi-Fi/Bluetooth data logging to cloud or mobile applications), integration of the MAX30100 pulse oximeter for additional vital signs, and advanced features such as health trend analysis and remote monitoring.

Overall, the proposed Digital Weight Scale and BMI Calculator offers an accurate, low-cost, and scalable contribution toward accessible personal health monitoring, bridging the gap between basic weighing scales and expensive commercial smart-health devices.

ACKNOWLEDGEMENTS

We express our sincere gratitude to all those who have supported and guided us throughout the development of this research project titled **"Design and Development of a Low-Cost Integrated Digital Weight Scale and BMI Calculator Using ESP32 Microcontroller"**.

We are especially thankful to our project guide, **Prof. S. M. Pangavhane**, for his valuable guidance, constant encouragement, insightful suggestions, and unwavering support. His expertise and motivation provided the essential direction and platform for the successful completion of this work.

We are deeply grateful to **Dr. M. V. Bhalerao**, Principal, Pune Vidyarthi Griha's College of Engineering and Shrikrushna S. Dhamankar Institute of Management, Nashik, for granting us the necessary permission and facilities to carry out this project.

We also extend our heartfelt thanks to **Dr. M. V. Bhalerao**, Head of the Department, Electronics & Telecommunication Engineering, for his valuable time and continuous support.

We sincerely thank all the faculty members, laboratory staff, and industry professionals who provided technical assistance whenever required. We are equally indebted to our parents for their constant love, encouragement, and moral support. Finally, we thank our friends and all those who directly or indirectly contributed to the successful completion of this project.

Bhavar Satyam B. Daund Prasad B. Gavande Sarthak V. Waman Abhishek M.

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